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DETERMINANTS OF RURAL WATER SUPPLY SUSTAINABILITY: A CASE STUDY IN QUANG NINH PROVINCE, VIETNAM

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ABSTRACT: Rural water supply plays a critical role in protecting public health and promoting sustainable socio-economic development. However, in many localities, rural water supply systems still face limitations in terms of access to standard-compliant domestic water, infrastructure capacity, and management and operation models. This paper presents an initial assessment of the current status of rural domestic water supply in Quang Ninh province through the analysis of water access coverage, conditions of centralized water supply facilities and system management models, via questionnaires (270 households) and in-depth interviews (14 technical officers and managers). The results indicate that the rural water supply system in Quang Ninh province has shown significant improvements in recent years, particularly in peri-urban areas where integration with urban water supply systems is feasible. Nevertheless, considerable disparities remain among regions, especially in mountainous and island areas, along with constraints related to treatment technologies and management models at several centralized water supply facilities. The findings demonstrate that governance capacity (technical management and supporting framework)—rather than infrastructure availability alone—constitutes the primary determinant of rural water supply sustainability.

Keywords: Rural Areas; Drinking Water Quality; Centralized Water Systems; Operational Sustainability

1. INTRODUCTION

Despite substantial investments in rural water supply infrastructure worldwide, ensuring long-term sustainability of rural water systems remains a persistent challenge, particularly in regions characterized by complex topography, dispersed settlements, and heterogeneous management arrangements [1,2]. Existing studies on rural water supply have predominantly focused on access coverage, water sources [3,4], technical performance [5,6], or isolated evaluations of management models [7,8], often at the project or community scale.

However, integrated assessments that simultaneously examine spatial conditions, infrastructure characteristics, management models, and sustainability outcomes at the provincial scale remain limited**,** especially in rapidly urbanizing regions where rural–urban infrastructure integration is increasingly promoted. In particular in developing countries, mitigating water security challenges by aiming to deliver piped water to every rural house has been the water supply strategy in rural areas for the past years [5]. In India, a major challenge related to water management and administration is the amount of investment necessary to set up initiatives in rural areas [9].

In Vietnam, previous research has highlighted improvements in rural water access rates [8,10]. A recent report revealed that 40% of rural ethnic-minority households informed significant volatility in water availability, largely attributed to fluctuating groundwater tables and climate-induced hydrological stress. Furthermore, 20% of these households experienced complete functional loss of specific improved water sources. For these vulnerable populations, the intermittency of primary water systems—driven by seasonal drought and aging infrastructure—remains a critical barrier to water security [11]. Yet evidence-based analyses linking water quality compliance, infrastructure performance, and governance arrangements are still fragmented and largely localized. This gap constrains the formulation of sustainable planning strategies tailored to geographically diverse provinces.

Therefore, this study aims to provide a comprehensive, province-scale assessment of rural domestic water supply systems in Quang Ninh Province, Vietnam. The specific objectives are to: (i) assess spatial disparities in access to standard-compliant rural domestic water supply; (ii) evaluate the technical condition and operational performance of centralized rural water supply facilities; and (iii) analyze the relationship between management models and system sustainability. Beyond its regional relevance, this study contributes empirical insights to global debates on governance-centered approaches to rural water sustainability in geographically complex settings.

The remainder of this paper is organized as follows: Section 2 highlights the research significance regarding the determinants for sustainable rural water supply. Section 3 details the methodology, including site description and data collection method. Section 4 presents the results and comprehensive discussion on some determinants of sustainable water supply systems such as geography condition (special challenges), water sources, and operation conditions, management models. Finally, Section 5 summarizes the key conclusions drawn from the study, some limitations and proposes recommendations for future research.

2. RESEARCH SIGNIFICANCE

Even though there have been some studies on the water supply in rural areas, the understanding on the water sources, operation conditions, willingness-to-pay or assessment of system sustainability and investment efficiency in a mountainous province has still been limited. The study has rendered some challenges related to topography and hydrogeology of this region, then proposed a suitable management model to make sure the piped water more affordable and sustainable to rural residents.

3. METHODOLOGY

3.1 Site description

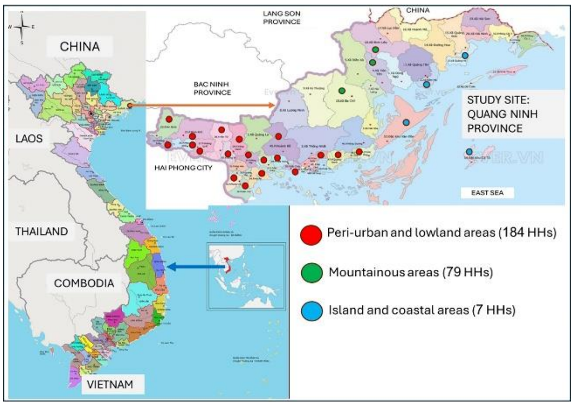

Fig. 1. Study site

Quang Ninh is a coastal province in Northern Vietnam that has demonstrated significant economic dynamism and development over the past decade (Fig. 1). The province is distinguished by its proactive approach to rural water supply (RWS), implementing strategic reforms to enhance coverage rates. Consequently, this province was selected as the primary study site to provide a comprehensive evaluation of RWS dynamics, serving as a benchmark for policymakers and regional authorities in other jurisdictions.

As of 2023, the total population of Quang Ninh Province was 1,375,727. The rural population accounts for 32.66% of total with 118,464 households.

