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Risk Factor Identification and Validation for Desalination Projects in Egypt

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ABSTRACT

Desalination of sea water projects are critical for addressing water scarcity in regions like Egypt, but they face numerous risks that can hinder their success. This study identifies and analyzes 53 risk factors affecting renewable energy desalination projects through expert interviews, literature review, and a questionnaire survey completed by 47 experts. Statistical methods, including descriptive statistics (mean, mode, standard error, and standard deviation), Pearson correlation, and Cronbach's alpha, were employed to validate the reliability and significance of these factors. The overall questionnaire showed excellent reliability ($\alpha = 0.815$ for probability of occurrence; $\alpha = 0.921$ for degree of impact). The results indicate a strong consensus among industry experts. Inflation and price fluctuations was ranked as the highest-probability risk (mean = 4.32/5), while faulty design of plant components (intake, outfall, mechanical systems) was ranked as the highest-impact risk (mean = 4.51/5). Conversely, environmental disasters (earthquakes, floods) showed the lowest probability of occurrence (mean = 1.91/5), and social pressures from entities not directly invested in the project's success showed the lowest degree of impact (mean = 2.70/5). These statistically validated findings provide project stakeholders with critical insights into the most significant

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threats to desalination initiatives in Egypt's unique operational context. These findings provide a robust basis for understanding and managing risks in desalination projects, contributing to grow the knowledge on desalination project sustainability and offers actionable insights for stakeholders in Egypt and similar arid regions.
Keywords: Desalination Projects; Water-Energy Nexus; Risk Assessment; Risk Management; Risk Factors Identification; Statistical Analysis

1. Introduction

Desalination of sea water projects play a critical role in addressing global water scarcity, particularly in coastal and arid regions where freshwater resources are limited. With only 1% of the world's freshwater considered easily accessible, the growing demand for water, driven by population growth and climate change, has made desalination an essential technology for securing reliable water supplies. By converting seawater or brackish water into potable water, desalination provides a sustainable and dependable source of freshwater, independent of rainfall or traditional water sources [1, 2]. However, despite its potential, desalination is not without challenges. These projects are exposed to a wide range of risks that can affect their feasibility, efficiency, and environmental sustainability.

The nearness of desalination facilities to marine environments introduces unique risks related to marine engineering, marine structures, and marine ecosystems. Desalination plants rely heavily on marine infrastructure, such as intake and outfall systems, which must be designed to withstand harsh marine conditions, including wave action, corrosion, and biofouling. Additionally, the construction and operation of these facilities can have significant impacts on marine life, including disruptions to local ecosystems, changes in water quality, and potential harm to marine species [3]. These risks highlight the need for careful planning and risk management to ensure the sustainability of desalination projects in marine environments.

The importance of desalination projects lies in their ability to enhance water security, support economic development, and mitigate the impacts of climate change on freshwater availability. Savun-Hekimoğlu et al. highlight desalination as a key alternative, alongside other methods such as recycled water irrigation and rainwater harvesting, in their evaluation of water supply alternatives for Istanbul [4]. However, the implementation of desalination projects is not without challenges. Zhang et al. propose a structured framework for assessing risks associated with large-scale desalination initiatives, categorizing risks into four primary domains: Water intake and outfall risk, processing risk, financial risk, and circumstance risk. Each domain is further subdivided into specific risk factors, such as changes in raw water quality, construction challenges, financing, and policy uncertainties. Their integrated fuzzy comprehensive evaluation and analytic hierarchy process provide a systematic approach to identifying and mitigating risks, thereby enhancing the feasibility and sustainability of large-scale desalination projects [5].

While water treatment technologies like advanced oxidation processes (AOPs), including heterogeneous electro-Fenton systems and UV-activated persulfate methods [6–8], demonstrate excellent effectiveness for targeted pollutant degradation, such approaches address fundamentally different challenges than those facing large-scale desalination infrastructure. Where AOPs focus on molecular-level contaminant removal through specialized chemical processes, desalination projects require holistic risk frameworks that account for systemic economic volatility, environmental impacts at ecosystem scales, and complex operational factors - particularly in renewable-energy-powered systems in water-scarce regions like Egypt.

