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Assessing Environmental Management Plan Implementation in Water Supply Construction Projects: Key Performance Indicators

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Abstract: Assessing the implementation of environmental management plans (EMPs) in construction projects is crucial for meeting environmental sustainability goals and reducing potential adverse impacts. By using performance indicators (PIs), stakeholders can objectively measure the performance of EMP implementation, identifying areas of success and areas that may require improvement. Therefore, this study aims to examine the PIs for assessing EMP implementation in water supply construction projects, using Saudi Arabia as a case study. Data from semi-structured interviews and a systematic literature review were used to develop a potential list of PIs. Then, the PIs were used to create a survey and distributed to industry professionals. Data from 112 respondents were analyzed using mean ranking analysis, the normalization method, exploratory factor analysis (EFA), and fuzzy synthetic evaluation (FSE). Eighteen critical PIs for assessing EMP implementation in water supply construction projects were identified, including public safety, road safety hazards, construction waste, clogged drainage, irregular flooding, the spilling of chemical substances, slope failures, soil erosion, landslide occurrence, increased schedule waste, changes in the color of bodies of water, oil/fuel spills, restricted site accessibility, the smell of run-off water, traffic accidents on construction sites, the spread of disease, changes in the color of run-off water, and overflowing silt traps. The EFA revealed that PIs can be grouped into three underlying constructs: fluid-related indicators, health and safety-related indicators, and site environment-related indicators. The FSE results confirmed that all PIs are between moderately critical to critical. This study's significance lies in its examination of PIs that aim to improve the environmental performance of water supply construction projects. Understanding which indicators are most effective allows for targeted improvements, helping to minimize negative environmental impacts and ensuring sustainable practices. Finally, this study is a pioneer in examining the critical PIs for assessing EMP implementation in water supply construction projects.

Keywords: environmental management plan; EMP; water supply construction projects; Saudi Arabia; exploratory factor analysis; EFA; fuzzy synthetic evaluation; FSE

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1. Introduction

Environmental management plans (EMPs) are developed to ensure that construction projects are carried out in an environmentally responsible and sustainable manner [1]. Normally, construction projects result in substantial energy and natural resource consumption [2,3], accompanied by the release of significant levels of air, water, noise, and land pollution [4,5]. Furthermore, the construction and demolition debris generated by this industry has detrimental consequences, contributing to environmental issues such as pollution in water, soil, and air [6–8]. These challenges also extend to economic repercussions, including the depletion of essential resources and increased public health risks [9]. Hence, EMPs are designed to protect the environment from the potential harm caused by project activities by reducing or mitigating various adverse impacts. On the contrary, poor EMP implementation can expose nearby communities to health risks such as waterborne diseases, respiratory issues, and other health problems, particularly if pollutants or hazardous materials are released into the environment [10]. Failure to implement EMP can result in significant environmental damage, including habitat destruction, water pollution, soil erosion, and biodiversity loss [11,12]. These environmental impacts can be long-lasting and may harm ecosystems and natural resources. Therefore, it is essential to ensure effective EMP implementation to minimize these risks and ensure responsible project management.

Construction project stakeholders may not correctly implement EMPs for several reasons. Some stakeholders, especially those indirectly involved in environmental management, may have little awareness and not fully understand the importance of EMP implementation [13]. Moreover, there is a lack of enthusiasm among project stakeholders when it comes to implementing EMPs due to the perception that the associated benefits and competitive advantages are relatively minimal [14]. In addition, implementing EMP measures often requires financial resources, technical expertise, and personnel. Stakeholders may face budgetary constraints or a shortage of trained personnel, making it challenging to execute the plan effectively. In addition, stakeholders may prioritize other aspects of the project, such as cost and schedule, over environmental considerations. Stakeholders who do not prioritize environmental sustainability or do not have a strong commitment to responsible environmental management may not allocate the necessary resources and attention to EMP implementation. Thus, there is a need to find appropriate approaches to ensure the correct and effective EMP implementation by construction project stakeholders. Despite this imperative, the existing body of literature in relation to indicators that assess EMP implementation holds limited studies. While [15] made notable contributions by developing a set of environmental operational indicators and performance indicators, the focus primarily centered on environmental performance assessment, and the perspectives were derived from project managers. Similarly, Ref. [16] delved into indicators for EMP implementation but primarily within the context of road construction projects. Additionally, Ref. [17] extended this inquiry to highway construction projects. Notably, these works have concentrated on indicators specifically tailored to highway and road construction, leaving a notable gap in the exploration of EMP indicators for a broader range of construction projects.

PIs are often an integral part of multi-criteria decision-making (MCDM) processes. In MCDM, decision makers evaluate and compare multiple criteria to make informed decisions. PIs serve as measurable criteria that are used to assess the effectiveness or performance of a system, process, or project. MCDM allows for the prioritization of the critical aspects of EMP implementation. By assigning weights to different PIs, stakeholders can focus on the most crucial elements, optimizing resource allocation, addressing the most pressing environmental concerns, and ensuring a more targeted approach to improvement. Moreover, PIs provide a structured way of monitoring the progress and effectiveness of EMP implementation by offering measurable data points that allow stakeholders to gauge how well environmental measures are being executed. These indicators are early warning signs of potential issues and challenges in EMP implementation. The early identification of problems allows for timely corrective action, preventing the escalation of issues that could disrupt this project's progress. In addition, project managers and environmental professionals can establish robust monitoring systems by understanding the indicators of poor EMP implementation. This project's environmental performance may be tracked more effectively, ensuring that EMP measures are consistently applied. Moreover, recognizing indicators of poor EMP implementation helps project stakeholders prioritize ecological protection by focusing on areas where EMP may fail, leading to the improved protection of ecosystems, water quality, and biodiversity. Thus, there is a need to investigate the appropriate PIs for assessing EMP implementation to improve environmental management practices in water supply construction projects, leading to more sustainable and environmentally friendly construction practices.

