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A comprehensive evaluation of private sector investment decisions for sustainable water supply systems using a fuzzy-analytic hierarchy process: A case study of Ha Nam province in Vietnam

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ABSTRACT

This study examined the factors that affect the private sectors' willingness to invest in rural water supply. The study applied a mixed methods approach, including an overview of relevant studies, expert consultation, exploratory factor analysis using SPSS software, and a fuzzy-analytic hierarchy process to identify and evaluate the factors applicable to Ha Nam province in Vietnam. Some factors were distinguished that are significant to private investors' rural water supply investment decisions, including tax incentive policy, policies to support preferred access to loans and credit, a state risk-sharing mechanism, a mechanism to adjust water price, community support, high community demand for clean water, and input water quality. In addition, the study constructed an investment attractiveness index to evaluate the attractiveness of private sector investment for two typical rural water supply projects in Ha Nam province. This index can be used as a basis for the government to design appropriate incentives to attract investment from private investors and construct an investment attractiveness map.

1. Introduction

As observed by the Hesperian Foundation, there are billions of people around the world living without access to safe water [1]. The foundation also noted that improved water supply and sanitation access can effectively improve community health [1]. However, in rural areas in many developing countries, access to safe water and sanitation remains unfeasible for a large portion of the population [2]. According to United Nations (UN) Statistics Division Development Data and Outreach Branch, as of 2020, two billion people were without managed water services, of which 1.2 billion did not even have access to basic services [3]. The UN has recognized water and sanitation as human rights [4]. Halving the number of people without access to safe water is encoded among the Millennium Development Goals (MDGs) [5]. Investing in the water supply is considered to be an indirect investment in other targets of the MDGs because the people in areas invested in developing sustainable clean water sources have improved health, are able to spend more time on studies and livelihood activities to improve their quality of life [6]. A milestone of water equity governance is defined as adequate access to enough water as recognized by the UN [7]. In the past two decades, newly constructed or expanded water supply systems have been constructed in an effort to improve the capacity of rural water supply [8].

Water supply systems in rural areas of developing countries have been commonly constructed by the public sector. As of 2006, an estimated 90% of the world's population was supplied with water and sanitation by public agencies [9]; however, government

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resources are often limited and must be allocated to multiple urgent and competing concerns of social security. Furthermore, private investment in this field is limited since investing in rural water supply has been described as one of the most complicated, difficult to implement, and considerably risky for investors [10] (i.e., *difficult to increase water price, difficult to cut attached services*), as any changes are vulnerable to public resistance and media scrutiny [11]. Furthermore, the market entry of new investors in this field also confronts many challenges. The initial unit has the advantages of cleaner water sources and subsequent reasonable water prices. In addition, people in rural areas in developing and underdeveloped countries often have multiple seasonal water sources to draw from to suit their conditions [12]. According to the World Bank Group (WB), as of October 2022, the proportion of investment capital allocated to water supply and sanitation projects was US $21.3 billion of the total US $31.2 billion of 262 water projects approved by the WB in developing countries over the past 10 years [13]. Between 1990 and 2005, over US $50 billion in private investment was committed to more than 380 water supply projects in low- and middle-income countries [14]. By 2012, the level of investment reached over US $69 billion in 814 projects in 63 countries [15]; however, various estimates, performed by the World Water Council, indicated that the current level of investment would have to be doubled to achieve the target 10 of MDGs [9,16]. These statistics paint a pale picture of private water supply investment. Identifying the factors balancing benefits between rural water users, the state, and private investors and determining their significance is a necessary and complicated endeavor to improve project outcomes such as service quality, operations, and maintenance.

To navigate this difficult circumstance, attracting private investment in rural water projects in the form of public-private partnerships (PPP) presents a promising solution [17]. This form of cooperative investment helps nations and private investors reduce budget pressure, allocate and manage risks more effectively, reduce costs, and improve service quality. Unfortunately, some studies have indicated that cooperative PPP projects often achieve underperforming outcomes, become distressed, or are even terminated [18] due to multiple factors such as inexpert regulation [19], public resistance [20], lack of government experience [21], poor contract design and negotiation [22], country-specific factors [23], and sector-related barriers [24]. In addition to identifying the influencing factors, it is also crucial to determine their significance to the success and investment attractiveness of water projects, as there is sometimes more than one objective involved that requires multicriteria decision analysis [25]. In addition, in many real-life situations, qualitative factors involve unstructured problems [26]. Therefore, it is imperative to develop relevant tools and methods to aid decision-makers in reasonable assessments as an essential need [27].

Several validated multicriteria decision-making methods are available to examine this problem, including the analytical hierarchical process (AHP), the analytical network process, the Technique for Order of Preference by Similarity to Ideal Solution (also known as TOPSIS), data envelopment analysis, fuzzy decision making [28], and Vlsekriterijumska Optimizacija Ikompromisno Resenje (VIKOR) [29], among others. One of the most commonly used techniques for assigning weights to different project factors used in a selection process is AHP [30]. Professor Thomas Saaty first proposed this technique in the 1970s. The AHP method helps decision-makers determine the most suitable options based on hierarchical criteria that include quantitative and qualitative factors [31]. However, the uncertainty and ambiguity associated with project selection are not considered in AHP, even though these two properties are recognized [32]. To solve this problem, Van Laarhoven proposed a triangular fuzzy number to apply to AHP. In this way, the results of the human subjective judgment process can become more reasonable since this process is quantified using an established fuzzy evaluation matrix [33]. This approach has been validated as an effective way to make decisions despite uncertainty in the pairwise comparison process [27]. Fuzzy-AHP (F-AHP) is refined using the geometric mean method to calculate weights after the fuzzy numbers are assigned [34].

The objectives of this study include (i) identifying and categorizing the factors that affect the private sector's willingness to participate in rural water supply, (ii) calculating the weights of those factors, and (iii) constructing a proposed investor attractiveness evaluation index and practical applications. First, the initial factors were identified based on related studies. Highly qualified experts working in relevant agencies and organizations were also invited to survey, supplement, and select the factors that most suit the practical conditions of Ha Nam province. Additionally, analyses using SPSS software were performed to screen and group factors, as raw materials for applying the F-AHP analysis. An F-AHP-based framework was developed to determine the weights of factors that affect the willingness of private investors to participate in rural water supply. Finally, a private investor attractiveness index was developed for practical application on two water works cases in Ha Nam province.

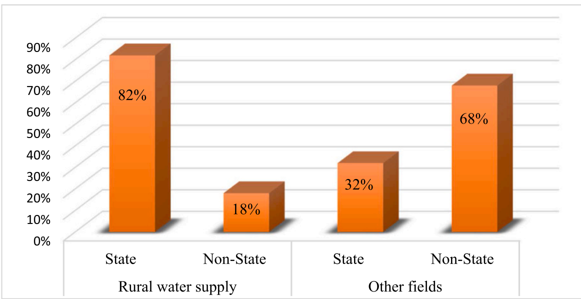

Fig. 1. Capital ratios of state and nonstate sources in investment fields.

2. Defining the problem

2.1. Status of rural water supply in Ha Nam, Vietnam

Ha Nam currently has 29 operating rural water supply plants, representing a total construction investment of US $54.20 million, of which the government contribution was US $44.68 million, accounting for 82%, and capital from nonstate investment was US $9.52 million, accounting for only 18%. Notably, in the period 2008–2021, total investment for all areas in Ha Nam was US $9194.49 million [35], of which the government contribution was US $2946.69 million, accounting for 32%, and private sector capital was US $6247.80 million, accounting for 68%. These investment statistics are detailed in Fig. 1. Obviously, private investment in rural water supply was much less attractive compared to other fields, although several support mechanisms from the government have been contributed. The major rationale for this unsatisfactory result is as follows.

- Most of the input water in Ha Nam is heavily polluted, which increases investment costs while water prices are controlled by the state and kept low.
- A monopoly of a water supply plant in one area is not competitive in terms of product and business growth.
- Investing in remote areas with poor water resources, low socioeconomic conditions, and scattered populations puts pressure on profit and capital recovery for private investors.