The world is targeting fully renewable energy by the middle of the century [9]. Renewable energy is employed to power water desalination units since decades in many countries including Egypt [10]. Many successful stories have been applied in this context. In [11], the authors applied wave and hydrogen energies to supply Humboldt Bay with water and electricity through water desalination units. In [12], the authors employed wind energy in Red sea region to get water and hydrogen through water desalination units for supplying and trading.

Recent studies have shown that overdose salinity caused by brine discharges from desalination plants can severely impact sensitive marine species, such as seagrasses. In the case of Zostera chilensis, a relict seagrass species in the south-east Pacific, overdose salinity conditions led to reduced photosynthetic performance, increased oxidative stress, and altered gene expression related to osmotic regulation and reactive oxygen species metabolism [13]. These findings highlight the importance of considering marine ecosystem impacts when assessing risks in desalination projects.

Furthermore, Darwish and Zubari emphasize that desalination challenges extend beyond environmental risks, such as greenhouse gas emissions and marine effluent discharge, to encompass broader issues. They highlight that technology acquisition remains a significant hurdle, as desalination technology is often imported, limiting local technological development. Additionally, the desalination sector's limited contribution to national economies poses a strategic risk. These challenges highlight the need for comprehensive risk management strategies to ensure the sustainable and economically beneficial integration of desalination, particularly in regions like the Gulf Cooperation Council (GCC) [14].

By addressing these risks and challenges, desalination projects can play a transformative role in securing water resources for future generations. While existing studies have identified various risks associated with desalination projects, critical gaps remain:

- No systematic, statistically validated framework exists to comprehensively identify and categorize risks.
- No comprehensive assessment specific to renewable-energy desalination in Egypt
- Limited prioritization of risks based on both probability and impact.

This gap limits the ability of stakeholders to develop targeted mitigation strategies and ensure project success.

This study fills this gap by:

- Developing a comprehensive risk framework tailored to Egypt's context.
- Validating the identified risks using robust statistical methods.
- Prioritizing high-probability and high-impact risks to guide mitigation strategies.

These contributions provide a foundation for improving the feasibility and sustainability of desalination projects in Egypt and beyond.

2. Research Methodology

This study utilized a mixed-methods approach to comprehensively assess risk factors associated with renewable energy desalination projects. The research design combined qualitative and quantitative methods to achieve a robust and holistic analysis as shown in **Figure 1**.

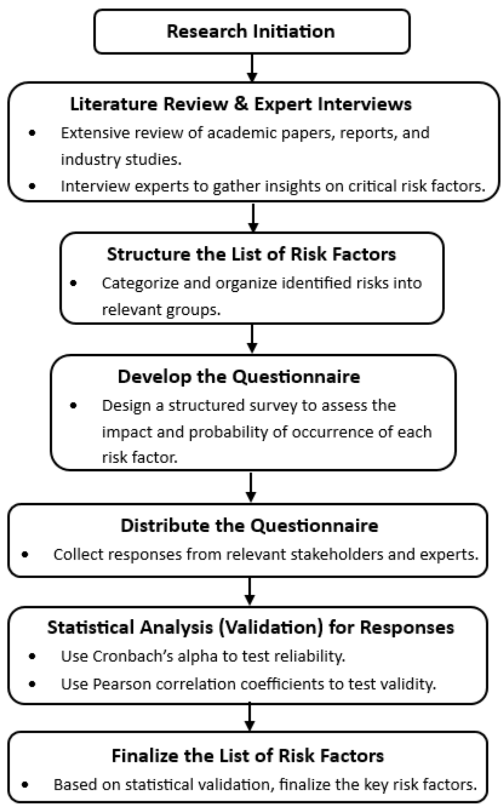

Figure 1. Research Methodology Framework for Identifying and Validating Risk Factors.

The qualitative phase began with in-depth interviews conducted with experts in the desalination field. These interviews aimed to identify key risk factors and gather insights into the challenges and uncertainties associated with desalination projects. Additionally, a thorough systematic literature review was undertaken to examine existing risk assessment methodologies and relevant studies. This review helped contextualize the identified risk factors within the broader academic and industry discourse, ensuring that the study built on established knowledge.