3.2 Data collection

The data was collected through questionnaires (300 households' samples), nevertheless, only 270 households (HHs) provided feedbacks, categorized by geographical strata:

- Peri-urban areas: 68.1%
- Mountainous regions: 29.2%
- Coastal and island regions: 2.7%

In addition to the household surveys, 14 in-depth interviews were conducted to gather qualitative insights. The persons, who were interviewed in depth, are management officials at the district level (11 staffs) and technical staff at water supply companies (3 staffs) (Fig. 2). The total sample size (n = 284) was determined based on methodology from previous literature, maintaining a precision level of 7% (Tran et al., 2021).

$$n = \frac{N}{1 + Ne^2}$$

Where n is the sample size, N is the population size, and e is the level of precision with a value of 7%.

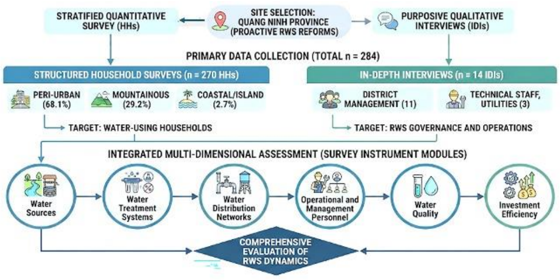

Fig. 2. Methodological framework for rural water assessment

The survey questionnaire structure includes the main contents as followings (i) Water source; (ii) Water treatment system; (iii) Water supply network; (iv) Human resources operating and managing the system; (v) Water quality; and (vi) Evaluation of investment efficiency of the water supply system. Within this paper, water quality was not discussed as it was not assessed quantitatively but only via sensory evaluation due to the budget constrain.

4. RESULTS AND DISCUSSION

4.1 Spatial disparities in access to rural domestic water supply

The rural domestic water supply coverage in Quang Ninh Province has improved substantially during the 2021–2024 period, primarily through the expansion of centralized water supply systems [12]. This improvement was largely driven by new infrastructure investments, rehabilitation of existing facilities, and network extensions connecting rural areas to urban water supply systems. Such an integrated approach is consistent with international experience, where linking rural service provision to urban-scale infrastructure has been shown to enhance service reliability and water quality compliance, particularly in peri-urban contexts [13]. Despite these positive trends, access to standard-compliant drinking water remains uneven across the studied province.

From a spatial perspective, rural areas in Quang Ninh can be broadly categorized into three groups: (i) peri-urban and lowland areas; (ii) mountainous areas; and (iii) island and coastal areas. Fig. 3 revealed that peri-urban localities, such as Quang Yen town and communes adjacent to urban centers, exhibit a rate of centralized clean water supply of 48.16%, lower than the average rate of the whole province of 56.6% and of the whole Vietnam (55%) [14]. In many provincial contexts, peri-urban residents maintain access to remnants of rural water infrastructure or local groundwater. This mixed-regime access can lead to lower enrollment in centralized systems, as households may perceive the cost of connection to be unnecessary if local wells are still functional, even if the water quality is lower [13]. Such integration can significantly improve service continuity and regulatory compliance in rural–urban transition zones [13, 15].

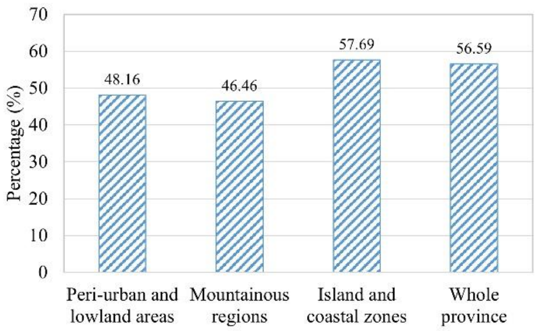

Fig. 3. Rate of centralized RSW system

In contrast, mountainous districts including Binh Lieu and Ba Che displayed slightly lower and less stable access to safe drinking water. Complex terrain and dispersed populations substantially increase the capital and operational costs of distribution networks, while water sources are predominantly small streams and springs with pronounced seasonal variability [16]. These structural constraints limit the scalability of centralized systems and increase the likelihood of non-compliance with drinking water quality standards, particularly during dry periods. Similar challenges have been widely documented in rural water supply systems in mountainous regions worldwide, where geography and hydrological variability act as persistent barriers to sustainability [6, 11, 16].

Island and coastal areas, such as Co To and Van Don communes, face a distinct set of challenges. Although centralized water supply facilities have been developed, long-term service reliability remains highly sensitive to environmental conditions. Limited freshwater availability due to the salinity issues, combined with high investment and operational costs, complicates the maintenance of stable water supply services, especially in sparsely populated areas. Nevertheless, since the residents have no other choice, plus the tourism develops remarkably along the coastal areas of this province supports the finance burdens for the residents and help them afford to use the piped water. Thus, the rate of using piped water in island and coastal areas was the highest (57.7%). Due to time-restricted data collection, the participation rate in island and coastal areas fell below the target threshold. Future research should prioritize a larger N-size in these specific geographical cohorts to refine the precision of the piped water coverage estimates and reduce potential sampling error. International evidence suggests that in such contexts, sustainable access depends not only on infrastructure provision but also on adaptive resource management and affordability of users [17].