The deficiency of private investment and the limited support of the government budget in the postconstruction period make water supply works in Ha Nam inefficient and unsustainable. First, factories have degraded and there is a lack of facilities for ensuring water quality; thus, productivity and water quality are not guaranteed. In addition, low funding leads to insufficient wages to attract high-

Table 1
Preliminary factors that affect the private sector's willingness to participate in rural water supply.

No.	Factor	Description	Reference
1	Tax incentive policies	*Tax incentives include tax rates, corporate income tax, and tax reductions for imported equipment.*	[43]
2	Land incentive policies	*Enterprises are given preferential treatment by the state for land allocation to implement project contracts.*	[47]
3	Policies to support access to preferential loans and credit	*The state's support for accessing loans and concessional credit.*	[48,49]
4	Dedicated PPP unit to support and promote rural water supply programs	*In addition to an advisory role, the unit also has a clear and specific mandate and is afforded certain rights.*	[48,50]
5	Policies to support the transfer and application of science and technology	*Purchase technology copyright, technology, technology research, and development results; conduct scientific research or pilot production projects.*	[51]
6	Training support policies to improve capacity management and operation	*Support policies to improve project management and operation ability for technical cadres.*	[51]
7	Mechanism to adjust water price	*Mechanism to appropriately adjust water prices to ensure a return on equity.*	[52]
8	Administrative procedures	*Such procedures are expressed through the project proposal order and procedures, investor selection, transparency of projects.*	[51]
9	State capital contribution	*The government capital contribution rate affects private investors' willingness to participate.*	[53]
10	State risk-sharing mechanism	*The private partner receives a share of the risk that is differentiated from a fully private investment.*	[53]
11	Experience in participating in PPP projects	*Experience in implementing PPP projects positively affects private enterprises' willingness to participate in PPP projects.*	[52]
12	Experience in participating in rural water supply projects	*Experience helps enterprises better control profit and risk.*	[37,52]
13	Finance of the enterprise	*Enterprises with abundant finance and higher profits tend to be interested and participate in PPP projects.*	[37]
14	Community support	*The community's willingness to assist in land acquisition, use the service, and pay service fees.*	[52]
15	The community's high demand for clean water	*High demand indicates potential high consumption, which suggests that the project will obtain higher profit and quickly recover capital.*	[11]
16	Water price stability	*Water prices that are too high or fluctuate often will affect service users' capacities, rendering many people unable to pay for water services.*	[38,45]
17	Economic characteristics of the locale	*Economic characteristics affect service users' ability to pay for services.*	[37]
18	Population in the surrounding areas	*The population distribution and density affect private investors' willingness.*	[37]
19	Local cultural features	*In many locales, people still maintain the habit of using drilled wells, dug wells, and other unregulated forms, which affects the consumption of clean water when the project is in operation.*	[37]
20	Media support and supervision	*Media support and supervision will also affect private investors' willingness to participate in PPP projects.*	[44]
21	A well-designed contract	*A well-designed PPP project will benefit the State, private sector, and service users.*	[54,55]
22	Profit of the project	*The profitability of the project is considered to be the most significant factor for the state and the private investors.*	[56]
23	The complexity of the project	*Related to the financial, technical, and management aspects of PPP projects.*	[37]
24	Quality of the works	*Investors consider a variety of related issues, such as the condition of the facilities (through technical management records), the quality of existing staff, and the fit of the staff layout.*	[56]
25	Availability of the project's water sources	*An abundant supply meets service users' increased demand for clean water and does not disrupt the demand for water.*	[57]
26	Input water quality	*A good quality water source reduces the costs of water treatment and operation.*	[57]

quality human resources, making successful operations difficult. In particular, by the end of December 2021, only 68% of rural households in Ha Nam accessed water that met the standards of the Ministry of Health for water supply plants [36]. According to the Ha Nam Provincial Water Supply Plan for 2030, a target was set to reach a 100% coverage rate of water and sanitation from the centralized water supply system in rural areas. Thus, Ha Nam province has less than eight years to achieve 100% water supply services coverage. This corresponds to the need to cover 32% of the population in rural areas, representing about 201,700 people without access to water from centralized water supply systems in regions that are less attractive to private investment. To achieve 100% coverage, the Ha Nam provincial government must develop appropriate mechanisms and policies to effectively attract private investment. The prerequisite for this is to fully identify the factors that influence the private sector's willingness to participate in rural water supply in Ha Nam province.

2.2. Research framework

The analysis was divided into three phases. In the first phase, we identified the various factors affecting the private sector's willingness to participate in rural water supply, which are presented in Table 1, through an exhaustive literature survey. A questionnaire survey was then conducted to refine the investigation and determine the significant factors involved. A factor analysis using SPSS (25.0) software was conducted based on the questionnaire results to determine the final factors and classify them into major categories. In the second phase, we applied the F-AHP to obtain weights for major factors to determine the extent to which each factor affects the private sector's willingness to invest. We then used the factor weights to construct a proposed investor attractiveness evaluation index in the final phase and applied this index to evaluate its practical application for two cases in Ha Nam province. Fig. 2 illustrates the framework of the study.

2.3. Identifying factors that affect the private Sector's participation in rural water supply

As described above and illustrated in Fig. 2, to determine the factors that affect the private sector's willingness to participate in rural water supply projects, this study adopted an exploratory approach using three main steps that include (1) a literature review to identify preliminary factors, (2) a survey including a group of rural water supply experts to assess the factors shortlisted in step one, and (3) identifying the final factors by analyzing the survey data using exploratory factor analysis (EFA) and categorizing the related factors into separate groups.

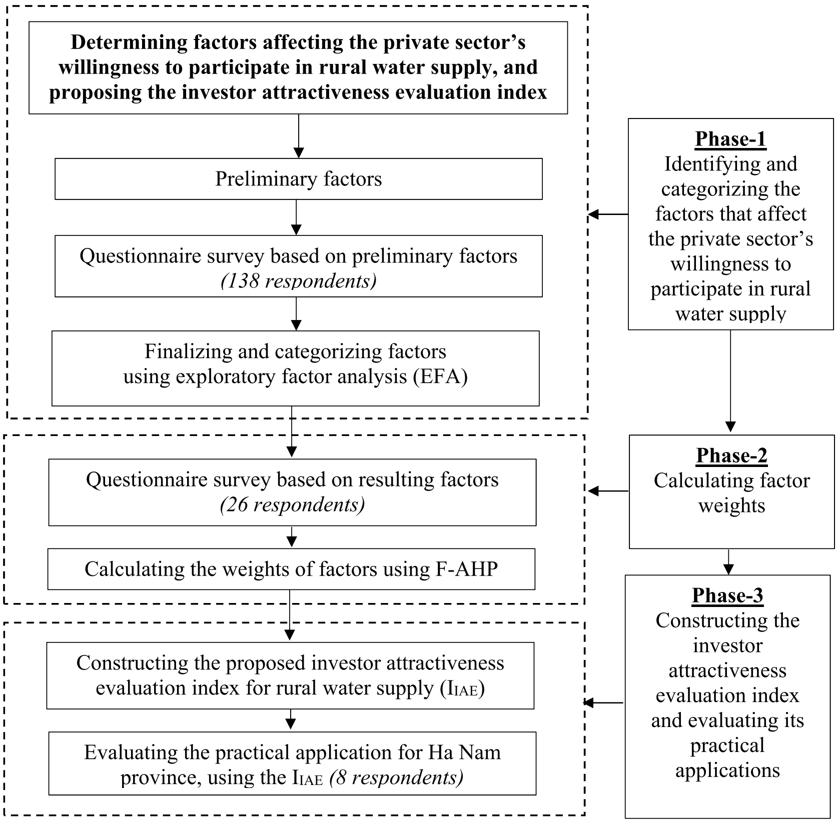

Fig. 2. The research framework of the study.