Based on the insights gathered from the expert interviews and literature review, a structured questionnaire was developed. The questionnaire was designed to collect data on the identified risk factors, focusing on their probability of occurrence and degree of impact. Participants for the questionnaire survey were selected from a diverse sample of stakeholders involved in desalination projects, including professionals from academia, industry, and client organizations. This ensured representation across different roles and levels of experience, enhancing the generalizability of the findings.

The field survey process served as the primary data collection tool for this research. To mitigate potential biases and ensure the quality of responses, strategies and administration methods recommended by Gillham and Dörnyei were employed [15, 16]. These strategies included announcing the questionnaire in advance, ensuring respectable and impressive sponsorship, emphasizing confidentiality, and promising feedback on the results. These measures aimed to enhance the quality and quantity of responses, ensuring the reliability of the data collected.

Data analysis incorporated both quantitative and qualitative techniques. The survey data were analyzed using statistical techniques, including descriptive statistics (mean, mode, standard error, and standard deviation) to summarize the data and assess the significance of each risk factor. Additionally, Pearson correlation and Cronbach's alpha were utilized to validate the reliability and consistency of the questionnaire. Conceptual analysis was performed to the interview transcripts to identify recurring themes and patterns related to risk factors, providing a comprehensive understanding of the risks associated with desalination projects.

By integrating qualitative and quantitative approaches, this study provides a comprehensive evaluation of risk factors in renewable energy desalination projects, offering actionable insights for stakeholders.

3. Risk Factors

The list of risk factors impacting the performance of desalination projects in Egypt was developed through a systematic process involving literature review, brainstorming sessions, and expert interviews. Through this process, 53 risk factors were identified and categorized into five main groups: (1) Design, Implementation, and Operation; (2) Financial; (3) Political and Legal; (4) Environmental; and (5) Logistics and Resources. A summary of these risk factors is presented in **Table 1**. This comprehensive list provides a basis for understanding the challenges associated with desalination projects in Egypt and serves as a basis for further analysis and the development of targeted risk management strategies.

4. Field Survey

The field survey process forms the foundation of this research. To ensure high-quality responses, strategies recommended by Dörnyei were employed, including announcing the questionnaire in advance, emphasizing confidentiality, and promising feedback on the results [16]. These strategies were applied to both Google Forms and hard copy versions of the questionnaire, enhancing response quality and quantity.

4.1. Questionnaire Content

The questionnaire was developed to evaluate the 53 risk factors identified through literature review and expert interviews. Each risk factor was assessed using a five-point scale based on two dimensions:

- Probability of Occurrence: The likelihood of the risk factor manifesting during the project lifecycle.
- Degree of Impact: The severity or impact of the risk factor on the performance of desalination projects.

The numerical scale for assessing the probability of occurrence, and degree of impact was as follows:

- Very High: 80–100% (5 points)
- High: 60–79% (4 points)
- Moderate: 40–59% (3 points)
- Low: 20–39% (2 points)
- Very Low: 0–19% (1 point)

Table 1. Risk Factors Affecting Desalination Projects in Egypt.

Group	Risk Factors
Design, Implementation and Operation	1) Faulty design of planet components (intake, outfall, mechanical systems, etc.). 2) Significance differences between the as built and the design drawings (too many change orders). 3) Ambiguities, fault and inconsistency of specification. 4) Design difficulty leads to difficulty in construction. 5) Incomplete design. 6) Lack of available design data. 7) Lack of Value Engineering Studies in such projects. 8) Power supply shortage. 9) Accident during operation. 10) High fluctuations in energy supply. 11) High fluctuations in salinated water supply. 12) Possible lack of technological knowledge, skills, applied techniques for the implementation. 13) Inaccurate project scheduling. 14) Unclearly defined scope of work.
Financial	1) Inflation and price fluctuations. 2) Delay in settling invoices as per the contract. 3) Unforeseen disruption of funding. 4) Monopoly of material needed for implementation. 5) Fluctuation in the currency exchange rate. 6) Lack of control over cash flow. 7) Public agencies lack of budget. 8) Random selection of the contractor (lower prices only) in Egypt. 9) There is no vote for the technical evaluation of companies and strong financial.
Political and Legal	1) Legal disputes during the construction phase between project parties. 2) Difficulty in obtaining permits and work licenses. 3) Lack of clarity in labor regulations. 4) New governmental acts or legislations. 5) Political unrest (wars, revolutions, strikes, etc.). 6) Bribery and corruption. 7) Lack of security. 8) Political pressure against project implementation. 9) Bureaucratic hurdles and uncooperative authorities.
Environmental	1) Extremely severe and harsh weather conditions. 2) Environmental disasters (earthquakes, floods, etc.). 3) Difficulty accessing the site (very remote, obstacles hindering access). 4) Compliance challenges with environmental laws and regulations. 5) Safety and healthy risks. 6) 4Unable to find a suitable brine disposal site. 7) Change in raw water quality. 8) Possible perceived environmental impacts from the project. 9) Social pressures from entities not directly invested in project success.
Logistics and Resources	1) Lack of specialized material. 2) Inability to transport material to work area. 3) Unavailability of qualified contractors/Subcontractors and skilled labors. 4) Unavailability of qualified consultants/Engineers. 5) Unavailability of qualified operator. 6) Special requirements for storage. 7) Unavailability of land for the project. 8) Intense competition during the bidding process. 9) Unavailability of material or equipment. 10) Poor communication/coordination among stakeholders. 11) First-time use of modern equipment without training. 12) Miscoordination when dealing with multiple subcontractors.

