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Identification and analysis of influencing factors on construction quality management for rural drinking water safety projects

Shuitai Xu [a], Meiling Chen [a,*], Yuhui Zhou[a] and Yabo Wang[b]

[a] School of Economics and Management, Jiangxi University of Science and Technology, Ganzhou 341000, China
[b] The Fifth Construction Company of China Nuclear Industry, Shanghai 201500, China
*Corresponding author. E-mail: 6120210402@mail.jxust.edu.cn

SX, 0000-0002-2910-6138; MC, 0009-0001-9373-5334

ABSTRACT

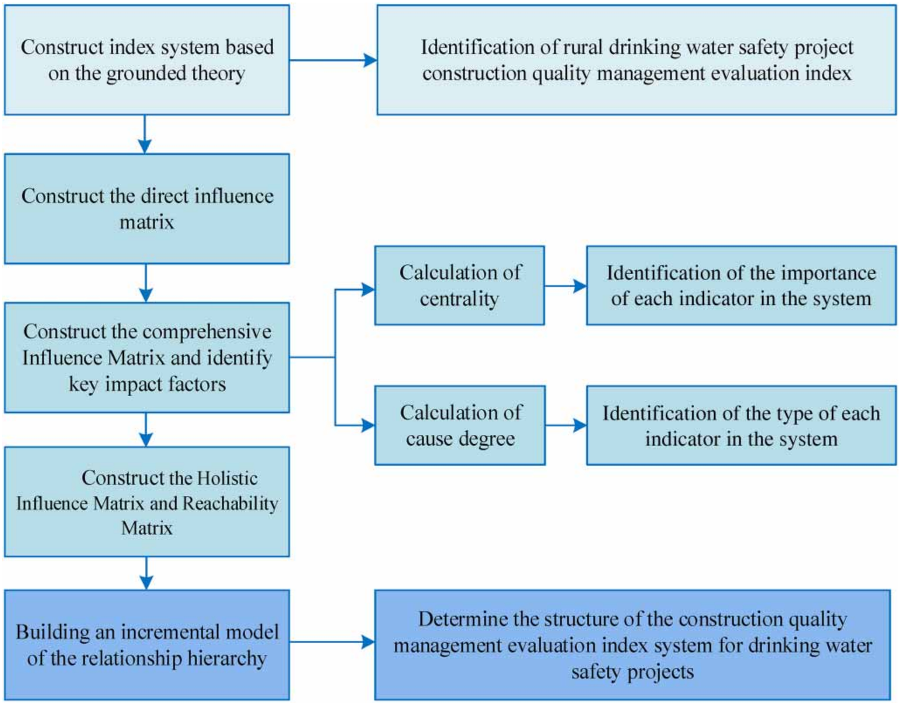
Exploring the influencing factors of construction quality management is the key to ensuring the quality of rural drinking water safety projects. Based on grounded theory, the influencing factors were identified and 65 relevant staff were selected by the objective sampling method for in-depth interviews to obtain the original data. In this study, 34 initial concepts, 18 main categories, and five core categories were collected and extracted for the rural drinking water project's safety engineering and construction quality management evaluation system. Furthermore, the incremental model of influencing factors on construction quality management performance of rural drinking water safety projects was established by the Decision-Making Trial and Evaluation Laboratory–Interpretive Structural Modeling (DEMATEL-ISM) model. Through calculation and analysis, the key influencing factors of construction quality management performance of rural drinking water safety projects were identified as controls on common quality problems, quality specification implementation, leadership level, acceptance management, design disclosure and modification, and human environment. Countermeasures and suggestions are proposed to improve the construction quality management performance of rural drinking water safety construction projects.

Key words: construction quality management, DEMATEL-ISM model, evaluation system, grounded theory analysis, rural drinking water

HIGHLIGHTS

- Construction quality management evaluation systems for rural drinking water safety projects were established based on grounded theory.
- Based on the DEMATEL-ISM model, the quality management performance evaluation model of rural drinking water safety project construction was constructed, which is convenient for clarifying the relationship between influencing elements at different levels in the system.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Drinking water safety in rural areas is a shared challenge in remote areas worldwide. In particular, rural areas in developing countries face these challenges (Massoud *et al.* 2010; Sogbanmu *et al.* 2020; Ding *et al.* 2022). The *World Water Development Report 2021* states that more than two billion people worldwide have no safe drinking water, which results in around one million deaths each year. This is due in part to water sources becoming unsafe as a result of pollution and leakage of water resources. The *China State of the Environment Bulletin 2021* shows that there are 10,345 rural drinking water quality monitoring sections, with a compliance rate of 78%. Some areas in China, particularly the more industrialized coastal areas and some mountainous rural areas, still have problems with water quality safety, leaking water supply networks, and surface contamination infiltration. Rural areas are often inaccessible, and the drinking water supply in these areas is often characterized by lower project construction standards, lower water quality, and poor project management. Exceptional interventions are needed to ensure drinking water safety in rural areas (Machado *et al.* 2019). In China, ensuring the safety of rural water supply has always been given high priority. The construction of drinking water safety in rural areas is currently the top priority for China's 'agriculture, rural areas, and farmers'. In recent years, with the continuous expansion of rural drinking water safety project construction, the overall quality management level of the industry has effectively improved, but difficulty in the construction of drinking water safety projects in rural areas, irregular construction management, and other problems are still prominent, so it is difficult to effectively guarantee the quality of engineering construction (Song *et al.* 2020). Some rural drinking water safety engineering construction units are ineffective in their awareness of construction quality, which makes the construction quality management system useless (Hu *et al.* 2017). There are considerable differences among the construction quality management levels of rural drinking water safety projects in each construction unit (Ankon *et al.* 2022).

The construction phase of water safety projects is the primary guarantee of rural drinking water safety. It is crucial to improve project quality to formulate workable construction quality management for rural drinking water safety projects. How to effectively improve the construction quality management level is an urgent problem in the field of rural water project construction. This study applies grounded theory to identify factors influencing construction quality management for rural drinking water safety projects, which avoids the disadvantage of overreliance on theoretical literature. Secondly, based on the Decision-Making Trial and Evaluation Laboratory–Interpretive Structural Modeling (DEMATEL-ISM) model, the complex relationship among the influencing factors in the evaluation index system is analyzed, which is conducive to determining the strategic influencing indicators and structural levels of the construction quality management for rural drinking water safety projects.

2. THEORETICAL BACKGROUND

2.1. Literature review

First, the main databases in both English and Chinese were searched. The literature was searched for 'drinking water safety', including 'construction' or 'management' as subject terms. Then, we searched for 'construction quality management', including 'drinking water' or 'safety' or 'impact factors' as subject terms. Search databases included CNKI, Science Direct, Web of Science, Elsevier, and Google Scholar.