Based on this background, this study aims to investigate the effectiveness of PIs in assessing EMP implementation in water supply construction projects, using Saudi Arabia as a case study. Specifically, the study objectives are to identify the critical PIs, group the PIs, and evaluate the effectiveness of the PIs to assess EMP implementation in water supply construction projects. To accomplish this goal, 112 environmental professionals completed a questionnaire survey. The data were analyzed using the mean ranking analysis, normalization method, exploratory factor analysis (EFA), and fuzzy synthetic evaluation (FSE). Finally, a set of effective PIs for assessing EMP implementation in water supply construction projects was established. This study contributes to a better knowledge of PIs for assessing EMP implementation in water supply construction projects. Moreover, the study findings can serve as a significant reference for industry practitioners and policymakers in assuring the success of EMP implementation in water supply construction projects. Using the right set of PIs is crucial for assessing EMP implementation accurately and improving environmental management practices in water supply construction projects, leading to more sustainable and environmentally friendly construction practices. Also, this study is a pioneer in examining the critical PIs for EMP implementation in water supply construction projects. By identifying critical PIs and evaluating EMP implementation, this study contributes to the protection and conservation of the environment, safeguarding natural resources, ecosystems, and biodiversity, which directly impact the well-being of the community. Moreover, this study uses of a combination of semi-structured interviews, a systematic literature review, and multiple analytical methods (mean ranking analysis, normalization method, EFA, and FSE) to provide a comprehensive methodological approach. Other researchers can learn from and potentially adopt these methods for future research, especially in the context of identifying PIs for assessing EMP implementation in construction projects. The list of critical PIs can serve as a starting point for researchers working on similar topics, providing a foundation for developing other performance indicators or refining existing ones. This study's outcomes can also serve as a benchmark for future comparative studies. Researchers may use the identified PIs and the categorization of constructs as a reference point when comparing the effectiveness of implementing an environmental management plan across different projects, regions, and time periods.

2. Literature Review

2.1. Performance Indicators for Construction Projects

PIs for construction projects are vital for monitoring and managing construction activities [18,19]. The construction industry has a long history of developing and using indicators, particularly in the context of sustainable development [20]. These indicators are essential tools for measuring and assessing the environmental, social, and economic impacts of construction projects and for guiding efforts to make the industry more sustainable. Moreover, as public awareness of environmental issues is paramount, educating the public about these concerns, including their causes, consequences, and potential policy solutions, can increase support for government initiatives addressing environmental challenges [21]. In this broader context, PIs play a vital role in evaluating environmental performance and monitoring progress toward sustainable development goals. They can also be applied at the national level to assist in planning, setting policy goals, and establishing environmental priorities. Through the measurement and analysis of environmental-related PIs, construction projects can minimize their environmental impact and contribute to the preservation of the environment, ensuring that development activities align with broader environmental conservation goals. In essence, PIs are integral to effective environmental management and public involvement in environmental issues.

Prior work has recognized the existence of various environmental PIs across different project types. The appropriate use of indicators can be a powerful tool in addressing the sustainability of businesses both at a corporate-wide level and at a project level [22]. For instance, Ref. [20] identified and evaluated performance indicators aimed at monitoring and appraising the sustainable performance of construction projects in the execution phase within the United Arab Emirates. Their findings underscore the significance of indicators related to renewable energy and construction site safety. Furthermore, Ref. [23] delved into environmental performance indicators to assess the sustainability of building projects. This work highlighted key indicators, such as the project's impact on water quality, air quality, energy consumption, conservation, environmental compliance, and management. These investigations contribute valuable insights to stakeholders, aiding in identifying the most pertinent sustainability indicators for construction projects, thereby facilitating assessments of sustainability performance.

2.2. Construction Industry in Saudi Arabia

The construction industry in Saudi Arabia is globally recognized as one of the largest and most influential industries, mainly due to its substantial contributions to the development of numerous mega projects [24]. In terms of economic significance, the construction industry accounts for approximately 6% of Saudi Arabia's Gross Domestic Product (GDP) [25]. Moreover, this contribution to the GDP is anticipated to continue increasing in the coming years. The Saudi Arabian government has made a substantial commitment to bolster the construction industry by earmarking a significant portion of the annual national budget for its growth over the next decade, with the aim of achieving the ambitious targets outlined in the Vision 2030 initiative [26]. Vision 2030, coupled with the National Transformation Programme 2020, aiming for a boost in private sector investments and ongoing reforms, collectively serve as the driving forces behind the expansion of the Saudi construction industry. These developments have yielded positive outcomes, particularly in the advancement of housing and industrial construction activities throughout the nation. Furthermore, Saudi Arabia has a multitude of megaprojects slated for completion by the year 2030, reflecting the nation's commitment to ambitious development goals and economic diversification.

Several works have been conducted to enhance the construction industry in Saudi Arabia. In a work by [27], critical success factors (CSFs) were identified to facilitate the adoption of value management practices within Saudi Arabia's construction industry. To enhance the adoption of value management, 25 CSFs were defined with insights from construction experts. Another work by [24] focused on understanding the constraints and restrictions affecting construction projects in Saudi Arabia, particularly during the planning stage. This work indicated that disputes over project timelines, cost overruns, and project abandonment were significant factors contributing to project failures. In addition, government officials and contractors were identified as contributors to project delays and delivery issues. Additionally, Ref. [28] examined the implementation and design of safety practices in the Saudi Arabian construction industry. This work highlighted that crucial success factors for safety practices include legislation and stakeholder awareness, while a major barrier involves clients' and their representatives' apprehension regarding cost overruns. These prior findings collectively provide valuable insights into different facets of the construction industry in Saudi Arabia, offering opportunities to enhance industry practices and address critical challenges for improved performance.