These criteria align with standards from The Project Risk Management Handbook [17], ensuring reliability and consistency in risk assessment practices.

4.2. Sample Size

The required sample size from the population is calculated using statistical principles relevant to this type of exploratory study, ensuring a 95% confidence level. The sample size is calculated using the following equation [18].

$$N = \frac{\left(Z_{1-\frac{\alpha}{2}}\right)^2 * \sigma^2}{e^2} \quad (1)$$

Where: N represents the sample size, $(Z_{1-\alpha/2})$ represents the desired level of confidence, that determines the critical Z value, σ is the standard deviation, and e is the acceptable sampling error.

In this study, a 95% confidence level ($\alpha = 0.05$) was selected. The area in each tail of the standard normal distribution is $\alpha/2 = 0.025$, leaving a central area of 0.475. According to the standard normal distribution table, a Z value of 1.96 corresponds to this confidence level. The margin of error (e) was assumed to be 0.25, and the standard deviation (σ) was calculated as 0.98 based on a preliminary sample of 20 responses. By substituting these values into the formula, the minimum required sample size was calculated as N = 60.

Thus, a minimum of 60 questionnaires was required to achieve a 95% confidence level. In practice, 47 responses were received. To assess the representativeness of this sample, the standard deviation was recalculated as 0.99 for the 47 respondents. Substituting these values into the formula, the critical Z value was recalculated as 1.73, corresponding to a confidence level of over 90%. This indicates that the 47 provide a highly representative sample of the population, as confirmed by the interpolation method.

5. Statistical Analysis

5.1. Descriptive Statistics

The gathered questionnaire responses were analyzed using essential statistical measures, including mean, mode, standard deviation (SD), and standard error (SE), for each risk factor individually. These measures were calculated for both the probability of occurrence and the degree of impact of the identified risk factors.

- Standard Deviation (SD): Measures the variability in responses.
- Standard Error (SE): Represents the standard deviation of the sampling distribution. The standard error of the mean was calculated to evaluate the variation in sample means relative to the population mean due to sampling error.

The calculated standard error was compared to a threshold of 0.2. A standard error below this value shows a relatively accurate point estimate and suggests acceptable agreement among experts on the significance of the risk factors [19, 20].

The statistical analysis encompassed 47 responses, with summarized results presented in **Table 2** for the probability of occurrence and **Table 3** for the degree of impact. Notably, all standard error values for the risk factors were below 0.2, indicating a strong consensus among experts concerning the significance of the assessed factors.

5.2. Questionnaire Validation and Reliability

Validity refers to the accuracy with which an instrument measures what it is intended to measure. To confirm the validity of the questionnaire, two statistical tests were applied internal validity, and structural validity [21].

Internal validity was measured using Pearson correlation coefficients, which assessed the correlation between each item within a specific field and the total score for that field. These calculations were performed for both the probability of occurrence and the degree of impact of the identified risk factors. As shown in **Table 4** (Correlation Coefficients for Risk Factors: Probability of Occurrence) and **Table 5** (Correlation Coefficients for Risk Factors: Degree of Impact), all correlation coefficients were significant at $\alpha = 0.01$or $\alpha = 0.05$ confirming the internal consistency of the questionnaire [22, 23].