2.3.1. Preliminary factor identification based on a literature review

To identify the factors that may influence the private sector's willingness to participate in rural water supply in Ha Nam province, the potential factors were first identified based on the results investigated in the literature. In particular, Chen et al. [37] found that five basic groups of factors affect private investors' investment decisions, including (1) factors of related parties, (2) factors of enterprises, (3) factors of external environmental risk, (4) construction location, and (5) local support solutions. Thomas Ng et al. [38] also identified five groups of factors that contribute to the attractiveness of private investment which included (1) technical, (2) financial and economic, (3) social, (4) political and legal, and (5) other factors (staff issues and possible management actions). Some other prominent studies related to the identification of specific factors affecting the private sector's investment willingness were included in the WB report [39], Xiaosu Ye et al. [40], Sudipto Sarkar [41], Shiu Tong Thomas et al. [38], Dulaimi et al. [42], the Organization for Economic Co-operation and Development [43], Ozdoganm et al. [44], Ameyaw et al. [45], and Bayliss [46]. Finally, a list of 26 potential factors is considered, as presented in Table 1.

2.3.2. Questionnaire survey

A questionnaire was designed to survey expert opinions to identify the major factors from the shortlist above. The relative significance of the factors was measured on a 5-point Likert-type scale [58], where 1 = very low significance and 5 = very high significance. This scale provided respondents flexibility in rating each factor. The participants selected for the survey included experts and cadres working at organizations related to the research field such as the General Department of Water Resources, the National Center for Rural Clean Water and Sanitation, relevant state agencies in Ha Nam province, relevant universities and research institutes, and other related organizations.

According to Hair et al. [59], the number of survey samples should be five times more than the number of variables being considered. In this case, 26 variables were identified; thus, at least 130 respondents were needed, and the authors surveyed 138 participants to ensure accurate results. Basic information on the 138 participants is presented in Table 2.

2.3.3. Reliability test of survey data

Reliability tests of survey data were performed using Cronbach's alpha on version 25.0 of SPSS statistic software. First, the internal consistency of the scale was assessed using Cronbach's alpha. The Cronbach's alpha coefficient (α) value ranges from 0 to 1 and can be used to describe the reliability of factors extracted from questionnaires or scales. A high α value indicates high internal consistency in the scale. According to Nunnally and Burnstein, the outcome values in SPSS must be greater than 0.7 to be accepted [60]. In this research, Cronbach's alpha regarding the factors' reliability was 0.757, indicating internal consistency. To distinguish the correlation between the variables, Bartlett's test of sphericity [61] and the Kaiser–Meyer–Olkin (KMO) test [62] (requiring a minimum of 0.50) were used to determine the applicability of factor analysis in factor extraction.

As shown in Table 3, Bartlett's test of sphericity was significant ($\rho < 0.001$), and the value of the KMO index was 0.803 (greater than 0.5). In summary, the results of the validity analysis confirmed that the data were suitable for factor analysis.

2.3.4. Final factor identification based on EFA

In factor analysis, selecting the correct number of factors to retain is a crucial decision. Norman and Streiner [63] provided an approximate formula for determining the statistical significance of pattern coefficients (Eq. (1)), wherein if factors have lower loadings than this, they should be excluded.

$$CV = \frac{5.152}{\sqrt{N-1}} \tag{1}$$

Here, N = the number of samples of survey data (N = 138 and CV = 0.442).

Factor extraction and rotation were then conducted, wherein higher factor loading indicates a factor's greater contribution to the component. Factor loadings for these 26 factors were determined based on varimax rotation. Among these, four factors had loadings that were smaller than 0.442, including the provision of a PPP unit to support and promote the host country's rural water supply program, training support policies to improve management and operations, experience in participating in PPP projects, media support and supervision, and a well-designed contract. These factors did not significantly interpret a component and were excluded. The final screened factors were divided into the four groups presented in Table 4.

Table 2
Information of experts participating in the survey.

Gender		Academic level		Work unit		Work position	
Male	54%	Bachelors	63%	State agencies	52%	Officers	58%
Female	46%	Ph.D.	20%	Private enterprises	36%	Head of department	28%
		Master's	17%	Institutes and universities	12%	Enterprise owners/Agency leader	14%

Table 3
Bartlett's test of sphericity and the KMO test.

Kaiser–Meyer–Olkin test		0.803
Bartlett's test of sphericity	Approximate Chi-Square	2164.998
	Freedom	138
	Significance	0.000

Table 4
Final screened factors.

Groups	Code	Affecting factors	Factor loading
Preferential Government Policies **C_1**	C_{11}	Tax incentive policies	0.846
	C_{12}	Land incentive policies	0.821
	C_{13}	Policies to support access to preferential loans and credit	0.801
	C_{14}	Policies to support the transfer and application of science and technology	0.736
	C_{15}	Finance of the enterprise	0.669
	C_{16}	Experience in participating in rural water supply projects	0.632
Profit, Mechanism of Capital Contribution, and Risk-sharing between the Government and Enterprises **C_2**	C_{21}	Profit of the project	0.795
	C_{22}	State capital contribution mechanism	0.747
	C_{23}	State risk-sharing mechanism	0.737
	C_{24}	Mechanism to adjust water price	0.706
	C_{25}	Water price	0.687
	C_{26}	Administrative procedures	0.648
Location of the Construction Site **C_3**	C_{31}	Population in the surrounding areas	0.813
	C_{32}	Economic characteristics of the locality	0.808
	C_{33}	Local cultural features	0.795
	C_{34}	Community support	0.776
	C_{35}	High demand for clean water of community	0.567
Engineering and Technology **C_4**	C_{41}	Availability of project's water sources	0.922
	C_{42}	The complexity of the project	0.840
	C_{43}	Quality of the works	0.806
	C_{44}	Input water quality	0.609

3. Fuzzy-AHP for determining the weights of investor attractiveness indices for rural water supply

3.1. General theory

3.1.1. Basic concept of fuzzy-AHP

The F-AHP model was applied in this study to determine factor weights by calculating the significance ratings of individual factors while accounting for their relationships. F-AHP handles the hierarchical process of interrelationships between factors through a series of pairwise comparisons.

Let $\widetilde{A}$ represent a fuzzified reciprocal $n \times n$ judgment matrix containing all pairwise comparisons $(\widetilde{a}_{ij})$ between elements i and j for all i, j $\in \{1, 2, ..., n\}$. The matrix $\widetilde{A}$ is represented in Eq. (2) as follows:

$$\widetilde{A} = \begin{pmatrix} (1,1,1) & \widetilde{a}_{12} & \cdots & \widetilde{a}_{1n} \\ \widetilde{a}_{21} & (1,1,1) & \dots & \widetilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \widetilde{a}_{n1} & \widetilde{a}_{n2} & \cdots & (1,1,1) \end{pmatrix} \tag{2}$$

Here, $\widetilde{a}_{ji} = \widetilde{a_{ij}^{-1}}$ and all $\widetilde{a}_{ij}$ are triangular fuzzy numbers (TFNs). $\widetilde{a}_{ij} = (l_{ij}, \mathrm{m}_{ij}, \mathrm{u}_{ij})$ with l_{ij} is the lower value, u_{ij} is the upper value of fuzzy number A, and m_{ij} is the point at which the membership function $\mu(x) = 1$ (see Fig. 3a and b). The membership function $(\mu(x))$ of the TFN can therefore be described in the following Eq. (3) [64].