As for drinking water quality, researchers at home and abroad mainly carry out studies from different perspectives, such as drinking water quality detection, drinking water safety planning, and water safety management. From the perspective of drinking water quality, some researchers found that the lack of resources and poor quality of supply infrastructure in coastal areas of Bangladesh are the principal challenges to drinking water safety in coastal areas (Hossain *et al.* 2022). Jiang *et al.* (2018) designed a detection system for water quality safety in drinking water supply areas. In terms of water security planning, Okotto-Okotto *et al.* (2021) evaluated the effectiveness of participatory mapping outputs for rural water safety planning in Siaya County, Kenya, and assessed community understanding of water safety. Implementing a water security plan in a rural community-managed supply is challenging (String *et al.* 2020). It has to be optimized to fit different scenarios (Pérez-Vidal *et al.* 2020). From the perspective of drinking water safety management, Bereskie *et al.* (2017) found that there is large room for improvement in the implementation and performance improvement of drinking water safety management policies across Canada. In addition, the management of rural drinking water supply safety projects is also crucial for the sustainability of rural water supply infrastructure management (Marks *et al.* 2018). These studies show that rural drinking water safety depends on many aspects, among which ensuring the quality of construction of rural drinking water safety projects is one of the essential tasks to ensure drinking water safety.

To study the influencing factors of construction quality management, scholars mainly carry out studies in three aspects: construction quality management, personnel management, and organization management. At the construction quality management level, He & Cheng (2011) believe that a scientific and reasonable prior evaluation system for rural drinking water safety projects is a prerequisite for guaranteeing the success of project works. Construction schedule, quality control, and contract management in the construction process are the main influencing factors that help to improve a construction project (Alaloul *et al.* 2016). At the personnel management level, Drouin *et al.* (2021) stated that scientific leadership methods and the self-management of team members can improve project performance. Project collaboration has a positive effect on construction project performance, and building successful partnerships in projects can increase efficiency and cost-effectiveness (Caniëls *et al.* 2019; Nevstad *et al.* 2021). In terms of organizational management, some scholars believe that the government management of rural drinking water safety projects after completion, the establishment of a rule system, and what underlies the long-term effective operation of rural drinking water safety projects strengthens the protection of rural water supply facilities (Dai *et al.* 2020). Hu *et al.* (2017) preferred water supply cooperative management in rural drinking water safety projects and recommended establishing government-led water supply cooperatives to promote the sustainability of drinking water safety projects. In the construction process of the drinking water safety project, comprehensive quality control is the most critical measure to ensure the success of the entire project, which involves numerous quality control points. Therefore, the establishment of a scientific evaluation system is an important guarantee for the quality management of drinking water safety project construction.

In terms of research on constructing indicator systems and identifying influencing factors, multicriteria decision analysis (Antonio *et al.* 2022), hierarchical analysis (Rajabi *et al.* 2022), fuzzy rough set, and the entropy power method (Hou *et al.* 2021) were applied to establish drinking water management or construction quality management indicator systems. Some methods suffer from an overreliance on the literature and a lack of practicality in the construction of indicators. To avoid this drawback, grounded theory is commonly used in the construction management indicator system of projects. For example, Bridi *et al.* (2021) used grounded theory to establish a construction site safety management system. Shojaei & Haeri (2019) applied grounded theory to the study of project supply chain risk management. In terms of influencing-factor identification, the principal methods are system dynamics (Alawag *et al.* 2023), fuzzy qualitative comparison sets (Marks *et al.* 2018), and the Decision-Making Trial and Evaluation Laboratory–Analytic Hierarchy Process (DEMATEL-AHP) (Mavi & Standing 2018). In recent years, an increasing number of researchers have been using the DEMATEL-ISM method, which is in a position to explore both the extent to which each influencing factor affects a complex system and to further analyze the interconnections and logical relationships between influencing factors.

2.2. Research questions development

In conclusion, the academic community is currently assessing drinking water safety in rural areas and has conducted researches in many areas. Early research focused on drinking water quality testing, contamination source analysis, and treatment techniques (Perveen & Haque 2023). The World Health Organization (WHO) proposed the Water Safety Plan in 2004, which brought more attention to drinking water safety risk assessment and management (String *et al.* 2020). At the same time, some researchers have suggested the need to encourage the sustainable and benign development of rural drinking water projects (Dai *et al.* 2020).

However, existing research tends to focus on the planning of drinking water safety before starting the drinking water safety projects and the evaluation and assessment of drinking water safety projects after completion, which is not applicable to quality management in the construction stage of drinking water safety projects. Few scholars have conducted an in-depth exploration of comprehensive quality control management in the construction stage of rural drinking water safety projects. These relevant project management theories have not been comprehensively utilized to study the construction quality management of rural drinking water safety projects, which constrains the practical application of management systems and evaluation systems for comprehensive quality control in the construction phase. Therefore, in this study, cutting-edge project management theory was applied to rural drinking water safety projects. The construction quality management evaluation systems of rural drinking water safety projects were set up based on grounded theory, and the key influencing factors on the construction quality management of rural drinking water safety projects were identified by the DEMATEL-ISM model.

3. MATERIALS AND METHODS

3.1. Research methodology

3.1.1. Grounded theory

Initially proposed by Glaser and Strauss, grounded theory is defined as the systematic process of collecting and analyzing data to discover or construct a theory (Glaser & Strauss 1967). Grounded theory effectively solves the problems of traditional qualitative theories, such as lack of research depth and procedures, and the inability to obtain both reliability and validity. With a certain logical flow of scientific analysis, grounded theory has been widely used in the fields of the sociology, philosophy, medical psychology, and other fields of the humanities and social sciences (Fletcher & Sarkar 2012; Sterling *et al.* 2020). Grounded theory has been extensively used in factor identification research, action mechanisms, and path theory, especially for research with insufficient explanatory depth or incomplete theory construction (Conlon *et al.* 2020). Therefore, the influencing-factor path coding model is established based on grounded theory.

3.1.2. DEMATEL-ISM model

DEMATEL, a system analysis method that integrates matrix theory and graph theory ideas, was first proposed by the Battelle Institute in Geneva, Switzerland, in 1976 (Fontela & Gabus 1976). The Interpretive Structural Modeling (ISM) method, first proposed by American scholar J. Warfield, is a widely used complex system analysis method based on Graph Theory that transforms the influence relationship between the internal elements of the system into the most simplified hierarchical-directed topology diagram, reflecting the causal structure level and logically increasing relationship between system elements (Xu & Zou 2020). The Interpretive Structural Modeling (ISM) method more visual and intuitive than pure numbers, enhances the sense of logic. Zhou *et al.* (2006) proposed the DEMATEL-ISM integration method. The ISM method establishes a hierarchical incremental model to intuitively and specifically present the direct influence relationship between the influencing factors of complex systems, and make up for the deficiency of the hierarchical structure that the DEMATEL method cannot intuitively express the hierarchical relationship between influencing factors. The comprehensive use of the DEMATEL-ISM method can determine the exact interrelationship between each influencing factor, and it clearly defines the direct connection of each influencing element at different levels within the system.