2.3. Water Supply Construction Projects

The body of existing work on water supply construction projects is relatively limited, but several noteworthy works have explored the critical aspects of these projects [29], for instance, investigated the key risk factors associated with public–private partnerships (PPPs) in water supply infrastructure projects. Their findings emphasized the importance of risk-sharing between the government and private sector entities rather than solely transferring the specific risks to one party. Ref. [30] delved into the CSFs for water infrastructure projects delivered through public–private partnerships. Their work underscored the significance of thorough planning to ensure project viability, a high degree of transparency and accountability, and the establishment of a legal framework ensuring policy continuity as CSFs for the successful delivery of water infrastructure projects under PPP initiatives. Their findings emerged from factor analysis, leading to the identification of grouped factors related to public cooperation, project viability, and policy and legislation enhancement. Furthermore, Ref. [31] explored the challenges associated with poor delivery and the underlying factors contributing to inadequate outcomes in water infrastructure projects in South Africa. Their work revealed major challenges, such as project completion delays, cost overruns, subpar work quality, inefficient fund utilization, and unsatisfactory service delivery. They further identified the factors contributing to these challenges across four critical dimensions of infrastructure projects: project management, organization and management, construction and construction management, and sociopolitical aspects.

2.4. Positioning This Study

The background information provided highlights a critical gap in the current body of knowledge on EMP implementation. While various works have been conducted in this country, there is a noticeable dearth of research on EMP implementation. Furthermore, it is worth noting that existing works on water supply construction projects have primarily centered around risk assessments, CSFs, and challenges. This study aims to proceed beyond these aspects by comprehensively analyzing PIs, their interrelationships, and their effectiveness in evaluating EMP implementation. This holistic approach can provide a more nuanced and comprehensive understanding of the role of PIs in promoting effective environmental management within water supply construction projects. Therefore, this study aims to address this gap by focusing on the effectiveness of PIs. In doing so, this study seeks to pinpoint areas where improvement is needed and propose tailored approaches for assessing EMP implementation. This approach is crucial for refining environmental management practices in water supply construction projects and ensuring sustainability and environmentally friendly construction practices. In other words, this study endeavors to fill a significant research gap, enhance an understanding of EMP implementation in the context of water supply construction projects and contribute to more sustainable and environmentally conscious construction practices.

3. Methodology

3.1. Survey Development

This study used a questionnaire survey to collect data on PIs quantitatively to assess EMP implementation in water supply construction projects. Surveys are a proven and efficient method for gathering diverse responses from professionals, especially when random sampling is applied [32]. The subsequent sections provide insights into the survey development process used in this study.

3.1.1. Systematic Literature Review

A systematic literature review (SLR) was conducted to identify the potential PIs reported in the prior literature. The process commenced with a search conducted in the Scopus database. Scopus was chosen as the database of choice due to its popularity and relevance in the field of construction management [33]. The SLR began with an extensive search for relevant articles, using the "title/abstract/keyword" function in the Scopus database, resulting in the identification of 199 papers. To ensure the robustness of the selected literature, only peer-reviewed journals were selected for their higher quality from a more thorough peer review process [34]. Following the initial screening of abstracts, 26 articles were deemed suitable for further review. However, not all articles were directly related to PIs in construction projects. Thus, articles that did not meet the subject matter were eliminated following a thorough examination of their content. Consequently, a total of 13 articles were found to be valid for further investigation. Figure 1 shows the SLR process conducted in this study.

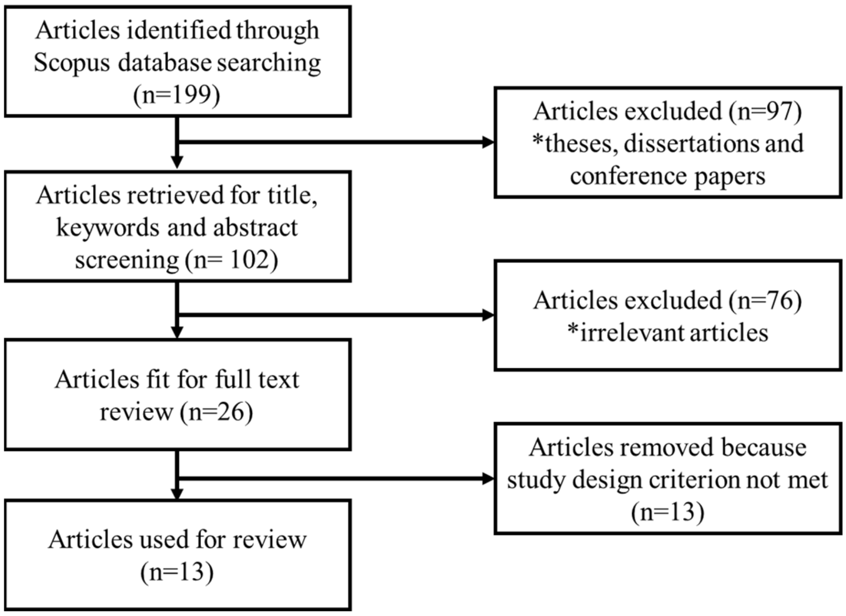

Figure 1. SLR process.

3.1.2. Interview

In addition to the SLR, interviews were conducted with environmental professionals to identify the potential PIs that might not have been previously documented in the existing body of knowledge. This approach aligns with previous works that have used a combination of SLR and interviews to comprehensively identify relevant variables during survey development [35,36]. The interview process commenced with an introductory phase, during which the purpose of the interview and the topic of discussion were outlined. Subsequently, interview questions were presented to the interviewee. In some instances, follow-up questions were posed based on the interviewees' responses to gain a deeper understanding of the information provided and ensure clarity. If needed, questions were rephrased to facilitate accurate responses. At the conclusion of each session, the interviewer expressed gratitude to the interviewees for their participation. To maintain transparency and accuracy, a summary of each interview was prepared and shared with the respective respondents for validation [37,38].

The interviews involved ten environmental professionals due to data saturation. Data saturation is an important tool for evaluating qualitative data [39]. Data saturation occurs when researchers reach a point where collecting more data does not provide additional information relevant to the research questions [40]. During the interviews, data saturation was achieved with the tenth participant, signifying that further data collection would likely yield redundant information. It is noteworthy that a qualitative inquiry employing interviews often advocates for a participant range between 5 and 25 [41]. Prior works in the construction project management area have also used data saturation in qualitative studies [42,43].