Overall, the observed disparities in rural water access across Quang Ninh Province reflect the strong interdependence between physical geography, settlement patterns, and the degree of integration between rural and urban water supply planning. Areas with favorable spatial conditions and higher tourism potential consistently achieve better outcomes, while mountainous region require more flexible, context-specific approaches to ensure sustainable access to safe drinking water. As a result, rural access to piped water in Quang Ninh was only 56.6%, compared to 73.85% in urban areas [18]. In comparison with previous studies, the piped water coverage in rural areas varied from 14.7% in Kenya [3] to 42.55% in central Kazakhstan [19] and 73% in Honduras [16]. Among South East Asia countries, Viet Nam in general or Quang Ninh in particular is in the middle level (55-56%), higher than Laos (18%), Cambodia (28%), Philippines (47%), but lower than Myanmar (59%), Malaysia (94%) [20]. It seems that Southeast Asia is a region of extreme contrasts. Vietnam (55-56%) was in the middle level, which is a classic characteristic of rapidly industrializing nations. While urban centers like Hanoi and Ho Chi Minh City have near-universal coverage, rural piped water remains the final frontier. In provinces like Quang Ninh, the geography (mountainous terrain and islands) makes water piping as expensive as compared to the Mekong Delta, where water is abundant but often requires high-tech filtration due to salinity and arsenic.

4.2 Water sources

The Fig. 4 illustrates a significant transition in the structure of raw water sources to supply for the distribution network in rural areas, reflecting a strategic shift toward greater centralization and enhanced water resource sustainability. At current water supply situation, the lake water constitutes the dominant source (50%), followed by groundwater (21.4%) and river water (14.3%), while streams and small creeks each account for approximately 7.1%. The projected future configuration indicates an interesting restructuring, in which, lake water shall be remarkably predominant (76.92%), river water will decline to 7.69%, streams and creeks will remain at a minor share (7.69%), and notably, groundwater abstraction is planned to be completely phased out.

The substantial increase in the share of lake water suggests a clear prioritization of regulated surface water sources with higher operational reliability. Compared to river water, reservoirs/lakes provide improved flow stability due to their storage and seasonal regulation capacity, thereby mitigating dry-season water shortages—an increasingly critical consideration under climate variability and change. Moreover, the hydraulic retention time in reservoirs facilitates natural sedimentation processes, stabilizing turbidity and improving raw water quality consistency [21]. This, in turn, enhances treatment efficiency and supports operational cost optimization. From a planning perspective, the concentration of supply on reservoir sources aligns well with the development of inter-communal and regional centralized water supply schemes, enabling economies of scale and more efficient system management. One should be noted that water bodies such as lake is used for storage of water but in India, people dump their wastes in lakes which results into eutrophication of lake [22], thus good protection of lakes which are used for domestic water supply source is very critical.

Conversely, the projected elimination of groundwater abstraction reflects a strategic adjustment in resource governance. In coastal and rapidly urbanizing areas, prolonged groundwater extraction can result in declining water tables, increased risks of saline intrusion and land subsidence, and persistent water quality concerns such as arsenic, ammonium, iron, and manganese contamination. Furthermore, decentralized small-scale groundwater facilities often face challenges in maintaining consistent technical standards and quality control. Therefore, reducing reliance on groundwater represents a proactive measure to safeguard long-term aquifer sustainability and minimize environmental risks. Nevertheless, the complete phase-out of groundwater necessitates the establishment of contingency mechanisms to ensure supply resilience in the event of reservoir contamination incidents or reductions in effective storage capacity due to climatic fluctuations [3]. In Africa, groundwater and rainwater harvesting are still the most potential water sources for community's safe and clean domestic water supply due to the topography, geology and hydrogeology of this region [3, 23]. Groundwater constitutes the primary water source in India, accounting for approximately 70% of total supply; however, the nation faces significant aquifer depletion, necessitating the formulation of a comprehensive water management framework. This strategic planning emphasizes enhanced inter-agency coordination regarding data acquisition and processing, alongside the critical integration of advanced technologies dedicated to water conservation and systemic management [9,24].

The reduction in the proportion of river water and the continued minor contribution from streams and creeks indicate a deliberate effort to limit dependence on hydrologically variable and pollution-sensitive sources. River systems are particularly vulnerable to upstream discharge and seasonal fluctuations, which can complicate treatment processes and increase operational uncertainty [25]. However, maintaining a small proportion (approximately 7–8%) of supply from streams and creeks reflects a degree of planning flexibility, especially for mountainous and geographically fragmented areas where extending centralized supply networks may be economically or technically infeasible.

Rainwater has not been used commonly as water source for large scale water plant in Vietnam despite its good quality [26]. The main reason is due to the limited quantity and dependance on the local climate. With the impact of climate change, the rainwater quantity is even more unpredicted.

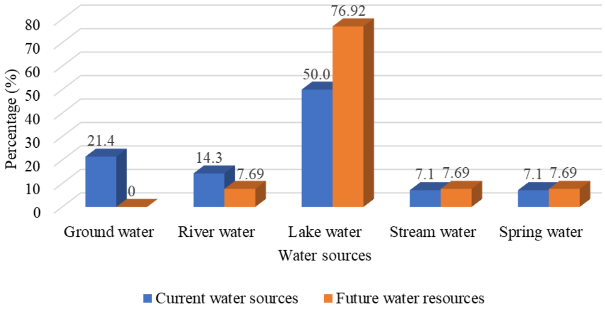

Fig. 4. Current and future trends in water resource exploitation

Overall, the projected raw water sources demonstrate a transition from a dispersed, multi-source abstraction model toward a predominantly reservoir-based centralized supply system. This reconfiguration is consistent with objectives to enhance sustainability, strengthen water quality control, and improve investment efficiency in rural water supply in Vietnam [12]. However, the high future dependence on a single source type (76.92% from reservoirs) also increases systemic vulnerability to source-specific risks, including watershed degradation, contamination events, and climate-induced hydrological variability. Accordingly, the restructuring of raw water sources should be accompanied by strengthened watershed protection measures, real-time water quality monitoring systems, and the integration of water resource management into broader socio-economic development planning.