The impact of using the DEMATEL-ISM method to study the construction quality management of rural drinking water safety projects has good adaptability. On the one hand, the construction quality management system of drinking water safety engineering is a complex and dynamic system. By carrying out the combined application of the DEMATEL-ISM method, it can both identify the key elements in the system and comprehensively analyze the structural level of the system, so as to provide theoretical support for clarifying the mechanism and construction strategy of construction quality management of drinking water safety projects. On the other hand, the quality management of rural drinking water safety project construction is affected by many factors, resulting in intricate relationships and unclear structures. The DEMATEL-ISM method takes full advantage of the knowledge and experience of experts and scholars to transform qualitative data into quantitative data to carry out empirical research, which has a strong operational and scientific nature.

3.2. Data collection

To identify the factors affecting the construction quality management of rural drinking water safety projects, materials were collected according to grounded theory. Fuyang District of Hangzhou City in Zhejiang Province is taken as the study area. In this study, field tracking, visits, and investigations were conducted in key rural drinking water safety projects in Fuyang District from June 2020 to June 2021. Selected interviewees were composed of fundamental groups of government departments, owner units, construction units, design units, and supervision units related to rural drinking water engineering projects. Using the objective sampling method, 13 staff members, respectively, from the above five departments were selected for in-depth interviews, with a total of 65 people. The outline of the interview is shown in Table S1 (Supplementary Information). To promote efficiency, interview time and place were booked in advance. Project interviews were conducted in a combination of semistructured interviews and focus group interviews, with the whole interview process being reduced to 30–60 min. At the same time, in order to understand and restore the original information of the project as much as possible, the interview outlines were developed in advance. During the interview process, interviewees were actively guided to divergent modes of thinking and deeply explored the project information and personal perceptions they master. The interviews were mainly conducted by audio recording with some assistance in paper recording. According to the requirements of grounded theory research procedures, 25 interview information samples were randomly reserved for subsequent saturation tests. Only 40 interview samples were selected as the original interview records.

3.3. Research sample – characteristics

The original record text data were sorted and summarized based on the original interview data, combined with quality assessment reports, special reports, journals, and other written materials on the spot of the project, comprehensively considering the actual situation of rural drinking water engineering projects. The background survey information of the interviewees is provided in Table 1.

Table 1 | Demographic profile of respondents

	Options	Number	Proportion (%)
Level of education	High school and below	9	13.846
	College education	18	27.692
	Bachelor's degree	23	35.385
	Postgraduate degree	10	15.385
	Doctoral degree	5	7.692
Nature of the sector	Government department	6	9.231
	Development organization	12	18.462
	Design organization	7	10.769
	Scientific research institutes	10	15.385
	Construction organization	19	29.231
	Supervisory organization	11	16.922
Working seniority	1–3 years	5	7.692
	3–5 years	15	23.077
	5–10 years	28	43.077
	>10 years	17	26.154
Number of participating rural drinking water projects	1–3	29	44.615
	3–5	16	24.615
	5–10	12	18.462
	>10	8	12.308

3.4. Methods

NVIVO12 qualitative analysis software was utilized to encode the data according to the three-step coding principle of grounded theory. Firstly, the interview data were abstracted and conceptualized through open coding induction and extraction, and logically divided into categories. Secondly, the main coding was obtained by further convergence analysis of spindle coding. Thirdly, in the selective coding stage, the main coding was based on the principle of 'storyline' to divide dimensions, conclude core coding, and construct a logical theoretical path. After coding was complete, saturation testing was required to ensure that no new concepts or categories were generated. Finally, a theoretical model was established based on good saturation tests. Then, the DEMATEL-ISM modeling was performed using MATLAB software as a way to determine the direct impact relationships between influencing elements.

4. DATA COLLECTION AND ANALYSIS

4.1. Influencing factors and index system construction

4.1.1. Open coding

To further understand and analyze the inherent logical and structural characteristics of the interview data after sorting and screening, NVIVO12 software was used to encode the original text sentence by sentence. Statements and words with similar meanings were conceptualized. Then, 34 initial concepts were preliminarily obtained, on the basis of which further collection and division were conducted, and a total of 18 categorical concepts were extracted, as shown in Table 2.

4.1.2. Spindle coding

Spindle coding further refines and divides the concepts of parallel categories according to the idea that 'birds of a feather flock together' in a certain logical framework. According to the characteristics of rural drinking water engineering and construction industries, 18 main category concepts were summarized and further classified into five dimensions. The meaning of each main category and its corresponding categories are presented in Table 3.

Table 2 | Open coding process

Coding	Categorization	Conceptualization
C1	Construction environment	Construction environment
C2	Human environment	Demolition; Management system; Personnel encouragement
C3	Quality specification implementation	Construction according to drawings; Construction standard control
C4	Design and modification	Design clarification; Design changes
C5	Quality control	Construction ability; Construction plans; Remedial measures
C6	Construction process control	Covert engineering process control; Key engineering process control
C7	Project acceptance	Excellent rate of unit project acceptance
C8	Construction security	Perfect preparation before construction; Construction coordination
C9	Supervision and inspection	Supervision of owner and supervisor; Government inspections; Surveillance by the masses
C10	Communication	Stakeholder satisfaction
C11	Mechanical equipment management	Mechanical equipment maintenance
C12	On-site quality control	Construction unit three-inspection system
C13	Subcontract management	Qualification of subcontractors; Construction quality monitoring of subcontractors
C14	Civilization construction	Construction of retaining; Personnel patrol
C15	Material quality management	Material quality inspection
C16	Employee behavior	Work attitude; Skill levels; Teamwork ability
C17	Leadership level	Management level; Leadership traits
C18	Employee education and training	Mentoring and help; Skill training assessment