The interview data were analyzed using the thematic analysis technique, as described by [44]. The analysis aimed to identify and categorize the PIs that emerged from the interviews, ultimately contributing to developing a comprehensive list of PIs for assessing EMP implementation in water supply construction projects. Table 1 summarizes the 39 potential PIs for assessing EMP implementation that were identified through the SLR and semi-structured interviews.

Table 1. PIs for assessing EMP implementation.

Code	PIs	Sources
PI01	Soil erosion	Interview, [45,46]
PI02	Traffic accidents on the construction site	Interview, [47–49]
PI03	The smells of run-off water	Interview, [46,50]
PI04	Appearance of dust	Interview, [51]
PI05	Spills of chemical substances	[52]
PI06	Construction waste	[15,46,53,54]
PI07	Clogged drainage	[45]
PI08	Overflowing silt trap	[Interview]
PI09	Oil/fuel spills	Interview, [52]
PI10	Traffic accidents among public users	[Interview]
PI11	Visibility drops	Interview, [51]
PI12	Changes in the color of bodies of water	[Interview]
PI13	Excessive cut and fill	Interview, [55]
PI14	Traffic emission gas	[51,52,56]
PI15	Vegetation depletion	[45,53,55,57,58]
PI16	Wildlife appearance at construction sites	[46,50,51,53,55,56,59,60]
PI17	Unpleasant air odors	[46,51,52,60–62]
PI18	Changes in the color of run-off water	[Interview]
PI19	Landslide occurrence	Interview, [47]
PI20	Light pollution (during nighttime)	[46,50]
PI21	Restricted site accessibility	[51]
PI22	The smell of nearby bodies of water	[Interview]
PI23	Slope failures	Interview, [45,55,57,58]
PI24	Depletion of agricultural land	[47]
PI25	Excessive noise	[Interview]
PI26	Irregular flooding	[Interview]
PI27	Destruction of animal habitats	[46,50,51,55,56,60]
PI28	Public safety	[45]
PI29	Deforestation	[47,55]
PI30	Changes in the color of silt traps	Interview
PI31	Open burning	Interview
PI32	Alteration of topography	[58]
PI33	Spread of disease	[63]
PI34	Vibration occurrences	Interview
PI35	Traffic congestion	Interview
PI36	Social disturbance	[54]
PI37	Increased schedule waste	[15,46,53,54]
PI38	Road safety hazard	Interview
PI39	Proliferation of pest	[63]

3.1.3. Survey Design

The front page of the survey included the study objectives and contact information. The first section of the survey asked respondents about their backgrounds and experience in relation to water supply construction projects to assess their applicability to answering the survey. The PIs were listed and evaluated in the second section on a five-point Likert scale (1 = not important; 2 = slightly important; 3 = moderately important; 4 = important; 5 = very important). The Likert scale is commonly used in construction project management research due to its precision [64,65]. At the end of the survey, respondents were given spaces to describe and rank any additional PIs to assess EMP implementation in water supply construction projects.

3.1.4. Pilot Test

Detecting design and instrumentation issues in a survey is possible through a pilot test [66]. Additionally, feedback from the pilot test is vital for enhancing the survey's quality and estimating the time needed for its completion [67]. A pilot test involving five environmental professionals and five academics possessing over a decade of experience in water supply construction projects was executed. This pilot study aimed to eliminate unclear language and ensure the correct usage of technical terms within the survey. Consequently, this survey was refined based on feedback from the pilot test participants and then deemed finalized.

3.2. Data Collection

The target population for the survey was environmental professionals involved in water supply construction projects in Saudi Arabia. Purposive sampling was adopted to achieve the target population. Purposive sampling entails identifying and choosing knowledgeable and skilled individuals [68]. In addition, the respondents must be available, willing to participate, and able to express their experiences and opinions clearly, expressively, and reflectively [69]. Finally, a total of 112 valid responses were obtained.

Table 2 shows that more than half of the respondents, accounting for 58.9% of the total sample, possessed 10 or more years of experience in water supply construction projects. Regarding the number of water supply construction projects they had been involved in, only 27.7% of those surveyed reported having experience with just one project. In contrast, the remaining 72.3% of the sample had experience with at least two water supply construction projects. This suggests that the data collected can be regarded as reliable for further analysis, given the respondents' substantial level of professional experience in water supply construction projects.

Table 2. Respondent profile.

Characteristics	Categories	Frequency	Percent (%)
Years of experience in water supply construction projects	Fresh graduate	17	15.2
	Less than 3 years of experience	12	10.7
	3 to 10 years	17	15.2
	10 to 15 years	17	15.2
	More than 15 years of experience	49	43.8
Number of water supply construction projects involved in	Only one project	31	27.7
	2 to 5 projects	23	20.5
	6 to 10 projects	14	12.5
	11 to 20 projects	17	15.2
	More than 20 projects	27	24.1

3.3. Data Analysis

3.3.1. Reliability of Data

Reliability analysis was undertaken to assess the survey's reliability and consistency. The internal consistency of the 39 PIs was tested using Cronbach's alpha (α) coefficient. The α value ranged from 0 to 1, where 0 denotes no consistency, and 1 denotes internal consistency. An acceptable level of consistency was indicated by an α value of 0.70 or above [70]. The 39 PIs obtained an overall score of 0.944 at the 5% significance level, confirming data reliability. As a result, the acquired data are suitable for further investigation.

Outliers were then identified by screening the dataset with a two-standard deviation technique [36]. Data points that deviated from the norm significantly and that could have a major impact on the outcome were considered outliers. In the two-standard deviation approach, two separate standard deviation intervals were calculated. Variables were considered outliers if their means were outside any of these two standard deviation ranges. Intervals of 2.504 and 4.178 were determined using the two standard deviation approaches. As "Deforestation" (PI29) and "Public Safety" (PI28) were outside the two SD interval values, they were considered outliers. "Deforestation" (PI29) was not included in the further analysis. given that practitioners deemed it to be less important than other variables. However, "Public safety" (PI28) was still included in subsequent analysis because it was considered to potentially be very important. The importance or relevance of an indicator may outweigh its deviation from the mean. In some cases, a particular indicator may have unique significance or may be considered critical by stakeholders or experts, even if it exhibits outlier characteristics. For example, "Public safety" (PI28) might indicate a high level of importance in a water supply construction project, justifying its retention despite being an outlier.