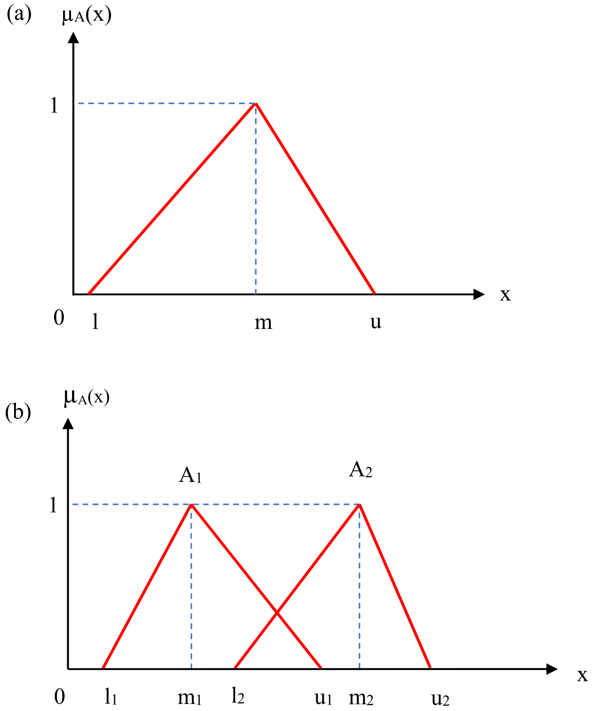

Fig. 3. Fuzzy variable model: a) The membership functions of the triangular fuzzy number (TFN); b) The intersection between two fuzzy numbers.

$$\mu_A(x) = \begin{cases} \frac{x-l}{m-l}, x \in [\mathrm{l}, \mathrm{m}] \\ \frac{u-x}{u-m}, x \in [\mathrm{m}, \mathrm{u}] \\ 0, otherwise \end{cases} \tag{3}$$

where $l_{ij} \le m_{ij} \le u_{ij}$, if $l_{ij} = m_{ij} = u_{ij}$, and the fuzzy number becomes a crisp number.

The factors underwent pairwise comparisons with others at the same level using a conventional arithmetic scale from 1 to 9 [65]. A detailed description is presented in Table 5. The subfactors were also compared with those belonging to the same group.

In cases with two TFNs, $\widetilde{A}_1 = (l_1, m_1, u_1)$ and $\widetilde{A}_2 = (l_2, m_2, u_2)$, the basic operations are presented in Eqs. (4)–(6):

$$\widetilde{A^{-1}} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \tag{4}$$

$$\widetilde{A_1} + \widetilde{A_2} = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{5}$$

$$\widetilde{A_1} \times \widetilde{A_2} = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \tag{6}$$

The operation laws above are required to estimate the priorities of the fuzzy matrix. Two elements must be accomplished beforehand, including (i) evaluating the consistency of experts' assessments and (ii) aggregating the single pairwise comparisons (group

Table 5
Fuzzy numbers for making pairwise comparisons [65].

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is favored very strongly, and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of importance
2, 4, 6, 8		When compromise is needed

decision).

3.1.2. Consistency analysis of evaluations

The pairwise comparison matrix must be consistent to verify the quality of expert judgment. One of the most practical capabilities of the AHP methodology is that it allows for slightly inconsistent pairwise comparisons since perfect consistency in the matrix of comparisons rarely occurs in practice.

Saaty [65] proposed Eq. (7) calculating a consistency index (CI) to analyze the consistency of the comparison matrix, wherein lower consistency indicates a higher CI value.

The CI takes the following form:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{7}$$

Here, $\lambda_{\max}$ = maximum eigenvalue, and n = number of comparison elements.

The major measure of consistency is the consistency ratio (CR). This measure is based on comparing expert ratings with the average value of the random pairwise comparisons. The pairwise comparisons made by experts should differ significantly from random comparisons, the CR is in the form of Eq. (8):

$$CR = \frac{CI}{RI} \tag{8}$$

Here, CI = consistency index and RI = random index.

For the CI when pairwise comparisons are completely random, in the AHP, the pairwise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding CR is less than 10%. The RI coefficient is presented in Table 6.

3.1.3. Aggregation of group decisions

An important concern in multicriteria decision-making is how to aggregate expert judgments into a single representative assessment for the entire group of experts. For TFNs, the synthesis of evaluation results from n experts applied Eqs. (9)–(12) used by Chang (2009) and Büyüközkam (2004) [67,68].

$$\widetilde{A} = \left(l_{ij}, m_{ij}, u_{ij}\right) : l_{ij} \le m_{ij} \le u_{ij}; l_{ij}, m_{ij}, u_{ij} \in \left[\frac{1}{9}, 9\right] \tag{9}$$

$$l_{ij} = \min\left(B_{ijk}\right) \tag{10}$$

$$m_{ij} = \sqrt[n]{\prod_{1}^{n} B_{ijk}} \tag{11}$$

$$u_{ij} = \max\left(B_{ijk}\right) \tag{12}$$

Here, B_{ijk} is the kth expert's assessment in a pairwise comparison between factors i and j.

However, according to Meixner [69], calculation based on minimum and maximum values is not very reasonable when the sample obtained has a wide distribution range. Indeed, if there is only one or a few experts that evaluate B_{ijk} differently, the distribution (support) of fuzzy numbers (l_{ij}, m_{ij}, u_{ij}) becomes extremely large. To overcome this issue, Meixner [69] proposed Eqs. (13)–(15):

$$l_{ij} = \sqrt[n]{\prod_{1}^{n} l_{ijk}} \tag{13}$$

$$m_{ij} = \sqrt[n]{\prod_{1}^{n} m_{ijk}} \tag{14}$$

$$u_{ij} = \sqrt[n]{\prod_{1}^{n} u_{ijk}} \tag{15}$$

Here, l_{ijk}, m_{ijk}, and u_{ijk} denote the fuzzy triangular number evaluated by the kth expert in the pairwise comparison between two factors i and j.

Meixner's calculation method was applied in this study.

Table 6
Random index for factors (RI) [66].

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3.1.4. Defuzzification and defining weights

Defuzzification refers to the transformation of a pairwise comparison matrix from a fuzzy number (l_{ij}, m_{ij}, and u_{ij}) to a crisp number. Many studies have suggested different methods to accomplish this. Assuming that $\widetilde{p}_{ij}$ is the result of a pairwise comparison of expert ratings, the pairwise comparison matrix can be written as Eq. (16):

$$\widetilde{P}=\begin{bmatrix} 1 & \widetilde{p}_{12} & \cdots & \widetilde{p}_{1n} \\ \widetilde{p}_{21} & 1 & \cdots & \widetilde{p}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \widetilde{p}_{n1} & \widetilde{p}_{n2} & \cdots & 1 \end{bmatrix} \tag{16}$$

Fuzzy weights were calculated referencing Buckley's mean method [70] as following Eqs. (17) and (18):

$$\widetilde{r}_i=\left(\prod_{j=1}^{n}\widetilde{p}_{ij}\right)^{1/n} \quad \mathrm{i}=1,2,\ldots,\mathrm{n} \tag{17}$$

$$\widetilde{w}_i=\widetilde{r}_i\otimes\left(\sum_{i=1}^{n}\widetilde{r}_i\right)^{-1}, \mathrm{i}=1,2,\ldots,\mathrm{n} \tag{18}$$
$$(Lw_i, Mw_i, \mathrm{U}w_i)$$

Various techniques can be used for defuzzification; however, each technique extracts different levels of information from the fuzzy numbers and may subsequently produce different ranking orders [71]. Hsieh et al. [72] introduced the defuzzification method and weight calculation by applying the center of area method as Eq. (19):

$$F_i=[(\mathrm{U}w_i-Lw_i)+(Mw_i-Lw_i)]\,/\,3+Lw_i \tag{19}$$

3.2. Application of F-AHP for the case study

The four main factors identified included (1) Preferential government policies; (2) Profit, mechanism of capital contribution, and risk-sharing between the state and enterprise; (3) Location of the construction site; and (4) Engineering and technology. Subfactors (intermediate factors) were selected for each of the main factors (details for C_{11}, C_{12}, …, and C_{44} are shown in Table 1). The hierarchical assessment structure of the weight determination of factors is illustrated in Fig. 4.