Structural validity was evaluated by analyzing the overall structure of the questionnaire, including the validity of each individual field and the questionnaire as a whole. Correlation coefficients between each field and the entire questionnaire were significant at α = 0.01 confirming the structural validity [20–23].

Table 2. Descriptive Statistics for Probability of Occurrence of Risk Factors.

Group	Risk Factors	Probability of Occurrence					
		No. of Responds	Sum of Points	Mean	S.D	S.E	Mode
Group 1. Design, Implementation and Operation	1.1 Faulty design of planet components (intake, outfall, mechanical systems, etc.).	47	127	2.702	0.897	0.131	3
	1.2 Significance differences between the as built and the design drawings (too many change orders).	47	125	2.660	0.906	0.132	3
	1.3 Ambiguities, fault and inconsistency of specification.	47	144	3.064	0.861	0.126	4
	1.4 Design difficulty leads to difficulty in construction.	47	107	2.277	1.046	0.153	2
	1.5 Incomplete design.	47	139	2.957	0.967	0.141	2
	1.6 Lack of available design data.	47	111	2.362	0.909	0.133	2
	1.7 Lack of Value Engineering Studies in such projects	47	116	2.468	1.164	0.170	2
	1.8 Power supply shortage.	47	126	2.681	0.970	0.141	2
	1.9 Accident during operation.	47	149	3.170	0.930	0.136	3
	1.10 High fluctuations in energy supply.	47	139	2.957	0.967	0.141	3
	1.11 High fluctuations in salinated water (seawater) supply.	47	106	2.255	1.081	0.158	1
	1.12 Possible lack of technological knowledge, skills, applied techniques for the implementation	47	124	2.638	0.932	0.136	3
	1.13 Inaccurate project scheduling.	47	137	2.915	1.145	0.167	3
	1.14 Unclearly defined scope of work.	47	143	3.043	1.010	0.147	2
Group 2. Financial	2.1 Inflation and price fluctuations.	47	203	4.319	0.970	0.141	5
	2.2 Delay in settling invoices as per the contract.	47	149	3.170	1.058	0.154	3
	2.3 Unforeseen disruption of funding.	47	145	3.085	0.986	0.144	3
	2.4 Monopoly of material needed for implementation.	47	130	2.766	0.972	0.142	3
	2.5 Fluctuation in the currency exchange rate.	47	194	4.128	0.959	0.140	4
	2.6 Lack of control over cash flow.	47	153	3.255	0.886	0.129	3
	2.7 Public agencies lack of budget.	47	153	3.255	1.041	0.152	4
	2.8 Random selection of the contractor (lower prices only) in Egypt.	47	143	3.043	1.031	0.150	3
	2.9 There is no vote for the technical evaluation of companies and strong financial	47	131	2.787	0.966	0.141	3
Group 3. Political and Legal	3.1 Legal disputes during the construction phase between project parties.	47	139	2.957	0.798	0.116	3
	3.2 Difficulty in obtaining permits and work licenses.	47	99	2.106	1.015	0.148	2
	3.3 Lack of clarity in labor regulations.	47	109	2.319	1.054	0.154	2
	3.4 New governmental acts or legislations.	47	130	2.766	1.134	0.165	3
	3.5 Political unrest (wars, revolutions, strikes, etc.).	47	101	2.149	1.071	0.156	1
	3.6 Bribery and corruption.	47	138	2.936	0.861	0.126	3
	3.7 Lack of security.	47	109	2.319	0.948	0.138	2
	3.8 Political pressure against project implementation.	47	107	2.277	1.004	0.146	2
	3.9 Bureaucratic hurdles and uncooperative authorities	47	154	3.277	1.046	0.153	3