3.3.2. Mean Ranking Analysis and Normalization Method

This study employed a mean score ranking method to establish the relative rankings of the PIs. In cases where multiple PIs had identical mean values, the PI with the lowest standard deviation (SD) was accorded the highest rank. A smaller SD indicates that the differences in responses are not statistically significant, making the mean value a more reliable representation for most respondents [70].

After ranking the PIs, a normalization technique was applied to facilitate a more meaningful interpretation of the data, particularly when identifying crucial variables. This normalization approach was adapted from the work of [71]. This procedure involved setting the minimum mean value to 0 and the maximum mean value to 1. Subsequently, the other mean values were converted into decimal values within the range of 0 to 1. PIs with normalized values of at least 0.50 were identified as critical for evaluating EMP implementation in water supply construction projects.

3.3.3. Exploratory Factor Analysis

This study employed EFA as a method that condenses a large number of interrelated variables into more manageable and relevant sets or constructs [72]. The ratio of the sample size to the number of variables was calculated to determine the sample size for the EFA. Eighteen critical PIs were identified based on the normalization method. The calculated ratio of the sample size to the number of variables was 6.22, which exceeded the recommended value of 5.00 [73], indicating that the sample size was sufficient for EFA.

Two assessments were conducted to determine the appropriateness of the data for EFA. The Kaiser–Meyer–Olkin (KMO) measure of sample adequacy compared the squared correlation between variables to the squared partial correlation between variables; a good EFA typically had a KMO value higher than 0.50 [74]. Additionally, Bartlett's test of sphericity was used to assess the relationships between variables. EFA is considered appropriate if the original correlation matrix is not an identity matrix, indicating significant relationships between the variables [75].

Principal Component Analysis (PCA) was utilized as the method for factor extraction to uncover the underlying constructs within the dataset. Variables with eigenvalues greater than one, indicating their substantial contribution to the principal constructs, were retained for further analysis. Following this, a varimax rotation was applied to the PIs to uncover any latent constructs. Variables with factor loadings surpassing 0.50 were deemed significant and valuable for interpreting these constructs [76].

3.3.4. Fuzzy Synthetic Evaluation

Finally, this study employed the FSE technique to assess the effectiveness of each PI and construct. This method has been used in previous construction project management research to evaluate different types of variables, including strategies and impacts [65,77,78]. The steps for executing the FSE are as follows:

Step 1: Weightings for each performance indicator

The effectiveness of the FSE method relies on the weights assigned to each component and subcomponent. Equation (1) was used to calculate the weightings for each critical PI.

$$W_i = \frac{M_i}{\sum_{i=1}^{5} M_i}, 0 \leq wi \leq 1, 0 \leq i \leq 1 \quad (1)$$

where W_i is the weighting; M_i is the mean score, and $\sum M_i$ is the summation of the mean score of all critical PIs.

Step 2: The membership function for each component

FSE employs grading alternatives to generate membership functions (MFs) for the critical PIs. A five-point Likert grading scale was used, ranging from 1 (very low) to 5 (very high), denoted as E = (1, 2, 3, 4, 5). Equation (2) was used to calculate the MF of each critical PI based on the survey responses.

$$MFu_{in} = \frac{x_{1u_{in}}}{E_1} + \frac{x_{2u_{in}}}{E_2} + \frac{x_{3u_{in}}}{E_3} + \frac{x_{4u_{in}}}{E_4} + \frac{x_{5u_{in}}}{E_5} \quad (2)$$

where u_{in} is the PIs; MFu_{in} is the MF of a given PI; $x_{ju_{in}}$ (j = 1, 2, 3, 4, 5) is the percentage of respondents who were rated j for the significance of a specific PI, which measures the degree of MF; $\frac{x_{ju_{in}}}{E_1}$ is the relationship between $x_{ju_{in}}$ and its grade alternative; and '+' is a notation in a fuzzy set. Using Equation (3), the MF of a specific critical PI could be indicated as follows:

$$MFu_{in} = x_{1u_{in}} + x_{2u_{in}} + x_{3u_{in}} + x_{4u_{in}} + x_{5u_{in}} \quad (3)$$

Equation (4) is used to process and can be adopted when multiple components are considered, and the difference in their weight is minimal.

$$M(\cdot, \oplus)b_j = \min\left(1, \sum w_i \times r_{ij}\right) min = 1 \forall b_j \in B \quad (4)$$

where w_i represents the weightings of each PI; r_{ij} is the membership function of each critical PI; and $\oplus$ is the sum of the weighting and membership function product.

Step 3: Overall effectiveness level

The overall effectiveness level (OEL) of critical PIs was computed using Equation (5). This equation considers the weightings (W), the degree of the MF (R), and L as the linguistic variables (1—very low, 2—low, 3—neutral, 4—high, 5—very high) to determine the OEL. The OEL of the critical PIs can be computed as follows:

$$\mathrm{OEL} = \Sigma \mathrm{n}_{\mathrm{i}=1} (\mathrm{W} \times \mathrm{R_i}) \times \mathrm{L} \quad (5)$$

4. Result

4.1. Result of Mean Ranking Analysis and Normalization Method

The results of ranking the PIs for assessing EMP implementation in water supply construction projects are presented in Table 3. The mean value of the PIs extends from 2.571 to 4.214. The critical PIs have normalized mean values of at least 0.50. Eighteen PIs were found to have normalized values of 0.50 or above, making them critical PIs.

Table 3. Results of mean ranking analysis and normalization method.