As described previously we conducted a survey including a sample of 26 experts to determine the weights of factors affecting the private sector's willingness to participate in rural water supply in Ha Nam province. The experts were asked to complete the questionnaire based on the linguistic variables and TFNs, which is presented in Table 7 [73] and Fig. 5. According to Seçme et al. [74], TFN parameters include left, middle, and right points that describe the smallest possible value, the most promising value, and the largest possible value, respectively. In this study, some respondents to the questionnaire survey were government officials working in rural water supply projects and working in rural water supply projects, and all were knowledgeable and experienced with practices in the field of rural water supply. Nevertheless, the respondents were not in-depth researchers; thus, the questionnaire had to be constructed as clearly and simply as possible to minimize any confusion or difficulty in the process of providing answers. Therefore, the questionnaire only asked them to choose the most promising value. In the process of synthesizing experts' responses, the values of left and right points were aggregated to form symmetrical TFNs as commonly used in previous research [75–78]. Table 7 and Fig. 5 present the aggregated symmetrical TFNs.

The 26 experts who participated in the survey had several years of experience in the field of rural water supply (as detailed in Table 8). Three criteria were applied for selecting experts. Some experts were cadres who worked in the rural water supply government departments of Vietnam, some worked on projects related to rural water supply, and other experts were academic researchers from research institutes and universities.

Although the highest academic degree level varied, all participating experts had more than 10 years of experience in projects

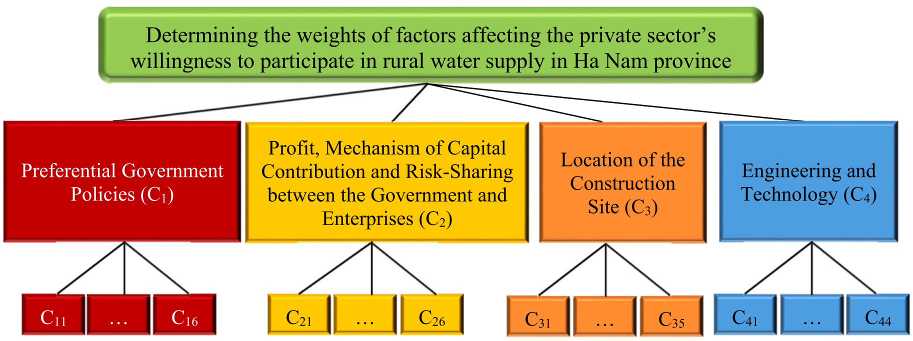

Fig. 4. Hierarchical assessment structure of factor weight determination.

Table 7
Fuzzy numbers used for pairwise comparisons.

Linguistic variables	Triangular fuzzy numbers (TFNs)	Reciprocal TFNs
Equal importance (EqI)	(1, 1, 1)	(1, 1, 1)
Weak importance (WI)	(2, 3, 4)	(1/4, 1/3, 1/2)
Strong importance (SI)	(4, 5, 6)	(1/6, 1/5, 1/4)
Demonstrated importance (DI)	(6, 7, 8)	(1/8, 1/7, 1/6)
Extreme importance (ExI)	(8, 9, 10)	(1/10, 1/9, 1/8)

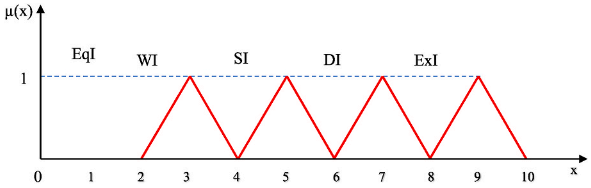

Fig. 5. Fuzzy set scale used in this study.

Table 8
Surveyed expert information.

Gender		Academic level		Unit of work	
Male	60%	Bachelors	42%	Government departments	39%
Female	40%	Master's	35%	Rural water supply projects	42%
		Ph.D.	23%	Institutes and universities	9%

related to the rural water supply. Respondents' number of years of experience was an important criterion for considering them to be subject matter experts, which was considered to enhance the reliability of their answers.

To represent the interrelationships of factors and subfactors in the same group most intuitively, the authors used a correlation heat map to present the pairwise comparison matrices. The elements in the vertical column were then compared with the elements in the horizontal row. A warmer color indicates a factor's higher importance compared with others, whereas a colder color indicates a less important factor.

The correlation of the main factors is presented in Fig. 6 heat map, revealing a minimal color range and dominant cool tones, which indicates only a slight difference in the influence of the factors presented according to experts' assessment. The comparison of C1/C3 had the largest value of 1.92, followed by the C2/C1 pair with a value of 1.76. This large and clear difference indicates that the general trend of the factors' importance will decrease in the order C2 > C1 > C3. In contrast, the influence of factor C3 is only 1.01 times higher than that of factor C4.

Subfactor correlations are presented in Fig. 7. The highest value for those under the C_1 factor (Fig. 7a) is 3.88 when comparing C_{12} and C_{14}, followed by C_{11}/C_{14} and C_{13}/C_{14} pair comparisons with values of 3.35 and 3.31, respectively. This indicates that the experts

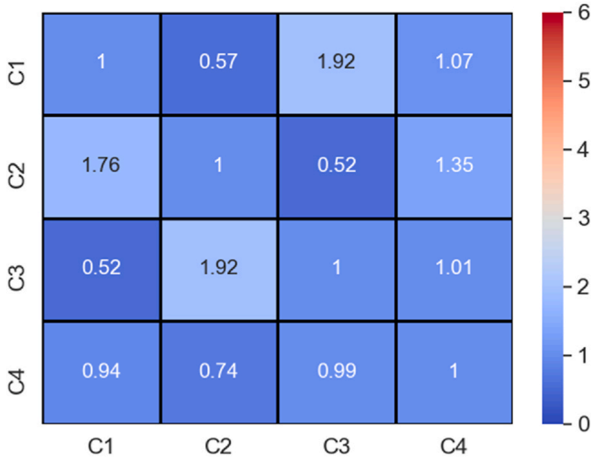

Fig. 6. Pairwise comparison heat map matrix of the main factors (CR < 0.1; n = 26).