In conclusion, the evolving raw water sourcing strategy in Quang Ninh province reflects a coherent movement toward centralized and sustainability-oriented rural water supply development. To ensure long-term system resilience, however, source planning must be embedded within a comprehensive risk management framework that incorporates alternative supply options, ecological watershed protection, and forward-looking assessments of climate change impacts on regional water balance [27].

4.3 Evaluation of water facilities' operation conditions

A comprehensive overview of the performance of key infrastructure components within the rural water supply system was presented in Fig. 5, including raw water pumping stations, water treatment facilities, clean water pumping stations, and distribution pipelines. The results, obtained mainly via in-depth interview with officers and managers, reveal notable disparities in operational conditions among these components and highlight several bottlenecks affecting overall service reliability.

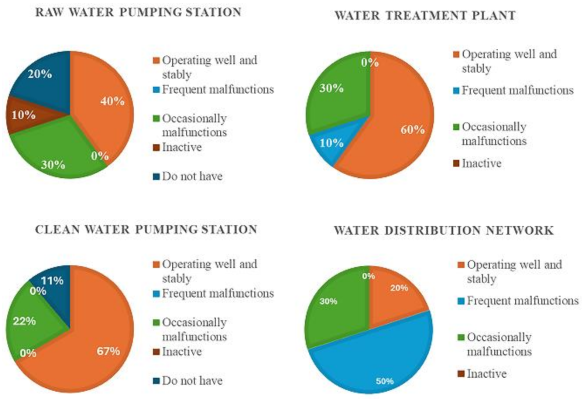

Fig. 5. Assessment of water facilities' operation conditions

According to the results, pumping stations had the high rate of good and stable operation plus no frequent malfunction. Occasional malfunction occurred in all water facilities with approximately 30%. In the context of rural water systems, the intake or raw water station is often the most prioritized because, without it, the entire downstream system is useless. It typically involves fewer chemical complexities than treatment plants. Frequent malfunction happened the most at the water distribution network (50%) due to the pipe broken, poor maintenance or water leakage at connection valves. Alvarez (2019) points out that rural settlements are often dispersed [16]. To reach every household, the distribution network must be exceptionally long relative to the number of users, so there is more physical infrastructure that can break, making the network the most statistically likely component to suffer a malfunction compared to a centralized treatment plant. The water treatment plant (WTP) also had the second-highest non-functional rate (approx. 10%). A WTP requires consistent chemical dosing, filter media replacement, and skilled labor—resources that are often scarce in rural settings. Singh et al. (2024) and both highlight that rural communities can often manage mechanical pumps but struggle with the biochemical processes of a WTP [4]. When a chlorinator breaks or a filter clogs, the plant often shifts to "Partially Operational" (bypassing treatment) or shuts down entirely. In particular with community-managed models in developing regions, the water systems often fail within 3–5 years due to a lack of technical training and financial reserves [7]. It was reported that raw water sources in Asia are increasingly degraded by urban-rural linkages (pollution from upstream). This explains why the WTPs were occasionally struggling. If the raw water quality drops significantly, the existing WTP infrastructure may no longer be capable of treating the water to safe standards, leading to its abandonment or non-functional status [13].

Overall, the Fig. 6 portrays a typical operational profile of rural water supply systems: upstream facilities such as treatment plants and pumping stations tend to exhibit relatively stable performance, whereas distribution networks constitute the most fragile and failure-prone segment. The high incidence of failures within the network underscores significant challenges in achieving technical sustainability and service reliability, particularly in the context of national targets for safe water access and continuous supply standards.

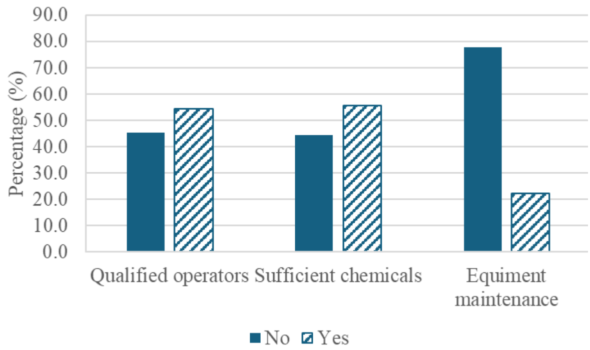

Fig. 6. Causes of frequent malfunction

A deeper examination of operational performance highlights that management capacity, rather than infrastructure availability alone, represents the primary bottleneck for sustainable rural water supply in Quang Ninh Province. Fig. 6 points to a systemic weakness in institutional and human resource capacity across a substantial share of existing rural water facilities. Survey results indicate that 44.5% of rural water facilities lack adequately trained technical staff responsible for daily operation and water quality control; 44.0% of them has not sufficient chemicals for the treatment units and 77.8% of the facilities don't implement the regular maintenance and service of equipment and machinery. Via the interviews, it was recorded that the facilities managed at the community or commune level frequently rely on part-time operators with limited technical training, leading to reactive rather than preventive maintenance practices. In Nigeria, a primary barrier to maintaining and extending piped water networks is limited technical manpower [1]. This mirrors findings in Ghana, where a lack of maintenance for mechanized boreholes is linked to insufficient technical oversight [23]. In Kenya, the community-based model was not successful was also due to lack of qualified operators. The above factors were found to drive unsustainable rural water service delivery in five regions across Ethiopia, Uganda, and Kenya as well [28]. To combat these gaps, some regions have implemented "integrity management" toolboxes to help community groups address internal management challenges and link with local water actors to establish performance-oriented arrangements [29].