Table 3 | Axial coding process

Core category	Main categories	Implication
B1 Environment	Construction environment	The natural environment of the construction site
	Human environment	The cultural environment and atmosphere of the enterprise
B2 Technology	Quality specification implementation	The behavior of strictly implementing the technical and quality standards by construction enterprises
	Design and modification	Before construction, the owner or the engineering design unit provides design details to the construction and supervision parties on the construction drawings
	Quality control	Construction personnel with rich engineering and construction experience can prevent and solve common quality problems in the construction process
	Construction process control	The construction unit strictly follows the process requirements, and concealed work and key processes do not enter the next process before inspection and acceptance by the supervision personnel
B3 Organization	Project acceptance	Project acceptance mainly focuses on the excellent acceptance rate of unit projects, namely the ratio between the number of unit projects with exceptional grades and the total number of unit projects
	Construction security	The preparatory work before construction is flawless, and the project has the basic starting conditions
	Supervision and inspection	Supervise and inspect the whole process of project parties
	Communication	Oral and written communication between project parties to coordinate and solve emergencies in a timely manner
B4 Construction process control	Mechanical equipment management	Daily maintenance, mechanical failure management, and daily use management of mechanical equipment involved in the project
	On-site quality control	Construction units control quality through self-inspection, mutual inspection, and special inspection
	Subcontract management	The general construction contractor is in charge of the supervision and management of the subcontractors and is jointly and severally liable for the construction quality and behavioral consequences of the subcontractors
	Civilization construction	Keep a safe and clean working environment during construction
	Material quality management	The use of substandard construction materials is prohibited in the project
B5 Human resources	Employee behavior	Employees' work attitude, experience, skill level, teamwork, etc.
	Leadership level	Team management ability of project manager
	Employee education and training	Education and training of employees' knowledge and skills on quality management systems

4.1.3. Selective coding

Guided by logical relations, selective coding was based on spindle coding to summarize and integrate main categories, extract more general core categories, and further present the entire theoretical framework system in the form of a 'storyline'. The 'storyline' from the five dimensions of environment, technology, organization, construction process control, and human resources is summarized from the main categories, which logically constitute an organic whole and can explore the construction quality management of rural drinking water safety projects from different perspectives.

4.1.4. Saturation test

To verify whether the theory has good reliability and validity, the extracted categories were tested. Saturation tests were conducted to ensure that the selected samples of 40 random interviews did not generate new concepts and categories. Following the same three-step coding process, concepts and categories were extracted again from 25 reserved random interview record samples. The results showed no new concepts or new categories, indicating that the research saturation of grounded theory passed the reliability and validity tests. Then, the final form of the theoretical framework was obtained.

Influencing factors were summarized, sorted, and arranged by standard layers and index layers based on grounded theory. The results showed that the construction quality management of rural drinking water safety projects comprises five dimensions and their constituent factors: environment, technology, organization, construction process control, and human resources. Finally, the construction quality management evaluation index system of rural drinking water safety projects is given in Figure 1.

4.2. Establishing hierarchy model of influence relation based on the DEMATEL-ISM model

4.2.1. Calculating direct influence matrix *X*

The DEMATEL factor analysis was used to quantify the influence indexes of construction quality management for 18 rural drinking water safety projects. Experts and scholars engaged in rural water conservancy research were invited to score the direct relationship between key influencing factors in the construction quality management of rural drinking water safety projects. After the scores of influencing factors were determined and the average values were obtained, the direct influence relationship matrix was obtained, as shown in Table 4.

4.2.2. Calculating comprehensive influence matrix *T*

The matrix was normalized by the method of row sum maximum, namely summing each row of matrix X, obtaining the maximum value from these values, normalizing matrix X factors, and obtaining gauge influence matrix C. On this basis, the normalized direct influence matrix was transformed into the comprehensive influence matrix T, as presented in Table 5.

The direct influence matrix was calculated by Equation (1):

$$C = (C_{ij})_{n\times n} = Y = \frac{1}{\max_{1\leq i\leq n}\sum_{j=1}^{n} X_{ij}} X \tag{1}$$

Based on matrix Y, the comprehensive influence matrix was calculated by Equation (2), where I represents the identity matrix:

$$\begin{aligned} T = [t_{ij}]_{n\times n} &= Y + Y^2 + Y^3 + \cdots + Y^q \\ &= Y(I + Y + Y^2 + \cdots + Y^{q-1})[(I - Y)(I - Y)^{-1}] \\ &= Y(I - Y^q)(I - Y)^{-1} \\ &= Y(I - Y)^{-1} \end{aligned} \tag{2}$$

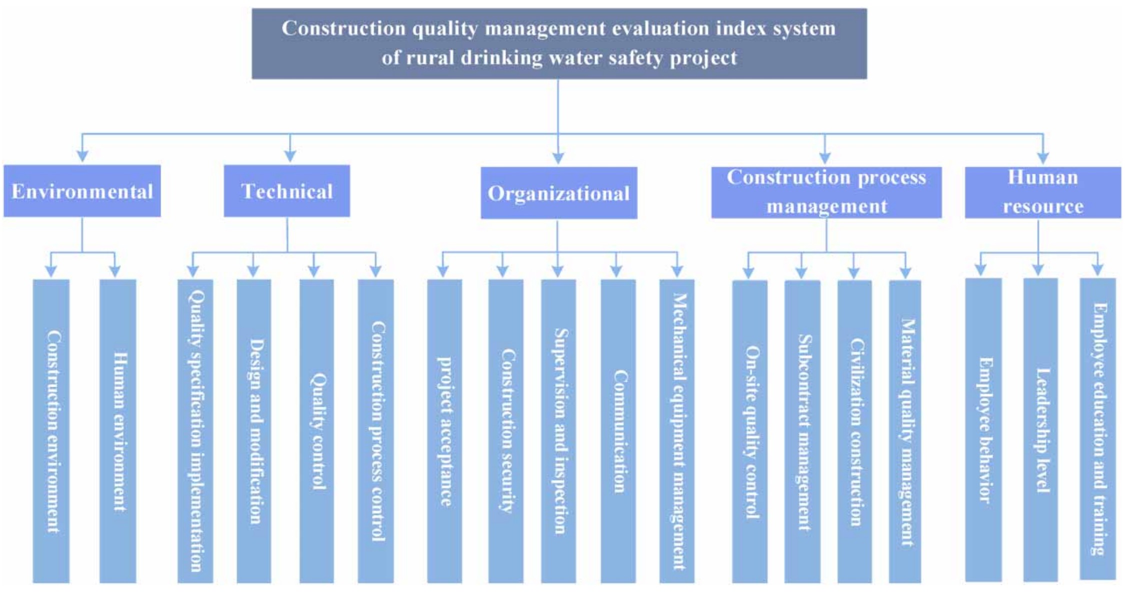


Figure 1 | Construction quality management evaluation index system of rural drinking water safety projects.