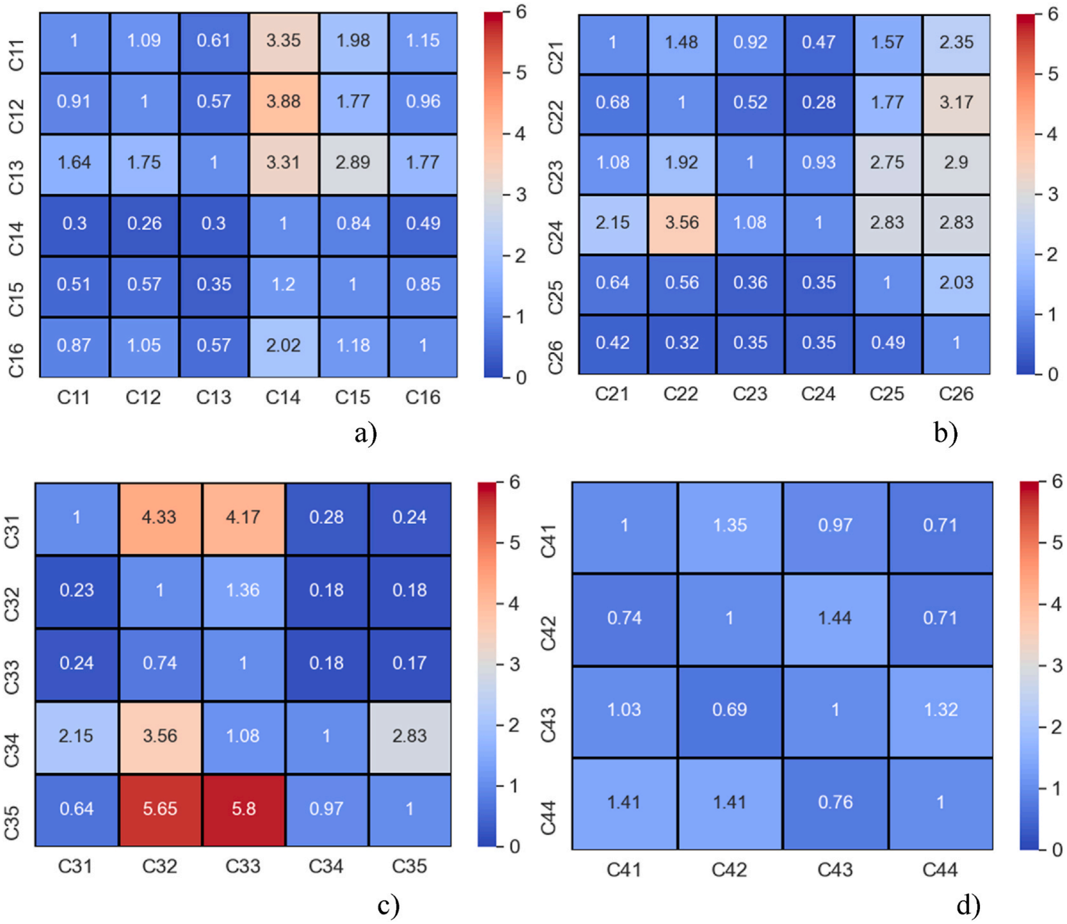

Fig. 7. Pairwise comparison heatmap matrix of the subfactors. Note: a) C_1; b) C_2; c) C_3; d) C_4.

considered land incentive policies, tax incentive policies, and policies to support access to favorable loans and credit to be at a relatively higher level than policies to support the transfer and application of science and technology. Regarding the C_2 matrix presented in Fig. 7b, the comparison results reveal the biggest difference between the mechanism to adjust water prices and the state capital contribution mechanism. The price factor was rated 3.56 points more important compared with the state capital contribution mechanism. The C_3 subfactors present the widest color range of the five main matrices as shown in Fig. 7c. The correlative comparison reached the largest and the smallest influence values of 5.8 and 0.17, comparing C_{35} and C_{33} subfactors, indicating a strong importance (SI) level. This also demonstrates that the demand for water supply service in the community is strongly more important than local cultural features. The comparison results of C_{35}/C_{32}, C_{31}/C_{32}, and C_{31}/C_{33} also had values representing fairly large influence differences in the paired comparisons, the score and the inverse score were 5.65/0.18, 4.33/0.23, and 4.17/0.24, respectively. Similar to Fig. 7a and d presents a dominant cool color tone and minimal color range, indicating that the subfactors in the C4 factor group were considered to be of equal importance by the experts.

3.3. *Investor attractiveness evaluation indices for rural water supply*

The attractiveness of rural clean water works investment to investors was assessed based on the identified factors affecting the private sector's willingness to participate and their weights.

The general formula is presented in Eq. (20):

$$I_{IAE} = \sum_{i=1}^{n} W_i \times K_i \tag{20}$$

where.

I_{IAE}: the evaluation index of investment attractiveness to investors.

W_i: the weight of the ith subfactor defined after F-AHP analysis (n = 21).

K_i: the scale of subfactors evaluated by experts for each specific project.

4. Results and discussion

4.1. Factor weights

The factor weights were defined using Eqs. (16)–(18), and the results of the defuzzification steps and weight calculation are presented in Tables 9 and 10, with visual descriptions shown in Figs. 8 and 9. The F-AHP analysis results revealed that the influence of the factors related to profit, the mechanism of capital contribution, and risk-sharing between the state and enterprises (C_2) were the most important, which was followed by the factors related to the state's preferential policies and enterprises' capacity, revealing respective weights for each group of 0.30 and 0.28. The weight difference between the two groups of factors above was minimal, indicating that the role of the state in encouraging private investors to participate in supplying water in Ha Nam province is extremely important. The final two groups include factors related to the social environment and factors related to engineering and technology, with weights of 0.25 and 0.17, respectively.

For the group of factors related to the state's preferential policies and enterprises' capacity, three subfactors, including policies to support access to preferential loans and credit, tax incentive policies, and land incentive policies had the highest respective weights, at 0.08, 0.06, and 0.05. Policies to support access to preferential loans and credit had the highest weight, indicating that the government must continue to promote priority policies and support access to loans and concessional credit for private investors involved in the field of rural water supply. A good institutional environment will positively influence private participation in infrastructure investment [52]. Private investors must carefully assess the institutional features and quality of institutions when they make decisions regarding participation in a PPP [79–81].

For the group of factors related to profit, the mechanism of capital contribution, and risk-sharing between the state and enterprises, the two subfactors included an appropriate mechanism to adjust water prices and government risk-sharing, with the highest weights of 0.09 and 0.07, respectively. Profitability is a crucial factor of investment [82], which takes third place in the group with a weight of 0.05. A project must have demonstrable profit potential to investors to attract the private sector's participation and initial investment [83,84]. The mechanism for appropriate adjustment of water prices was also a factor of great interest to the private sector because the field of rural water supply is a complex, politically and socio-sensitive field that directly affects communities. Adjusting water prices is not a simple matter, and a clear mechanism is required. Furthermore, the government's risk-sharing mechanism must be high-quality support that improves the investment performance of the private sector [85].

The two most weighted subfactors of the group of factors related to the location of the construction site included high community demand for clean water and community support, which share the same weight of 0.08. The community support factor was considered to have an extremely significant influence, as reflected in such issues as willingness to use the service, willingness to pay the service fee, commitment to support the project, land donation, and land clearance support. Thomas Ng et al. asserted that long-term demand in the community for the service is one of the most crucial factors for successful PPP projects [38]. The community must be confident that their concerns, needs, and preferences are honored in the project and that the project will provide maximum value for the public to minimize any potential public resistance [11]. Community support ensures that a project is both economically and socially viable. This was followed by the factor of the population in the surrounding areas, ranking third in the group with a weight of 0.05. Population concentration also partly affects investors' willingness. Investment costs will be lower and the ability to recover capital will be higher for areas with large populations and concentrated residential areas.

The input water quality factor in the group related to engineering and technology had the highest weight of 0.06. This indicates that investors were concerned about the input water source for water plants in rural areas because most surface water is taken from polluted rivers, except the Red River. Polluted input water requires the considerable expense of treatment technology, and people will also be hesitant to use the service.

4.2. Investor attractiveness evaluation of rural water supply in Ha Nam province

Based on the results of the weight calculation of each factor in Eq. (20), determining the investor attractiveness of rural water supply investment is detailed in Eq. (21).

$$\begin{aligned} I_{IAE} = & (0.06 \times K_{C11} + 0.05 \times K_{C12} + 0.08 \times K_{C13} + 0.02 \times K_{C14} + 0.03 \times K_{C15} + 0.05 \times K_{C16}) \\ & + (0.05 \times K_{C21} + 0.04 \times K_{C22} + 0.07 \times K_{C23} + 0.09 \times K_{C24} + 0.03 \times K_{C25} + 0.02 \times K_{C26}) \\ & + (0.05 \times K_{C31} + 0.02 \times K_{C32} + 0.02 \times K_{C33} + 0.08 \times K_{C34} + 0.08 \times K_{C35}) \\ & + (0.04 \times K_{C41} + 0.03 \times K_{C42} + 0.04 \times K_{C43} + 0.06 \times K_{C44}) \end{aligned} \tag{21}$$

To assess the attractiveness of rural water supply to investors in Ha Nam in detail, the authors sought the evaluating opinions of

Table 9
Priorities for the main factors with calculation results.

Factor	$\tilde{r}_i$	$\tilde{w}_i$	F_i	Weight
C_1	(0.18, 0.29, 0.45)	(0.11, 0.28, 0.70)	0.48	**0.28**
C_2	(0.20, 0.31, 0.48)	(0.12, 0.30, 0.74)	0.51	**0.3**
C_3	(0.15, 0.25, 0.40)	(0.10, 0.25, 0.63)	0.42	**0.25**
C_4	(0.11, 0.17, 0.29)	(0.07, 0.17, 0.45)	0.30	**0.17**

Table 10
Priorities for subfactors with calculation results.