Additionally, the physical degradation of infrastructure due to neglect is a global challenge for rural water sustainability. In Nigeria, access to piped water is actively declining due to deteriorating distribution network infrastructures [1]. While boreholes serve the vast majority of households in regions like Turkana, Kenya (94.1%), their functionality poses a constant challenge [29]. Similarly, in Ghana, the lack of maintenance for mechanized boreholes and a complete reliance on thin, shallow aquifers lead to system failures [23]. To address these maintenance gaps, smart water systems (SWS) are being explored as self-learning tools to detect and manage leakages more efficiently than traditional manual oversight [2]. Even though the SWS seems to be the good and advanced tool for sustainable system operation, it requires other resources which cannot afforded by low-income or low-middle-income countries.

4.4 Evaluation of rural water projects' sustainability

It was reported that the majority of rural water facilities was invested through state budget allocations, including national targeted programs such as Program 135 and other rural development initiatives [12]. Although many facilities have remained functional for a certain period, overall investment efficiency remains limited, as evidenced by insufficient cost recovery and a continued reliance on government subsidies for operation and maintenance.

The report by Quang Ninh Rural Water Center in 2024 reveal that, out of a total of 262 rural domestic water supply facilities and systems, only 30 were classified as operating effectively and sustainably, representing just 11.4% of the total [12]. This notably low proportion highlights the structural fragility of the current rural water supply system. Most of the remaining facilities were assessed as moderately sustainable (53.8%), while 19.1% were considered unsustainable and 15.7% had ceased operations due to infrastructure deterioration, insufficient water sources, or replacement by alternative supply systems (Fig. 7). Compared to the average national assessment on rural water sustainability, the unsustainable works of Quang Ninh province is lower than the average (19.1% versus 26.8%). It should be noted that the classification of different level of sustainability was regulated by Ministry of Agriculture and Rural Development (see Table 1).

Table 1. Classification of rural water project sustainability levels

No	Criteria	Sustainable	Relatively Sustainable	Unsustainable	Inactive
1	Enough fee for operation	Pass	Pass (Mandatory criteria)	Fail (Mandatory criteria)	-
2	Treated water meets standard	Pass	-	-	-
3	Continuous water supply*	Pass	Pass (Mandatory criteria)	Fail (Mandatory criteria)	-
4	Connection rate ≥ 60%	Pass	Pass (Mandatory criteria)	Or Fail (Mandatory criteria)	-
5	Qualified personnel**	Pass	-	-	-
	Note	Meets 5/5 criteria	Meets at least criteria 1, 3, and 4	Fails to meet 2 out of 3 core criteria (1, 3, 4)	No water supply for 90 consecutive days

*Note: * No interruption more than 5 days/each event, no more than 60 days/year*
*** Specialized staff required if > 250 household connections.*

One of the primary factors contributing to low operational efficiency and unsustainability is the system scale (i.e., small scale), coupled with constrained management and operational capacity at rural water facilities. Most facilities lack dedicated personnel formally trained in water supply engineering, system operation, and water quality control as mentioned above. This shortage of technical expertise—combined with restricted funding for routine maintenance and repairs—directly undermines the ability of these systems to sustain stable operations and consistently meet treated water quality standards. Restricted funding often leads to the deferment of routine maintenance, causing minor issues to escalate into major, costly failures [1, 13]. Alvarez (2019) also emphasized that post-construction technical and financial assistance was essential, as community boards often lacked the resources for major repairs [16]. In the study in Ghana, Agyemang (2025) found that poor maintenance of mechanized boreholes and a complete reliance on thin shallow aquifers as significant technical risks [23]. About the operators, Hoque et al. (2026) confirmed professionalizing rural water services to bridge the gap between local management and the technical expertise is required for stable operations [6].

Overall, the sustainability rate of approximately 11.4% suggests that the effectiveness of rural water infrastructure investment depends not only on construction but also on management arrangements, operational capacity, and long-term financial viability. Numerous facilities have been developed without accompanying governance mechanisms or secured operational resources, leading to rapid deterioration or service interruption after relatively short periods of use. This situation presents a significant challenge to achieving sustainable rural water supply, particularly as regulatory expectations for drinking water quality continue to increase. The proposed practical engineering recommendations for the studied area could be: (i) preventive maintenance schedules tied to system size (i.e., monthly intake screen cleaning, chlorine level check; or pipe leak patrol), (ii) minimum staffing and spare parts lists, (iii) annual operator training, and (iv) a simple affordability metric such as a uniform volumetric or lifeline (low-level) tariff.

4.5 Management models of rural water supply systems

Currently, rural domestic water supply facilities in Quang Ninh Province are managed and operated under multiple institutional arrangements, including community- or local government-managed models, enterprise- or public utility-operated systems, and hybrid configurations involving shared responsibilities (Fig. 8). This diversity reflects the phased development of rural water infrastructure and is strongly shaped by local socio-economic conditions, population scale, and spatial characteristics. Similar models were well defined in details previously [30].