Table 4 | Direct influence matrix X of quality management of rural drinking water safety projects

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
C1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
C2	0	0	0	0	2	0	0	0	0	2	0	0	3	0	0	0	0	0
C3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
C4	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
C5	0	0	1	1	0	2	0	0	0	3	2	0	0	0	2	1	0	2
C6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C7	0	0	0	0	3	1	0	0	0	2	0	0	0	1	0	1	0	0
C8	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
C9	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0
C10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
C12	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C13	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
C17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4.2.3. Determining the impact factors

Elements in the comprehensive influence matrix T were used to calculate influence degree e_i, influenced degree f_i, centrality S_i, and cause degree D_i, respectively, calculated by Equations (3)–(6):

$$e_i = \sum_{j=1}^{n} t_{ij} \ (i = 1, 2, 3, \ \ldots, n) \tag{3}$$

$$f_i = \sum_{i=1}^{n} t_{ij} \ (j = 1, 2, 3, \ \ldots, n) \tag{4}$$

$$S_i = e_i + f_i \tag{5}$$

$$D_i = e_i - f_i \tag{6}$$

According to Equations (3)–(6), the influence degree, influenced degree, centrality, and cause degree of each influencing factor of construction quality for rural drinking water safety projects were calculated, and the results are illustrated in Table 6.

With centrality as the horizontal axis and cause degree as the vertical axis, the causal diagram of influencing factors for rural drinking water safety projects construction quality was drawn using MATLAB software while also referring to the key factor MICMAC quadrant determination method (Dewangan *et al.* 2015). The value of 0 and the average centrality value of 0.678 were selected as the dividing line of the coordinate system of four quadrants. The distribution diagram of cause–effect is shown in Figure 2.

4.2.4. Hierarchy of factors using ISM

After the DEMATEL analysis, the hierarchical relationship of each factor in the system was further analyzed using ISM. The analysis process is as follows.

Table 5 | Comprehensive influence matrix *T* of quality management of rural drinking water safety projects

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
C1	0.000	0.000	0.022	0.013	0.143	0.020	0.000	0.000	0.000	0.031	0.020	0.000	0.000	0.000	0.020	0.010	0.012	0.020
C2	0.000	0.000	0.059	0.044	0.143	0.020	0.000	0.000	0.000	0.174	0.020	0.000	0.214	0.000	0.020	0.010	0.026	0.020
C3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.214	0.000
C4	0.000	0.000	0.214	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.260	0.000
C5	0.000	0.000	0.152	0.092	0.000	0.143	0.000	0.000	0.000	0.214	0.143	0.000	0.000	0.000	0.143	0.071	0.083	0.143
C6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C7	0.000	0.000	0.033	0.020	0.214	0.102	0.000	0.000	0.000	0.189	0.031	0.000	0.000	0.071	0.031	0.087	0.028	0.031
C8	0.000	0.000	0.022	0.013	0.143	0.020	0.000	0.000	0.000	0.031	0.020	0.000	0.000	0.000	0.020	0.010	0.012	0.020
C9	0.000	0.000	0.008	0.005	0.051	0.018	0.143	0.143	0.000	0.031	0.007	0.000	0.000	0.010	0.007	0.014	0.006	0.007
C10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.143	0.000
C12	0.000	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.000
C13	0.000	0.000	0.174	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.068	0.000
C14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C15	0.000	0.000	0.245	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.000
C16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.143	0.000
C17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C18	0.000	0.000	0.214	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.046	0.000

Table 6 | Results of DEMATEL analysis

Factors	e_i	f_i	S_i	Ranks	D_i	Ranks	Factor attribution
C1	0.3120	0.0000	0.3120	16	0.3120	5	Cause
C2	0.7515	0.0000	0.7515	6	0.7515	1	Cause
C3	0.2143	1.2850	1.4993	2	−1.0707	17	Result
C4	0.4745	0.4719	0.9464	5	0.0026	11	Cause
C5	1.1842	0.6939	1.8781	1	0.4904	3	Cause
C6	0.0000	0.3236	0.3236	15	−0.3236	15	Result
C7	0.8354	0.1429	0.9783	4	0.6925	2	Cause
C8	0.3120	0.1429	0.4549	11	0.1692	9	Cause
C9	0.4496	0.0000	0.4496	12	0.4496	4	Cause
C10	0.0000	0.6691	0.6691	8	−0.6691	16	Result
C11	0.1429	0.2420	0.3848	13	−0.0991	14	Result
C12	0.1735	0.0000	0.1735	17	0.1735	7	Cause
C13	0.3841	0.2143	0.5984	9	0.1698	8	Cause
C14	0.0000	0.0816	0.0816	18	−0.0816	13	Result
C15	0.4708	0.2420	0.7128	7	0.2289	6	Cause
C16	0.1429	0.2026	0.3455	14	−0.0598	12	Result
C17	0.0000	1.1543	1.1543	3	−1.1543	18	Result
C18	0.2602	0.2420	0.5022	10	0.0182	10	Cause

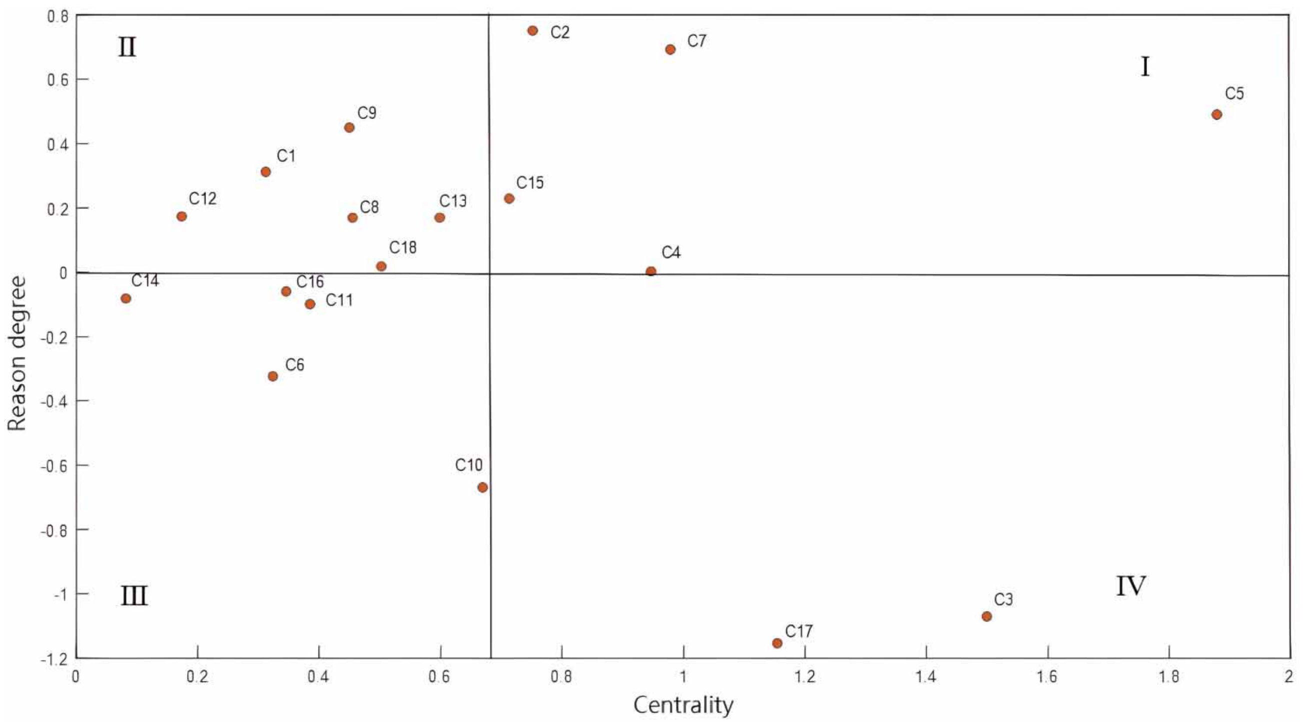


Figure 2 | Cause–effect diagram of the factors.