Code	Mean	Standard Deviation	Normalized Value
PI28	4.214	1.043	1.000 *
PI38	4.098	0.910	0.929 *
PI4	3.955	0.874	0.842 *
PI7	3.839	1.205	0.772 *
PI26	3.813	1.061	0.755 *
PI6	3.795	1.428	0.745 *
PI25	3.759	1.042	0.723 *
PI1	3.732	1.147	0.707 *
PI19	3.696	1.130	0.685 *
PI37	3.661	0.982	0.663 *
PI12	3.652	1.213	0.658 *
PI9	3.634	1.464	0.647 *
PI21	3.571	1.145	0.609 *
PI13	3.545	1.030	0.592 *
PI2	3.500	1.208	0.565 *
PI33	3.482	1.259	0.554 *
PI18	3.455	1.222	0.538 *
PI8	3.429	1.063	0.522 *
PI36	3.375	0.978	0.489
PI10	3.313	1.186	0.451
PI3	3.304	1.177	0.446
PI24	3.286	1.196	0.435
PI22	3.205	1.164	0.386
PI5	3.161	1.070	0.359
PI35	3.152	1.117	0.353
PI32	3.116	1.184	0.332
PI34	3.107	1.126	0.326
PI11	3.089	0.954	0.315
PI23	3.071	1.029	0.304
PI20	3.036	1.154	0.283
PI16	3.027	1.069	0.277
PI17	3.009	1.143	0.266
PI14	2.964	1.039	0.239
PI30	2.955	1.181	0.234
PI31	2.866	1.284	0.179
PI15	2.768	1.208	0.120
PI27	2.688	1.446	0.071
PI39	2.571	1.299	0.000

Note: * = critical PIs.

4.2. Result of EFA

The Kaiser–Meyer–Olkin (KMO) value for the PIs stands at 0.855, surpassing the minimum threshold of 0.50 [74]. Conversely, Bartlett's test of sphericity returned a significant value of 0.000, indicating that the dataset is not an identity matrix. Consequently, the data are deemed suitable for EFA.

As illustrated in Table 4, 14 PIs are successfully loaded into three underlying constructs, each possessing factor loadings greater than 0.50. These three constructs collectively account for 60.414% of the total variance. To determine the appropriate label for each construct, one can consider variables with higher factor loadings or the entire set of variables. Hence, the constructs are categorized as fluid-related indicators (F), health and safety-related indicators (HS), and site environment-related indicators (SE).

Table 4. Results of EFA.

Constructs	PIs	Code	Factor Loadings	Variance Explained	Cronbach Alpha
Fluid-related indicators	Changes in the color of bodies of water	PI12	0.843	28.561	0.891
	Spills of chemical substances	PI6	0.774		
	Changes in the color of run-off water	PI18	0.758		
	Overflowed silt trap	PI8	0.702		
	Clogged drainage	PI7	0.682		
	Oil/fuel spills	PI9	0.681		
	Soil erosion	PI1	0.621		
Health and safety-related indicators	Public safety	PI28	0.771	17.118	0.713
	Traffic accidents on construction sites	PI2	0.691		
	Spread of disease	PI33	0.671		
	Landslide occurrence	PI19	0.583		
Site environment-related indicators	Restricted site accessibility	PI21	0.785	14.735	0.691
	Road safety hazard	PI38	0.731		
	Irregular flooding	PI26	0.713		

Additionally, Cronbach's alpha reliability test was conducted to ensure the accuracy of the grouping of factors. As indicated in Table 4, Cronbach's alpha coefficients exceeded the minimum threshold of 0.60 [79]. This implies that each construct exhibits good internal consistency.

4.3. Result of FSE

Tables 5–7 display the FSE results for key PIs, including MFs for levels 3, 2, and 1, along with an OEL value of 3.72. Meanwhile, site environment-related indicators have the highest criticality at 3.84. This is followed by health and safety-related indicators (3.75) and fluid-related indicators (3.65). In other words, all constructs have values between "moderately critical" to "critical". Policymakers should consider focusing on the key PIs in site environmental-related indicators. However, the other constructs cannot be ignored when assessing EMP implementation in water supply construction projects.

Table 5. Description of performance indicator input variables.

Code	MI	SD	NV	CI	OR	CR	TM	CW
FL	-	-	-	u_{fl}	-	-	25.54	0.492
PI7	3.84	1.20	0.52	u_{fl1}	3	1	-	-
PI6	3.80	1.43	0.47	u_{fl2}	5	2	-	-
PI1	3.73	1.15	0.39	u_{fl3}	6	3	-	-
PI12	3.65	1.21	0.28	u_{fl4}	8	4	-	-
PI9	3.63	1.46	0.26	u_{fl5}	9	5	-	-
PI18	3.46	1.22	0.03	u_{fl6}	13	6	-	-
PI8	3.43	1.06	0.00	u_{fl7}	14	7		
HS	-	-	-	u_{hs}	-	-	14.89	0.287
PI28	4.21	1.04	1.00	u_{hs1}	1	1	-	-
PI19	3.70	1.13	0.34	u_{hs2}	7	2	-	-
PI2	3.50	1.21	0.09	u_{hs3}	11	3	-	-
PI33	3.48	1.26	0.07	u_{hs4}	12	4	-	-
SE	-	-	-	u_{se}	-	-	11.48	0.221
PI38	4.10	0.91	0.85	u_{se2}	2	1	-	-
PI26	3.81	1.06	0.49	u_{se2}	4	2	-	-
PI21	3.57	1.14	0.18	u_{se2}	10	3	-	-
						Total	51.91	1.000

Note: MI = mean index SD = standard deviation; NV = normalized value = (mean e minimum mean)/(maximum mean x minimum mean); CI = codes for index system; OR = overall rank; CR = construct rank; TM = total mean; and CW = construct weighting.

Table 6. Results from the fuzzy synthetic evaluation.