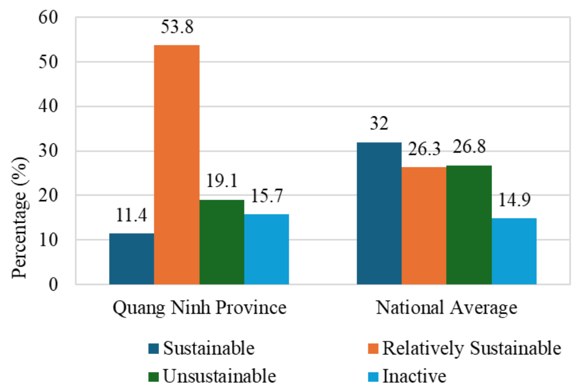

Fig. 7. Sustainability assessment of RWS projects in the studied area

Survey results indicate that community-based model remains prevalent, particularly in mountainous and island areas (Table 2). While this model offers flexibility and encourages local participation, its major limitations lie in technical capacity and the availability of financial resources for operation, maintenance, and water quality monitoring. The absence of skilled personnel and stable financing mechanisms has resulted in intermittent service delivery in many systems, with treated water quality often failing to remain consistently compliant with water quality standard.

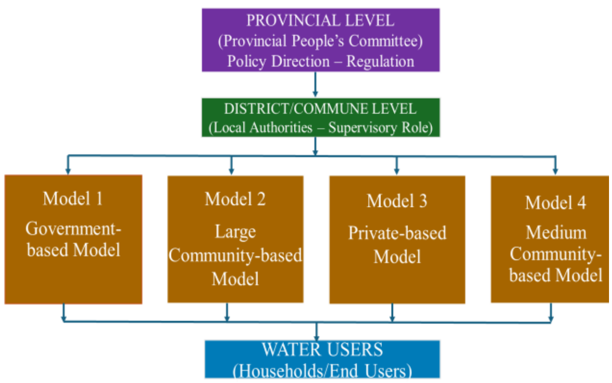

Fig. 8. Rural water supply management models

By contrast, facilities operated by enterprises or specialized utilities generally demonstrate higher efficiency and stronger sustainability. These entities are better equipped to implement professional operational structures, apply standardized technical and financial management procedures, and conduct routine water quality surveillance. In addition, the workforce at these facilities is better trained. Consequently, such systems are more capable of utilizing design capacity effectively, minimizing technical failures, and maintaining stable compliance with drinking water quality standards over extended periods.

Importantly, the relationship between management model and system performance is clearly reflected in operational continuity and regulatory compliance. Facilities with comparable scale and treatment technologies but governed under different management arrangements exhibit substantial variation in efficiency and sustainability outcomes. This evidence reinforces the view that governance structures play a decisive role in realizing the benefits of infrastructure investment, particularly for small-scale rural systems operating under complex environmental conditions.

Table 2. Management model of centralized rural water supply in Quang Ninh province

Model (Scale)	Management unit/Investment Source	Objective	Account for
Government-based Model **(Large and medium)**	Joint stock companies (Government and Private budget)	Medium profit driven	8.8%
Large Community-based Model (Medium)	Community Cooperatives (Government budget)	Low profit, social service driven	19.1%
Private-based Model **(Large and medium)**	Private enterprises (Private funds)	High profit driven	3.4%
Community-based Model **(Medium)**	Village Water Board (Villagers' payment)	Villagers/ HHs benefits	68.7%

Based on this assessment, selecting management models that align with local contexts emerges as a critical determinant for enhancing both efficiency and long-term sustainability of rural water supply in Quang Ninh Province. Moving forward, a gradual transition from fragmented, non-specialized management toward more centralized or semi-centralized arrangements—featuring the participation of professional operators—should be prioritized. Concurrently, strengthened technical and financial support mechanisms are necessary for localities facing geographic and resource constraints [28]. Therefore, the Model 1, operated and managed by joint-stock company, sounds to be the most appropriate and effective model applied in the rural areas in Quang Ninh. In another province of Vietnam, which is in the delta region, the private management model was considered the one that significantly contributed to the sustainability of the rural water systems in the study area [10]. While in some African countries, where the economic conditions are at lower lever, community-driven model seems to be both feasible and context-appropriate for them as majority of households already rely on small-scale variants [3].

A question may be raised if people living in rural areas can afford to pay water tariff to the company according to Model 1. The study conducted the willing-to-pay and current payment of residents for water bill as in Fig. 9. Evidence suggests that monthly water tariffs ranging from \$2.00 to \$4.00 per household (HH) exceed the affordability threshold for rural consumers, necessitating significant financial strain to meet these obligations. A monthly expenditure below 2.00 per HH is deemed economically viable for this demographic. However, because the average monthly water bill per HH provided by joint-stock utility corporations is about \$4, rural inhabitants are systemically precluded from fulfilling their payment requirements. Even residents in a suburb area of Hanoi city (capital) were not able to afford \$3-\$6/HH/month for piped water [31]. Consequently, to safeguard water resilience and ensure social equity, objectives fundamental to sustainable development and the broader interests of diverse stakeholders, government subsidies must be implemented as a targeted policy intervention to alleviate this socio-economic burden.