Subfactor	$\widetilde{r}_i$	$\widetilde{w}_i$	F_i	Subfactor weight	Interrelating weight
C_{11}	(1.05, 1.31, 1.59)	(0.13, 0.20, 0.30)	0.26	**0.2**	**0.06**
C_{12}	(0.99, 1.23, 1.47)	(0.12, 0.19, 0.28)	0.24	**0.18**	**0.05**
C_{13}	(1.51, 1.91, 2.31)	(0.18, 0.29, 0.44)	0.37	**0.28**	**0.08**
C_{14}	(0.37, 0.46, 0.57)	(0.05, 0.07, 0.11)	0.09	**0.07**	**0.02**
C_{15}	(0.54, 0.68, 0.91)	(0.07, 0.10, 0.17)	0.14	**0.11**	**0.03**
C_{16}	(0.79, 1.04, 1.41)	(0.10, 0.16, 0.27)	0.21	**0.16**	**0.04**
C_{21}	(0.98, 1.15, 1.34)	(0.13, 0.17, 0.23)	0.21	**0.17**	**0.05**
C_{22}	(0.77, 0.91, 1.04)	(0.10, 0.13, 0.18)	0.16	**0.13**	**0.04**
C_{23}	(1.34, 1.58, 1.81)	(0.17, 0.23, 0.31)	0.28	**0.23**	**0.07**
C_{24}	(1.72, 2.01, 2.28)	(0.22, 0.30, 0.40)	0.36	**0.29**	**0.09**
C_{25}	(0.56, 0.67, 0.83)	(0.07, 0.10, 0.14)	0.12	**0.1**	**0.03**
C_{26}	(0.39, 0.45, 0.54)	(0.05, 0.07, 0.09)	0.08	**0.07**	**0.02**
C_{31}	(0.86, 1.04, 1.27)	(0.13, 0.19, 0.26)	0.23	**0.19**	**0.05**
C_{32}	(0.34, 0.40, 0.48)	(0.05, 0.07, 0.10)	0.09	**0.07**	**0.02**
C_{33}	(0.30, 0.35, 0.43)	(0.05, 0.06, 0.09)	0.08	**0.06**	**0.02**
C_{34}	(1.76, 1.88, 2.12)	(0.27, 0.34, 0.44)	0.4	**0.33**	**0.08**
C_{35}	(1.52, 1.82, 2.22)	(0.23, 0.33, 0.46)	0.41	**0.34**	**0.08**
C_{41}	(0.09, 0.23, 0.65)	(0.03, 0.23, 1.67)	0.77	**0.23**	**0.04**
C_{42}	(0.08, 0.19, 0.50)	(0.03, 0.18, 1.28)	0.6	**0.18**	**0.03**
C_{43}	(0.08, 0.23, 0.63)	(0.03, 0.23, 1.62)	0.76	**0.23**	**0.04**
C_{44}	(0.15, 0.38, 0.99)	(0.05, 0.36, 2.54)	1.19	**0.36**	**0.06**

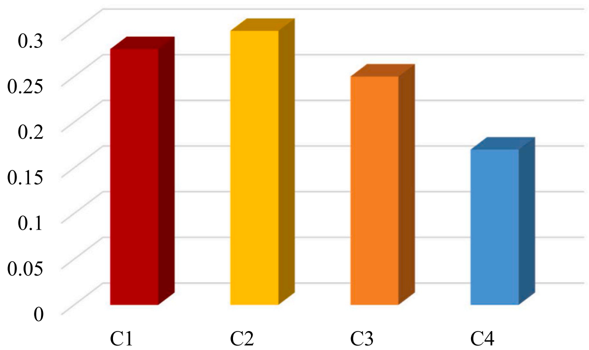

Fig. 8. Main factor weights.

eight experts for each specific factor. The assessment process examined the characteristics of each area, including population distribution, water source characteristics, water quality, current preferential policies, and mechanisms of each area, and closely followed up regarding the 21 subfactors. A Likert-type scale of 0–10 was used to make it simple for the experts to answer and make decisions during the assessment process. We then summarized the eight experts' average evaluation responses for each factor of the construction area for rural waterworks. The final results provide an overview of the attractiveness of rural water supply in Ha Nam province for investors. These findings will allow the People's Committee of Ha Nam province to develop appropriate preferential and support policies for each area with different attractiveness levels to attract private investors.

The assessment result (illustrated in Fig. 10) revealed that the central area of Phu Ly city has the highest attractiveness, with a score greater than 8.5. This area has a developed economy and a high and growing population density due to urbanization. Water demand has also subsequently increased, along with residents' willingness to pay higher fees than other areas. Good technical infrastructure (water supply network, transportation) and favorable natural conditions (plain terrain, stable water source) also increase attractiveness to private investors. Average attractiveness areas include the rest of Phu Ly city, Duy Tien borough, Ly Nhan district, and Que town in Kim Bang district, with attractiveness levels in the range of 6.5–8.5. These areas are developing economically with an average population concentration and growing demand for water services. Regarding other relevant conditions including complete infrastructure, stable water sources, and relatively favorable terrain, attractiveness levels are lower than the central area of Phu Ly city. Low attractiveness areas include Kim Bang, Thanh Liem, and Binh Luc districts with attractive points <6.5. These districts have less developed socioeconomic conditions and are sparsely populated. The availability income to pay for water service is also limited. In addition, the geography in these districts includes mixed mountainous terrain, making it complicated to construct waterworks. Although tax incentives are available, private investment has not yet been attracted in these areas.

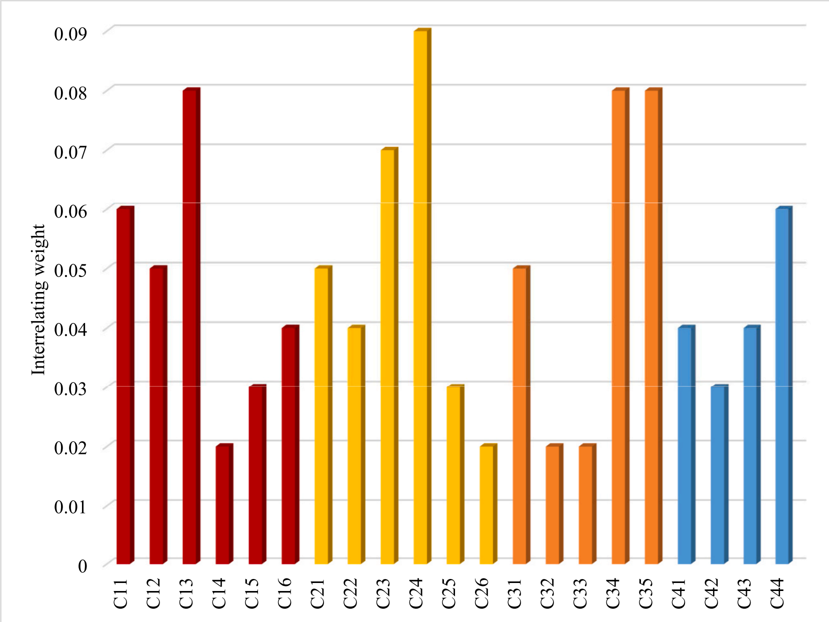

Fig. 9. Correlation of the subfactor weights.