(i) Calculating the holistic influence matrix H and reachability matrix K. According to the comprehensive influence matrix T, holistic influence matrix H was calculated by Equation (7), where I represents the identity matrix. The holistic influence matrix is shown in Table 7.

$$H = [h_{ij}]_{n\times n} = I + T \tag{7}$$

Elements in holistic influence matrix H with little influence on each other were screened out. Reachability matrix K was calculated by Equation (8):

$$K = k_{ij} = \begin{cases} 1 & h_{ij} \geq \lambda \\ 0 & h_{ij} \leq \lambda \end{cases} \tag{8}$$

In Equation (8), λ is the threshold. There is no uniform rule on the threshold value. Threshold $\lambda 1 = 0.0189$ was obtained using the mean value method, and threshold $\lambda 2 = 0.0679$ was obtained by means of the sum of mean value and standard deviation method. Removing excessively high thresholds can result in over-simplification of the matrix, leading to the loss of important causal relationships. To avoid this problem, the nodal degree curves of thresholds $\lambda 1$ and $\lambda 2$ were compared and analyzed. Finally, $\lambda 2 = 0.0679$ was selected as the threshold based on expert opinions. After determining the threshold, the reachability matrix was calculated, as indicated in Table 8.

(ii) Obtaining the reachable and antecedent set of each factor according to reachability matrix K. The reachable and antecedent sets and intersections were marked $P(C_{ij})$, $Q(C_{ij})$, and $R(C_{ij})$. According to the Boolean algorithm, the first step was to find factors in the row of the reachable set and use these as the first-layer factor set {C6, C10, C14, C17}. The second step was to reestablish the reachable and antecedent sets after screening out any elements of C6, C10, C14, or C17 contained in each row of the reachable set. The element in the row where the reachable set is by itself was found, and the second-level influential factor set {C3, C11, C16} was obtained. The above operations were repeated to obtain the third-level {C4, C12, C18}, fourth-level {C13, C15}, fifth-level {C5}, sixth-level {C1, C2, C7, C8}, and seventh-level {C9} influential factor sets. These factors established the hierarchical relationship between rural drinking water safety project elements. The topological hierarchy extraction process is shown in Table 9.

According to the hierarchical classification process and analysis results of the DEMATEL model, the DEMATEL-ISM structure diagram of the construction quality management of rural drinking water safety projects is shown in Figure 3.

As seen in Figure 3, the factors affecting the construction management of rural drinking water safety projects have multilevel and multistructural characteristics and can be divided into seven layers. L1 and L2 are the direct factors, L3–L5 are transitive factors, and L6 and L7 are essential factors.

5. DISCUSSION

In this study, grounded theory was selected as the initial qualitative research method, and an evaluation system was constructed by combining actual interview materials to identify the set of influencing factors containing five dimensions of construction quality management of rural drinking water safety projects: environment, technology, organization, construction process control, and human resources. The DEMATEL-ISM model was further used to determine the key drivers, barriers to construction quality management of rural drinking water safety projects and the hierarchical structure and mechanism of action between influencing factors.

5.1. Identification of key factors

The importance of the factors for the construction quality management of rural drinking water safety projects can be judged by centrality. Centrality reflects the influence of these factors on the construction quality management of rural drinking water safety project impact factors. The greater the value is, the greater the impact of the role is. According to the results shown in Table 6 and Figure 2, the top six influencing factors in terms of centrality are quality control (C5), quality specification implementation (C3), leadership level (C17), project acceptance (C7), design and modification (C4), and human environment (C2). It indicates that these six factors have significant influences on the construction quality management of this project. The

Table 7 | Holistic influence matrix *H* of quality management of rural drinking water safety projects

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
C1	1.000	0.000	0.022	0.013	0.143	0.020	0.000	0.000	0.000	0.031	0.020	0.000	0.000	0.000	0.020	0.010	0.012	0.020
C2	0.000	1.000	0.059	0.044	0.143	0.020	0.000	0.000	0.000	0.174	0.020	0.000	0.214	0.000	0.020	0.010	0.026	0.020
C3	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.214	0.000
C4	0.000	0.000	0.214	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.260	0.000
C5	0.000	0.000	0.152	0.092	1.000	0.143	0.000	0.000	0.000	0.214	0.143	0.000	0.000	0.000	0.143	0.071	0.083	0.143
C6	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C7	0.000	0.000	0.033	0.020	0.214	0.102	1.000	0.000	0.000	0.189	0.031	0.000	0.000	0.071	0.031	0.087	0.028	0.031
C8	0.000	0.000	0.022	0.013	0.143	0.020	0.000	1.000	0.000	0.031	0.020	0.000	0.000	0.000	0.020	0.010	0.012	0.020
C9	0.000	0.000	0.008	0.005	0.051	0.018	0.143	0.143	1.000	0.031	0.007	0.000	0.000	0.010	0.007	0.014	0.006	0.007
C10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.143	0.000
C12	0.000	0.000	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.031	0.000
C13	0.000	0.000	0.174	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.068	0.000
C14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
C15	0.000	0.000	0.245	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.083	0.000
C16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.143	0.000
C17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
C18	0.000	0.000	0.214	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.046	1.000

Table 8 | Reachability matrix *K* of quality management of rural drinking water safety projects

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
C1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C2	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0
C3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
C4	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
C5	0	0	1	1	1	1	0	0	0	1	1	0	0	0	1	1	1	1
C6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
C7	0	0	0	0	1	1	1	0	0	1	0	0	0	1	0	1	0	0
C8	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
C9	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
C10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
C11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
C12	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
C13	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
C14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
C15	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0
C16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
C17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
C18	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 9 | Topological hierarchy extraction process of quality management of rural drinking water safety projects