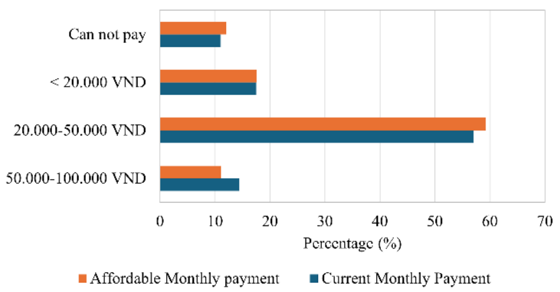

Fig. 9. Payment of water tariff per household (1USD = 26,000 VND)

This study has several limitations. First, the analysis relies primarily on provincial datasets, which may not fully capture temporal variability in system performance. Second, the semi-quantitative sustainability classification involves a degree of expert judgment. Third, while the study identifies governance as a critical determinant, further research using longitudinal data and advanced quantitative methods is needed to establish causal relationships more robustly.

5. CONCLUSIONS

This study provides a comprehensive assessment of the current status of rural domestic water supply in Quang Ninh Province, based on an integrated analysis of water access levels, infrastructure conditions, and management and operational models (key determinants of water supply systems) and how these determinants collectively influence the performance and sustainability of rural water supply systems.

Initial survey indicates that spatial heterogeneity in access to potable water remains a critical developmental bottleneck, primarily dictated by topographic imperatives and the existing stochastic integration between rural provision strategies and urban infrastructural frameworks. Furthermore, the suboptimal investment efficiency and lack of longitudinal viability in water supply systems are largely symptomatic of deficient technical-managerial capacity—specifically the absence of certified operators, inadequate chemical dosing, and irregular preventive maintenance—all of which are underpinned by chronic fiscal constraints. Regarding water sources, lake water constitutes the primary abstraction source for the current and mid-term horizon. Ultimately, the governance and management modalities serve as the primary determinants of operational longevity. Attaining long-term resilience in rural water security necessitates a paradigm shift: transitioning from community-based model toward a model of governance-led institutional strengthening.

Future study shall focus more closely on other important factors affecting water sustainability, including soil type, rainfall, hydraulic infrastructure, and environmental conditions for better understanding of rural water supply context.

6. ACKNOWLEDGEMENT

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7. REFERENCE

[1] Adeoti O. and Fati B.O. Barriers to extending piped water distribution networks: The case of Ekiti State, Nigeria. Utilities Policy 63 2020, pp. 1-10. https://doi.org/10.1016/j.jup.2019.100983

[2] Sharma M., Gupta V. and Gupta D. Advancement in technologies of water management in rural areas. In Water resources management for rural development, Elsevier

2024, pp. 117–126. https://doi.org/10.1016/B978-0-443-18778-0.00019-2

[3] Abungu V., Adanu K., Firouzjaei M.D., Wasonga B. and Elliott M.A. Multiple household water sources and uses in rural ASALs: Evidence and proposed solutions from Turkana, Kenya. Groundwater for Sustainable Development 31 2025, pp. 1-12. https://doi.org/10.1016/j.gsd.2025.101531

[4] Singh N., Kamboj S., Siwal S.S., Srivastav A.L. and Naresh R.K. Toxic, non-toxic, and essential elements in drinking water: Sources and associated health issues in rural Asia. In Madhav, S. et al. (Eds.), Water resources management for rural development, Elsevier 2024, pp. 171–190. https://doi.org/10.1016/B978-0-443-18778-0.00012-X

[5] Mukherjee A., Senapati T. and Ghosh A. Jal Jeevan Mission and role of smart technologies in achieving water security in rural India. In Dubey, A.K. et al. (Eds.), Computational automation for water security, Elsevier 2025, pp. 363–386. https://doi.org/10.1016/B978-0-443-33321-7.00015-9

[6] Hoque S.F., Hope R., Charles K.J., Alam M.M., Osman M.N. and Mazomder M.S.I. Driving impacts through science-practitioner partnership: Professionalising water service delivery in rural Bangladesh. Environmental Science & Policy 176 2026, pp. 1-11. https://doi.org/10.1016/j.envsci.2026.104316

[7] Machado A.V.M., Oliveira P.A.D. and Matos P.G. Review of community-managed water supply—factors affecting its long-term sustainability. Water 14(14) 2022, pp. 1-17. https://doi.org/10.3390/w14142209

[8] Anh N.T., Dung N.H. and Thu D.T. Privatization in rural water supply and customer satisfaction: An empirical case study in Vietnam. Sustainability 14(9) 2022, pp. 1-15. https://doi.org/10.3390/su14095537

[9] Nath D., Peramaiyan P., Kumari V., Laik R. and Dotaniya M.L. Water resources of rural India: Challenges and management strategies for sustainable development. In Madhav, S. et al. (Eds.), Water resources management for rural development, Elsevier 2024, pp. 191–200. https://doi.org/10.1016/B978-0-443-18778-0.00015-5

[10] Toan T.D., Hanh D.N. and Thu D.T. Management models and the sustainability of rural water supply systems: An analytical investigation in Ha Nam province, Vietnam. Sustainability 15(12) 2023, pp. 1-22. https://doi.org/10.3390/su15129212

[11] UNICEF. Formative research on rural water supply, sanitation, hygiene, and nutrition in Viet Nam 2023, pp. 1-20. https://www.unicef.org/vietnam/reports/formative-research-rural-water-supply-sanitation-hygiene-and-nutrition-viet-nam

[12] Department of Agriculture and Environment – DAE Vietnam. Rural water supply project in Quang Ninh Province until 2025 [In Vietnamese] 2024.