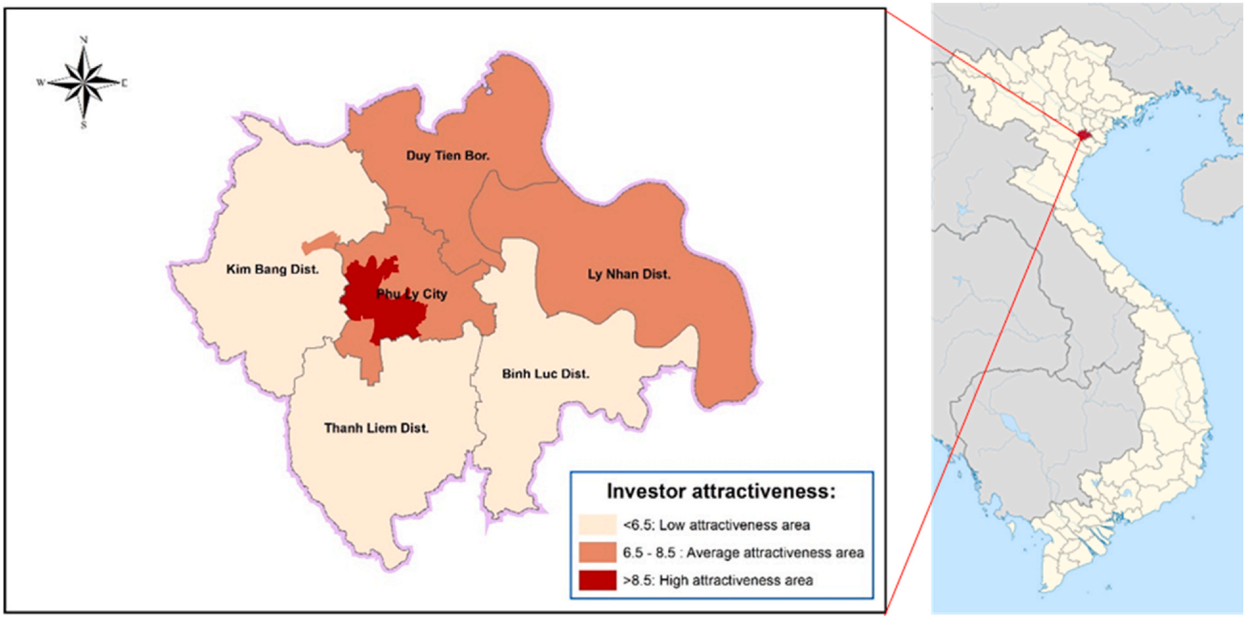

Fig. 10. Investor attractiveness map of rural water supply in Ha Nam province.

4.3. Practical application of private investment attractiveness assessment

This study selected two typical rural water supply projects in Ha Nam province to calculate and evaluate the investor attractiveness index. Table 11 presents some essential information about two practical projects.

Based on information from the two selected water supply projects, the eight experts were invited to rate the two works according to each factor based on a 10-point scale. Table 12 presents the application of Eq. (21) to calculate the investor attractiveness index for participating in rural water supply projects.

The results in Table 12 reveal that the water supply work in Moc Nam commune has a private investor's attractiveness index of 7.37, indicating average attractiveness. Meanwhile, the water supply work in Liem Son commune presents a low attractive level, with

Table 11
Information about the two practical projects in Ha Nam province.

	Moc Nam	Liem Son
Capacity	Design: 11.000 m^3/h Practice: 5.000 m^3/h	Period I: 5.500 m^3/h
Supplied areas	Moc Nam Commune, Chau Giang Commune	Liem Son Commune, Thanh Tam Commune
Water source	Red river	Day river
Construction capital source	60% government +40% enterprise	Enterprise
Construction capital	US$0.29 m	US$2.31 m

Table 12
Private investor attractiveness index calculation.

Factor	Subfactor	Weight	Experts' evaluation points		Weighted points	
			Moc Nam	Liem Son	Moc Nam	Liem Son
	(1)	(2)	(3)	(4)	(5) = (3) × (2)	(6) = (4) × (2)
Preferential Government Policies **C_1**	Tax incentive polices	0.06	8.34	8.24	0.50	0.49
	Land incentive policies	0.05	7.43	7.43	0.37	0.37
	Policies to support access to preferential loans and credit	0.08	8.27	5.98	0.66	0.48
	Policies to support the transfer and application of science and technology	0.02	7.87	7.97	0.16	0.16
	Experience in participating in rural water supply projects	0.03	7.65	5.23	0.23	0.16
	Finance of the enterprise	0.05	8.19	4.33	0.41	0.22
Profit, Mechanism of Capital Contribution and Risk-sharing between the Government and Enterprises **C_2**	Profit of the project	0.05	7.74	6.51	0.39	0.33
	State capital contribution mechanism	0.04	8.16	8.13	0.33	0.33
	State risk-sharing mechanism	0.07	5.03	5.01	0.35	0.35
	Mechanism to adjust water price	0.09	5.06	5.05	0.46	0.45
	Water price	0.03	5.33	5.15	0.16	0.15
	Administrative procedures	0.02	4.96	4.93	0.10	0.10
Location of the Construction Site **C_3**	Population in the surrounding areas	0.05	8.21	5.71	0.41	0.29
	Economic characteristics of the locality	0.02	8.04	5.83	0.16	0.12
	Local cultural features	0.02	7.63	6.83	0.15	0.14
	Community support	0.08	6.73	3.11	0.54	0.25
	High demand for clean water of community	0.08	8.36	8.14	0.67	0.65
Engineering and Technology **C_4**	Availability of project's water sources	0.04	9.21	7.53	0.37	0.30
	The complexity of the project	0.03	7.4	4.26	0.22	0.13
	Quality of the works	0.04	7.11	7.51	0.28	0.30
	Input water quality	0.06	7.62	4.43	0.46	0.27
Private investor attractiveness index					**7.37**	**6.02**

an index of 6.02. The reasons that the inter-commune water supply project in Liem Son commune, Thanh Liem district is less attractive to private investors include the poor quality of input water, the complexity of the project, low community support (the land clearance work is difficult), the uncertain financial returns for the investor.

5. Conclusions

An effective framework was developed to identify and categorize factors affecting the private sector's willingness to participate in rural water supply. The EFA was conducted using SPSS data analysis software to select, analyze, and group the most relevant factors to the research area. The F-AHP method was then used to effectively determine the factors' weights, indicating how important each factor is to private investors' willingness to invest. In addition, an attractive index for private investment in rural water supply was developed. In the case study of Ha Nam province (Vietnam), a list of 26 initial factors was first identified through an exhaustive literature review. The final 21 factors were then identified and divided into four groups that were used as raw materials for F-AHP analysis via expert consultation and EFA on specialized SPSS analysis software to determine each factor's degree of influence on the investment sentiment of the private sector. The factors found to have a significant influence on the willingness of the private sector to participate in rural water supply in Ha Nam province included tax incentive policy, policy to support access to preferential loans and credit, state risk-sharing, an appropriate mechanism to adjust water price, community support, high community demand for clean water, and input water quality. Finally, the investment attractiveness index was used to realistically assess the attractiveness of two rural water supply plants in Ha Nam. The results can contribute to effective strategies for the government to develop policies that attract the participation of private partners, ensure the sustainable development of rural water supply, and build an investment attractiveness map.

Notably, despite being of considerable importance, the topic of attracting private sector willingness to participate in rural water supply investment has received limited research attention. The results of this study can be applied in localities with similar geographical, living, and socioeconomic conditions to Ha Nam, with the same research objective. However, factors affecting the private willingness to participate in rural water supply evolve and differ depending on national or regional background; thus, it is essential to conduct research that includes factors that are specific to the country or region being investigated. Vietnam in general, and Ha Nam in particular, is a developing region, with infrastructure and socioeconomic conditions that differ from other developed regions; therefore, further studies must examine the distinctive features more closely. This study provided a framework for researching to determine and evaluate the factors that affect the investment attractiveness of rural water projects. The research framework developed in this study can be flexibly applied to other research endeavors that share the same research objectives, even when the research areas have radically different economic, social, and natural conditions. Similar research topics in fields such as information technology, health, education, energy, and transportation can also be expanded and further investigated. In addition, another potential research direction opened by this study is the question "How can private investors effectively participate in PPP rural water projects and/or other fields?" Answering this question requires specific studies regarding the factors that affect the private sector's willingness to participate.

Author contribution statement

Minh-Tien Nguyen: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data. Quoc-Hung Vu: Analyzed and interpreted the data; Wrote the paper. Viet-Hung Truong: Contributed reagents, materials, analysis tools or data; Wrote the paper. Huu-Hue Nguyen: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data included in article/supp. Material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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