Factor	Reachable set $P(C_{ij})$	Antecedent set $Q(C_{ij})$	Intersections $R(C_{ij})$	Hierarchy
C1	C1, C5	C1	C1	L6
C2	C2, C5, C10, C13	C2	C2	L6
C3	C3, C17	C3, C4, C5, C12, C13, C15, C18	C3	L2
C4	C3, C4, C17	C4, C5, C13, C15	C4	L3
C5	C3, C4, C5, C6, C10, C11, C15, C16, C17, C18	C1, C2, C5, C7, C8	C5	L5
C6	C6	C5, C6, C7	C6	L1
C7	C5, C6, C7, C10, C14, C16	C7, C9	C7	L6
C8	C5, C8	C8, C9	C8	L6
C9	C7, C8, C9	C9	C9	L7
C10	C10	C2, C5, C7, C10	C10	L1
C11	C11, C17	C5, C11	C11	L2
C12	C3, C12	C12	C12	L3
C13	C3, C4, C13	C2, C13	C13	L4
C14	C14	C7, C14	C14	L1
C15	C3, C4, C15, C17	C5, C15	C15	L4
C16	C16, C17	C5, C7, C16	C16	L2
C17	C17	C3, C4, C5, C11, C12, C15, C16, C17	C17	L1
C18	C3, C18	C5, C18	C18	L3

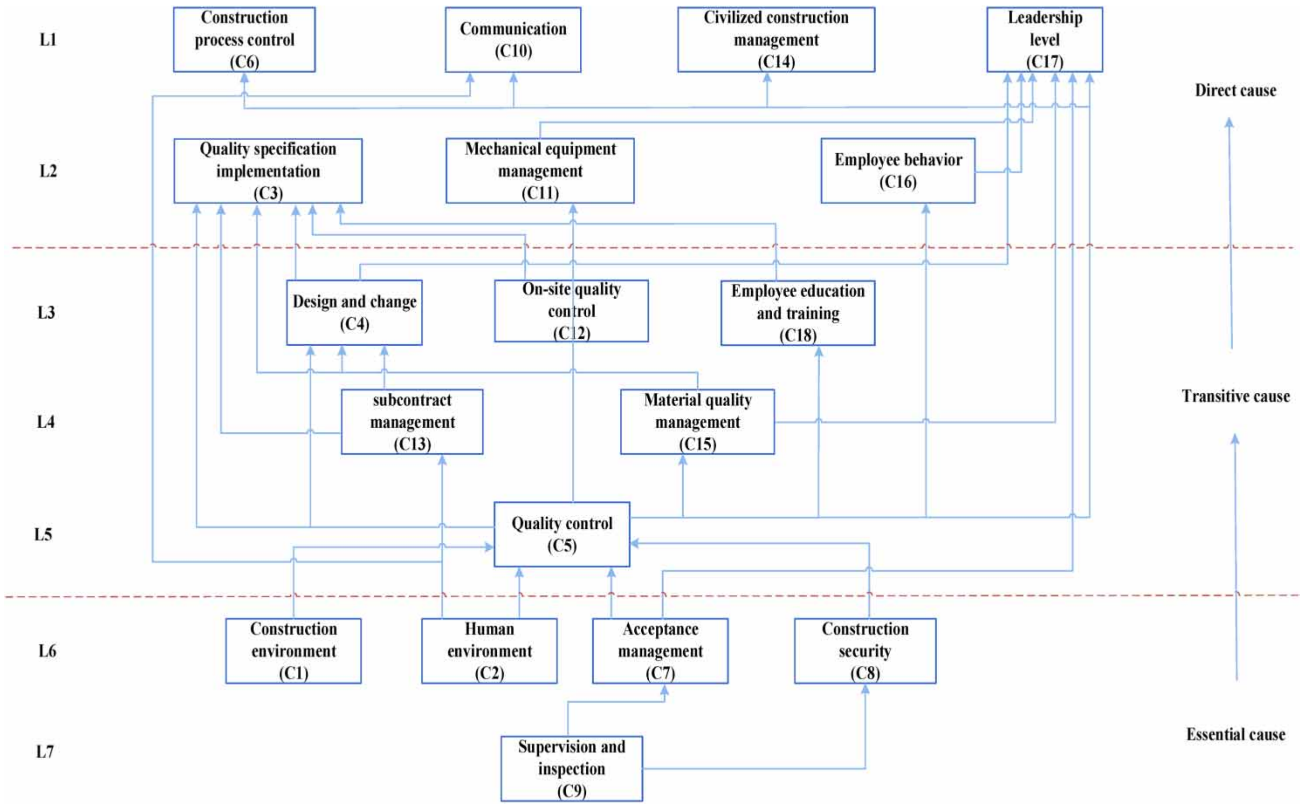


Figure 3 | ISM model for construction management of rural drinking water safety projects.

three influencing factors with the lowest centrality are civilization construction (C14), on-site quality control (C12), and construction environment (C1), indicating that these three factors exert a relatively weak influence on project construction quality management.

Cause degree allows further analysis of the relationship between factors. Cause factors refer to the factors with cause degree $Q > 0$. Result factors refer to factors with a cause degree $Q < 0$. According to the results shown in Table 6 and Figure 2, there are 11 cause factors and seven result factors in the construction quality management system of rural drinking water safety projects. Among the 11 cause factors, human environment (C2) has the largest cause degree, which means that it has the greatest influence on other elements. Meanwhile, project acceptance (C7) has the second highest cause degree and is also a key element that affects other elements. Therefore, to improve the quality management of rural drinking water safety project construction, the human environment must be a key priority focus, and the acceptance management of the project must be strengthened to improve the acceptance rate of good unit work. Design and modification (C4) and education and employee education and training (C18) have the smallest cause degrees. This also means that these two factors are most likely to be influenced by other factors. Therefore, the pre-design of drinking water safety projects and the education and training of relevant staff during the construction process must be paid attention to. Construction process control (C6), communication (C10), mechanical equipment management (C11), civilization construction (C14), employee behavior (C16), quality specification implementation (C3), and leadership level (C17) are result factors. These seven result factors are susceptible to the influence of other factors, which in turn cause fluctuations in management levels.

From the five dimensions of environment, technology, organization, construction process control, and human resources, the cause degree of environment, organization, and construction process control is greater than 0, and the cause degree of organization and human resources is less than 0, indicating that environment, organization, and construction process control play an important role in the overall system, and have a strong constraint and driving force in the construction quality management of rural drinking water safety projects. Organization and human resources are more sensitive and susceptible to the influence of extra dimensional factors and thus need to be paid special attention to.

5.2. ISM hierarchical relationship model

According to the DEMATEL-ISM model, the various factors within the construction quality management system of rural drinking water safety projects constitute a compound multilayer hierarchy. The first and second layers directly affect the construction quality management of the rural drinking water safety project. These influencing factors mainly include quality specification implementation (C3), mechanical equipment management (C11), employee behavior (C16), construction process control (C6), communication (C10), civilization construction (C14), and leadership level (C17), which are the direct causes of the whole system and act through transitive and essential causes.