Code	Level	MI	Weightings	MF Value
Overall	1	-	-	0.07, 0.09, 0.19, 0.34, 0.31
FL	2	-	0.492	0.09, 0.11, 0.18, 0.31, 0.31
PI7	3	3.84	0.150	0.04, 0.13, 0.14, 0.29, 0.38
PI6	3	3.80	0.149	0.13, 0.09, 0.12, 0.21, 0.46
PI1	3	3.73	0.146	0.05, 0.11, 0.18, 0.38, 0.29
PI12	3	3.65	0.143	0.08, 0.10, 0.19, 0.36, 0.28
PI9	3	3.63	0.142	0.15, 0.08, 0.16, 0.20, 0.41
PI18	3	3.46	0.135	0.10, 0.13, 0.17, 0.41, 0.19
PI8	3	3.43	0.134	0.04, 0.14, 0.31, 0.34, 0.16
HS	2	-	0.287	0.07, 0.07, 0.21, 0.31, 0.33
PI28	3	4.21	0.283	0.04, 0.05, 0.08, 0.32, 0.51
PI19	3	3.70	0.248	0.06, 0.07, 0.24, 0.36, 0.27
PI2	3	3.50	0.235	0.10, 0.08, 0.27, 0.33, 0.22
PI33	3	3.48	0.234	0.10, 0.10, 0.29, 0.24, 0.27
SE	2	-	0.221	0.04, 0.07, 0.17, 0.43, 0.29
PI38	3	4.10	0.357	0.02, 0.04, 0.15, 0.42, 0.38
PI26	3	3.81	0.332	0.04, 0.08, 0.16, 0.45, 0.27
PI21	3	3.57	0.311	0.07, 0.11, 0.21, 0.41, 0.21

Table 7. Effectiveness index of the constructs.

No.	Construct	Construct Code	Weighting
1	Fluid-related indicators	FL	3.65
2	Health and safety-related indicators	HS	3.75
3	Site environment-related indicators	SE	3.84

5. Discussions

5.1. Fluid-Related Indicators

The first construct identified through factor analysis is referred to as "Fluid-Related Indicators." This construct encompasses indicators that pertain to fluid elements used to assess the implementation of an EMP in water supply construction projects. It comprises the following seven specific indicators: PI12, PI18, PI6, PI9, PI8, PI7, and PI1.

Changes in the color of bodies of water (PI12) are an indicator of the poor implementation of an EMP in water supply construction projects. Water bodies changing color, typically to a murky or unnatural hue, can be a visible and easily noticeable sign of pollution or contamination. It serves as an early warning signal that something may be wrong with the water quality. Another indicator of poor EMP implementation is changes in the color of run-off water (PI18). Run-off water is water that flows over the surface of the ground rather than soaking into it. It occurs when precipitation, such as rain or melted snow, falls onto the Earth's surface and cannot be absorbed by the soil or vegetation. Changes in the color of run-off water, especially if it becomes discolored or murky, can be a clear sign of pollution or contamination. Run-off water should ideally be clear or match the natural color of the surrounding environment. Color changes can indicate the presence of sediments, chemicals, or other pollutants.

In addition, the spill of chemical substances (PI6) is one of the indicators of poor EMP implementation in water supply construction projects. When chemical spills occur despite the presence of an EMP, it may suggest shortcomings in the plan's implementation and management. Water environments are often highly sensitive to chemical contamination. Even small chemical spills can have significant adverse effects on aquatic ecosystems, water quality, and the health of aquatic organisms. Furthermore, oil/fuel spills (PI9) are also one of the indicators to assess the implementation of an EMP. Oil and fuel spills can lead to water pollution, affecting the quality of water bodies. Monitoring and mitigating such spills are essential to prevent contamination and ensure that water remains safe for various uses, including drinking water supply and recreational activities.

Also, an overflowing silt trap (PI8) indicates poor EMP implementation in water supply construction projects. When a silt trap overflows, erosion control measures may not effectively prevent sediment run-off, potentially leading to increased water pollution. Sediment pollution is the most significant pollutant from construction sites as it could potentially simultaneously affect the economy, environment, and society [80]. Clogged drainage (PI7) is another indicator of poor EMP implementation. Drainage systems are crucial for managing the flow of water on construction sites. When drainage systems become clogged, it can disrupt the intended flow of water, potentially leading to localized flooding, erosion, or other water-related issues. Soil erosion (PI11) is another indicator to assess the implementation of an EMP in water supply construction projects. Soil erosion is a primary concern in construction projects, especially those near water bodies. Uncontrolled erosion can result in the loss of topsoil, the sedimentation of water bodies, and the release of contaminants, which can negatively impact water quality and aquatic ecosystems.

5.2. Health and Safety-Related Indicators

The second construct identified through factor analysis is referred to as "Health and Safety-Related Indicators". This construct comprises indicators that are associated with health and safety considerations and are used to assess the implementation of an EMP in water supply construction projects. It has the following five specific indicators: PI28, PI33, PI19, PI2, and PI25.

Public safety (PI28) is one of the indicators to assess the implementation of an EMP in water supply construction projects. Public safety incidents, such as accidents or injuries involving nearby residents or visitors, indicate that safety measures outlined in the EMP may not be adequately enforced or effective. Ensuring the safety of workers, nearby residents, and the general public is a top priority in any construction project. Also, the spread of disease (PI33) is another indicator of poor EMP implementation in water supply construction projects. Construction activities can pose a risk of contributing to the growth and spread of waterborne pathogens in building water systems [81]. Moreover, construction sites near water bodies can pose health risks due to the potential for the spread of waterborne diseases. Monitoring the spread of disease is critical for safeguarding the health and safety of workers and nearby communities.

Another indicator of poor EMP implementation is the occurrence of landslides (PI19). Landslides pose a significant safety risk to workers on the construction site and nearby communities. Construction activities near water bodies can alter the stability of slopes and increase the likelihood of landslides [82]. Traffic accidents on construction sites (PI2) are also an indicator to assess the implementation of an EMP in water supply construction projects. Traffic accidents on construction sites can lead to injuries or fatalities among construction workers. Traffic accidents can disrupt nearby communities, lead to complaints, and negatively impact community relations, especially if the public perceives that the construction project is causing avoidable accidents. In addition, slope failures (PI25) are one of the indicators of the poor implementation of an EMP. Slope failures pose a significant safety risk to construction workers on the site, as well as to nearby communities and the public. Slope failures can result in soil erosion, the sedimentation of water bodies, or the release of contaminants, harming aquatic ecosystems, disrupting habitats, and degrading water quality.

5.3. Site Enviroment-Related Indicators

The third construct identified through factor analysis is referred to as "Site Environment-Related Indicators". This construct encompasses indicators that are associated with the site's environment and are used to assess the implementation of an EMP in water supply construction projects. It includes the following three specific indicators: PI21, PI26, and PI38.