[13] Asian Development Bank. Transforming urban-rural water linkages into high quality investments 2020. https://sdghelpdesk.unescap.org/sites/default/files/2020-09/urban-rural-water-high-quality-investments.pdf

[14] Vietnam News. Rural clean water supply faces several challenges 2024, pp. 1-70. https://vietnamnews.vn/society/1687118/rural-clean-water-supply-faces-several-challenges.html

[15] Gomez M., Perdiguero J. and Sanz A. Socioeconomic factors affecting water access in rural areas of low- and middle-income countries. Water 11(2) 2019, pp. 1-21. https://doi.org/10.3390/w11020202

[16] Alvarez L. Access to water and sanitation services in dispersed rural settlements: The path to universalization. Technical Note No. IDB-TN-01729, Inter-American Development Bank 2019, pp. 1-92.

[17] Hoque S.F., Hope R., Arif S.T., Akhter T., Naz M. and Salehin M. A social-ecological analysis of drinking water risks in coastal Bangladesh. Science of The Total Environment 679 2019, pp. 23–34. https://doi.org/10.1016/j.scitotenv.2019.04.359

[18] National Statistics Office of Vietnam. Health, culture, sport, living standards, social order, safety and environment 2022. https://www.nso.gov.vn/en/health-culture-sport-living-standards-social-order-safety-and-environment/

[19] Omarova A., Tussupova K., Hjorth P., Kalishev M. and Dosmagambetova R. Water supply challenges in rural areas: A case study from central Kazakhstan. International Journal of Environmental Research and Public Health 16(5) 2019, pp. 1-14. https://doi.org/10.3390/ijerph16050688

[20] World Health Organization and UNICEF. Progress on household drinking water, sanitation and hygiene 2000–2020: Five years into the SDGs 2021, pp. 1–164.

https://www.who.int/publications/i/item/9789240030848

[21] Zhang Y., Deng J., Qin B., Zhu G., Zhang Y., Jeppesen E. and Tong Y. Importance and vulnerability of lakes and reservoirs supporting drinking water in China. Fundamental Research 3(2) 2022, pp. 265–273. https://doi.org/10.1016/j.fmre.2022.01.035

[22] Patel A. and Shah A. Sustainable solution for lake water purification in rural and urban areas. Materials Today: Proceedings 32(4) 2020, pp. 740–745.
https://doi.org/10.1016/j.matpr.2020.03.473

[23] Agyemang V.O. Groundwater resources development for a sustainable water supply in developing countries: A case study of Ghana. Cleaner Water 4 2025, pp. 1-16. https://doi.org/10.1016/j.clwat.2025.100104

[24] Srivastava S., Singh A. and Dwivedi D. Facing groundwater depletion in India: The role of human activities and climate extremes. Groundwater for Sustainable Development 29 2025, pp. 1-21. https://doi.org/10.1016/j.gsd.2025.101430

[25] Hassan H.B., Moniruzzaman M., Majumder R.K., Ahmed F., Bhuiyan M.A.Q., Ahsan M.A. and Al-Asad H. Impacts of seasonal variations and wastewater discharge on river quality and associated human health risks: A case of northwest Dhaka, Bangladesh. Heliyon 9(7) 2023, pp. 1-18. https://doi.org/10.1016/j.heliyon.2023.e18171

[26] Tran S.H., Dang H.T., Dao D.A., Nguyen V.A., Nguyen T.L., Nguyen V.A. and Han M. On-site rainwater harvesting and treatment for drinking water supply: Assessment of cost and technical issues. Environmental Science and Pollution Research 28 2021, pp. 11928–11941. https://doi.org/10.1007/s11356-020-07977-0

[27] Jafari G., Omidvar B. and Ardestani M. A resilience-based framework for attuning integrated water resources management strategies in social-ecological systems of river basins. Journal of Water and Climate Change 16 2025, pp. 3545–3565. https://doi.org/10.2166/wcc.2025.271

[28] Walters J., Valcourt N., Linden K., Javernick-Will A. and Lockwood H. Challenges and solutions to rural water service sustainability in East African countries: A 'systems scaffolding' perspective. Environmental Science & Policy 136 2022, pp. 564–574. https://doi.org/10.1016/j.envsci.2022.07.023

[29] Leclert L., Nzioki R.M. and Feuerstein L. Addressing governance and management challenges in small water supply systems – the integrity management approach in Kenya. Aquatic Procedia 6 2016, pp. 39–50. https://doi.org/10.1016/j.aqpro.2016.06.006

[30] Hendry S. and Akoumianaki I. Governance and management of small rural water supplies: A comparative study. Report No. CRW2015/05, CREW 2016, pp. 1-75. https://www.crew.ac.uk/sites/www.crew.ac.uk/files/publication/CRW2015_05%20Final%20report.pdf

[31] Tran T.H.M., Le P.N., Nguyen V.S., Nguyen V.H., Nguyen D.Q., Thai V.H. and Eluriaga L.M.T. Factors affecting decision and willingness to pay to connect to pipe water of households: A case study in Vietnam. Academy of Strategic Management Journal 20(6) 2021, pp. 1-15. https://german.abacademies.org/abstract/factors-affecting-decision-and-willingness-to-pay-to-connect-to-pipe-water-of-households-a-case-study-in-vietnam-14029.html