The third, fourth, and fifth layers are indirect and transitional factors affecting the construction quality management of rural drinking water safety projects, including quality control (C5), subcontract management (C13), material quality management (C15), design and modification (C4), on-site quality control (C12), and employee education and training (C18). In the internal structure of the system, the transitive cause is affected by both upper and lower factors, playing a transitional role. Quality problems occasionally occur in the construction processes, which require reworking the project, waste manpower and material resources, and slow the project's progress. The main contractor has weaknesses and difficulties in subcontract management, and the phenomenon of illegal and layered subcontracts often occurs. Supervisors do not monitor the entry of construction materials, the defective rate is high, and cement material slump tests are not up to standards, eventually leading to jerry-built projects. The three-inspection system of technical construction units is nonstandard, and the implementation of the team quality inspection is ineffective; especially, the construction quality control of concealed works is not strict, which easily causes major quality accidents. Construction units' lack of occupational safety and quality education and training for workers has led to the lack of awareness of project quality. These transitive causes significantly impact rural drinking water safety projects, hindering the improvement of construction quality management.

Finally, supervision and inspection (C9), construction environment (C1), human environment (C2), project acceptance (C7), and construction security (C8) in the sixth and seventh layers fundamentally impact the whole system. These sets of root-cause factors are at the bottom of the system and do not receive the influence of other factors to directly or indirectly influence other factors and outcomes within the system. A sound regulatory and inspection system is a medium-term guarantee force for the quality management of drinking water safety projects (Ma *et al.* 2020). Meanwhile, Li *et al.* (2020) found important deficiencies in rural water supply management in terms of management, construction, and self-monitoring of water quality. After the completion of the rural drinking water safety project, government departments are required to strictly control the quality of the project in order to avoid hidden dangers in the prudent use of water resources (Dai *et al.* 2020). Therefore, after the completion of the rural drinking water safety project, acceptance management is a fundamental factor that needs to be taken into account and managed. The construction environment and human environment have important impacts on the construction quality management of rural drinking water safety projects. Construction companies with a strong culture tend to produce efficient organizational performance. In addition, the natural environment of the construction site, such as weather and geological conditions, is bound to have an impact on the construction work.

6. CONCLUSION

6.1. Research conclusions

In this study, a comprehensive analytical framework and methodology are proposed to explore the factors influencing the construction management of rural drinking water safety projects. Firstly, 18 indicators of construction management performance of rural drinking water safety projects were determined through grounded theory. Furthermore, through analyzing the influencing factors by DEMATEL, the importance of the factors was analyzed based on the ranking of factor centrality and cause degree. Finally, a multilayer recursive structure model was built by ISM to clarify the logical relationship and the path of action between the factors, and to deeply analyze the action relationship of each factor. The main conclusions are as follows:

(1) Through grounded theory, this study formed the evaluation index system of construction management performance of rural drinking water safety projects. The index system contains five dimensions of environment, technology, organization, construction process control, and human resources (a total of 18 indicators).

(2) The results of the DEMATEL model show that the three dimensions of environment, organization and construction process control are found to play an important role in the overall system. Based on a comprehensive weight analysis of each factor, quality control (C5), quality specification implementation (C3), and leadership level (C17), with greater centrality, are at the core of the system and have a greater impact on the construction quality management performance of rural drinking water safety projects. The cause degree of human environment (C2) ranks first in this indicator system and has a great influence on other factors.
(3) The ISM hierarchical relationship model divides the 18 influencing factors into seven layers. The influencing factors from the first layer to the second layer are direct effects, which have a strong dependence and rely on the underlying influencing factors. The influencing factors from the third layer to the fifth layer are transitive effects, which have the role of transmitting influence. The influencing factors of the sixth and seventh layers are essential effects, which have a greater influence. It was found by the relationship incremental structure model that the five influencing factors of supervision and inspection (C9), construction environment (C1), human environment (C2), project acceptance (C7), and construction security (C8) have the most fundamental and deepest influence on the whole system. These factors are not affected by other factors and can directly or indirectly affect other factors and results in the system, so they should be paid attention to.

6.2. Management implications

Strengthening the construction phase quality management evaluation assessment is an important measure to ensure the quality of the construction of rural drinking water safety projects. This study can provide a reference for construction management decisions in rural drinking water safety projects. The analysis and evaluation of influencing factors on construction quality management are conducive for discovering the weak links in the construction of rural drinking water safety projects and accumulating experience and lessons in the quality of construction and management. This study is a reference for water conservancy construction enterprises in strengthening future project quality and management, thus promoting the healthy development of rural water works construction. Based on the above analysis and results, the implications of the study for the development of construction quality management for rural drinking water safety projects are as follows.

6.2.1. Strengthening the supervisory functions of government construction departments and trade organizations

As the departments in charge of the rural drinking water safety project, the competent departments of construction are duty-bound to strengthen the supervision of the rural drinking water project. The government should examine and approve the qualifications of construction enterprises in strict accordance with laws and regulations, formulate and improve the quality of water conservancy project enterprises, and strengthen the construction of supervision systems. Site inspection, regular spot inspection, big data cloud monitoring, and other diversified means should be adopted to supervise the project's construction. In addition, trade associations should act as trade organizations, conduct active research and extensive publicity, and improve industrial discipline.

6.2.2. Optimizing the construction of project quality management appraisal systems

Rural drinking water safety projects are constructed based on supervision and supervision systems. As the performance evaluation is subjective, no authoritative evaluation system has been formed, and authoritative quality management evaluation needs authoritative evaluation subjects. Therefore, it is necessary to receive input from expert think tanks in the field of rural water conservancy construction and involve third-party consulting companies.

6.2.3. Introducing a diversified certification system for construction quality management

Internal management is not customary in most small-scale rural drinking water engineering and construction enterprises. It is necessary to introduce certification systems for external quality management systems such as the ISO 9000 quality management system to supervise related construction enterprises and strengthen quality control, standardize the implementation of construction technical standards, as well as improve the skill level of construction personnel and their awareness of quality.

6.3. Research limitations and further research directions

First, rural drinking water safety engineering research has its own complexity and situational variability. Rural construction quality management varies greatly from region to region. This study only takes Fuyang District, Hangzhou, Zhejiang Province, a developed region in eastern China, as a case study, and the applicability of the obtained findings to residents in other regions has to be verified in the next step. The survey area can be extended in the future to enhance the generalizability of the study findings.

Second, in the construction of the evaluation index system, this study is based on interview data using the idea of grounded theory to identify the influencing factors. Subject to the breadth and depth of the survey research, the indicators discussed may be missing. The current study is a qualitative analysis; future researchers can extend the scope of the study, and the use of empirical analysis of research methods to further explore the impact of construction management of rural drinking water safety projects from different perspectives can be attempted.

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DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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