The first indicator in this construct is restricted site accessibility (PI21). Limited site accessibility can impact the safety of construction workers and site visitors. Restricted access routes can lead to delays in emergency response, potentially jeopardizing the safety of workers and the public. Irregular flooding (PI26) is also one of the indicators to assess the implementation of an EMP in water supply construction projects. Irregular flooding can pose a severe safety risk to construction workers on the site, as well as to nearby communities and the public. Road safety hazards (PI38) are another indicator of poor EMP implementation. Construction sites near water bodies, including heavy construction vehicles, often involve increased traffic. Road safety hazards can also affect nearby communities and the general public. Additionally, injuries and fatalities associated with construction accidents impose a huge cost on the industry [83].

5.4. Comparison with Prior Works

A comparison of this study's results with prior findings offers a nuanced understanding of the PIs for assessing EMP implementation. Specifically, this study's outputs were compared with PIs identified in the context of road construction [16] and highway construction projects [17], revealing both commonalities and disparities. Table 8 captures the essence of this comparative analysis, indicating that out of the 18 critical PIs identified in this study, 6 were not deemed critical in prior works. Notably, in road construction projects, indicators such as restricted site accessibility, road safety hazards, the smell of runoff water, traffic accidents on construction sites, and the spread of disease were not considered critical. Similarly, in highway construction projects, increased schedule waste, restricted site accessibility, the smell of runoff water, and the spread of disease did not emerge as critical indicators. Despite these variations, a noteworthy observation is the substantial overlap in critical PIs between this study and prior research. Most of the PIs identified as critical in the current study were consistently reported as critical in the context of road and highway construction projects. This consistency underscores the pivotal role that these particular indicators play in assessing EMP implementation across diverse construction scenarios, implying that certain environmental considerations encapsulated in these critical PIs have universal relevance and importance in evaluating the sustainability of construction projects. In essence, the persistent identification of these shared critical PIs underscores their centrality in gauging the effectiveness of EMP implementation. Recognizing and acknowledging these indicators is not only crucial but forms an integral part of ensuring sustainable construction practices, fostering a comprehensive and standardized approach toward achieving environmentally responsible construction outcomes.

Table 8. Comparison with prior works.

Performance Indicators	Road Projects [1]	Highway Projects [2]	Water Supply Projects (This Study)
Public safety	•	•	•
Road safety hazards	-	•	•
Construction waste	•	•	•
Clogged drainage	•	•	•
Irregular flood	•	•	•
Spills of chemical substances	•	•	•
Slope failures	•	•	•
Soil erosion	•	•	•
Landslide occurrence	•	•	•
Increased schedule waste	•	-	•
Changes in the color of bodies of water	•	•	•
Oil/fuel spills	•	•	•
Restricted site accessibility	-	-	•
The smell of run-off water	-	-	•
Traffic accidents on construction site	-	•	•
Spread of disease	-	-	•
Changes in the color of run-off water	•	•	•
Overflowed silt trap	•	•	•

Note: [1] = [16] [2] = [17].

6. Conclusions

This study focuses on identifying and assessing the effectiveness of PIs for assessing the implementation of EMPs in water supply construction projects. This study identified a total of 39 potential PIs based on insights from interviews with environmental professionals and a comprehensive review of the existing literature. This study collected data from 112 environmental professionals who completed surveys to evaluate the effectiveness of these PIs. The analysis employed several techniques, including mean ranking, normalization, EFA, and FSE. This study identified 18 critical PIs for assessing EMP implementation through these analyses. These critical PIs encompass a wide range of factors, including public safety, road safety hazards, construction waste, clogged drainage, irregular flooding, spilling chemical substances, slope failures, soil erosion, landslide occurrence, increased schedule waste, changes in the color of bodies of water, oil/fuel spills, restricted site accessibility, the smell of run-off water, traffic accidents on construction site, spread of disease, changes in the color of run-off water, and overflowing silt traps. Additionally, the result of EFA grouped these PIs into the following three underlying constructs: fluid-related indicators, health and safety-related indicators, and site environment-related indicators. The FSE results confirmed that all PIs are between moderately critical to critical in their importance.

This study's findings have several implications. First, the results can serve as a valuable resource for academics and researchers interested in developing frameworks for improved EMP implementation in water supply construction projects. Second, the results can enhance environmental management practices in water supply construction projects, ultimately leading to more sustainable and eco-friendly construction practices. In conclusion, this study provides valuable insights into PIs for assessing EMP implementation in water supply construction projects, offering a foundation for further research and potential improvements in environmental management practices in the construction industry.

Despite its contributions, this study has certain limitations. The sample size of 112 survey respondents might be considered relatively small. Thus, future scholars can replicate this study with a larger sample size. Also, the findings are specific to the local context of the case study. Therefore, caution should be exercised when applying these results to other countries or regions. Additionally, future research could expand upon this study by employing more advanced statistical techniques, such as structural equation modeling, to explore causal relationships among the identified PIs. Additionally, the application of machine learning techniques could contribute to external validation and bolster the robustness assessment of the current study. Moreover, this study uses FSE as one of its data analysis methods. FSE is known for its simplicity and ease of interpretation. In assessing EMP implementation in water supply construction projects, where stakeholders may include industry professionals with diverse backgrounds, a straightforward and easily understandable method can be more effective. FSE clearly indicates the criticality of performance indicators without the need for the complex probabilistic reasoning inherent in Bayesian networks. Also, FSE is particularly useful when dealing with imprecise or uncertain data. Data may not always be precise or quantifiable in construction projects, and FSE allows for a flexible and adaptive approach to handling such uncertainties. Bayesian networks, while powerful in handling probabilistic relationships, might require a more precise dataset and may be less accommodating to vagueness in the data. Thus, future studies could explore the use of Bayesian networks to model the complex interdependencies among performance indicators, providing a more nuanced understanding of how these indicators influence each other in the context of EMP implementation. Nevertheless, this study's findings still provide significant knowledge about the PIs that can assess EMP implementation in water supply construction projects.

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