Table 2. *Cont.*

Group	Risk Factors	Probability of Occurrence					
		No. of Responds	Sum of Points	Mean	S.D	S.E	Mode
Group 4. Environmental	4.1 Extremely severe and harsh weather conditions.	47	116	2.468	0.919	0.134	2
	4.2 Environmental disasters (earthquakes, floods, etc.).	47	90	1.915	1.048	0.153	1
	4.3 Difficulty accessing the site (very remote, obstacles hindering access).	47	106	2.255	1.081	0.158	2
	4.4 Compliance challenges with environmental laws and regulations.	47	123	2.617	0.864	0.126	2
	4.5 Safety and healthy risks.	47	125	2.660	0.929	0.135	2
	4.6 Unable to find a suitable brine disposal site.	47	134	2.851	0.989	0.144	3
	4.7 Change in raw water quality.	47	114	2.426	1.087	0.158	2
	4.8 Possible perceived environmental impacts from the project.	47	132	2.809	0.937	0.137	3
	4.9 Social pressures from entities not directly invested in project success.	47	112	2.383	1.022	0.149	2
Group 5. Logistics and Resources	5.1 Lack of specialized material.	47	127	2.702	0.848	0.124	2
	5.2 Inability to transport material to work area.	47	100	2.128	0.937	0.137	2
	5.3 Unavailability of qualified contractors/ Subcontractors and skilled labors.	47	137	2.915	0.871	0.127	3
	5.4 Unavailability of qualified consultants/ Engineers.	47	137	2.915	0.941	0.137	3
	5.5 Unavailability of qualified operator.	47	144	3.064	0.954	0.139	3
	5.6 Special requirements for storage.	47	110	2.340	1.016	0.148	3
	5.7 Unavailability of land for the project	47	117	2.489	1.146	0.167	2
	5.8 Intense competition during the bidding process.	47	116	2.468	0.964	0.141	3
	5.9 Unavailability of material or equipment.	47	141	.000	0.945	0.138	3
	5.10 Poor communication/coordination among stakeholders.	47	142	3.021	1.139	0.166	3
	5.11 First-time use of modern equipment without training.	47	133	2.830	1.098	0.160	2
	5.12 Miscoordination when dealing with multiple subcontractors.	47	138	2.936	1.040	0.152	3

Table 6 illustrates the correlation coefficients for each field related to the probability of occurrence and the entire questionnaire. All correlation coefficients were significant at α = 0.01, further confirming the structural validity of the questionnaire for measuring the probability of occurrence.

Table 7 illustrates the correlation coefficients for each field related to the degree of impact and the entire questionnaire. Similarly, all correlation coefficients were significant at α = 0.01, confirming the structural validity of the questionnaire for measuring the degree of impact.

The validity analysis results indicate that the questionnaire is a robust and reliable tool for measuring the intended risk factors in desalination projects. The significant correlation coefficients for both internal validity and structural validity confirm that the questionnaire accurately captures the probability of occurrence and degree of impact of the identified risk factors. These findings highlight the questionnaire's effectiveness in providing a comprehensive assessment of risks, ensuring that stakeholders can make informed decisions to enhance the sustainability and success of desalination projects.

5.3. Reliability of the Questionnaire

Cronbach's alpha coefficient is used to evaluate the reliability of the questionnaire by measuring its internal consistency across different fields and their overall mean. The coefficient ranges from 0.0 to 1.0, with higher values indicating stronger internal consistency. The Cronbach's alpha is calculated for each field of the questionnaire to ensure reliability [21].

Table 3. Descriptive Statistics for Degree of Impact of Risk Factors.

Group	Risk Factors	Degree of Impact					
		No. of Responds	Sum of Points	Mean	S.D	S.E	Mode
Group 1. Design, Implementation and Operation	1.1 Faulty design of planet components (intake, outfall, mechanical systems, etc.).	47	212	4.511	0.872	0.127	5
	1.2 Significance differences between the as built and the design drawings (too many change orders).	47	167	3.553	0.941	0.137	3
	1.3 Ambiguities, fault and inconsistency of specification.	47	203	4.319	0.747	0.109	5
	1.4 Design difficulty leads to difficulty in construction.	47	173	3.681	0.775	0.113	4
	1.5 Incomplete design.	47	209	4.447	0.767	0.112	5
	1.6 Lack of available design data.	47	180	3.830	0.807	0.118	4
	1.7 Lack of Value Engineering Studies in such projects	47	143	3.043	1.271	0.185	4
	1.8 Power supply shortage.	47	189	4.021	0.812	0.118	4
	1.9 Accident during operation.	47	183	3.894	1.015	0.148	5
	1.10 High fluctuations in energy supply.	47	172	3.660	0.929	0.135	4
	1.11 High fluctuations in salinated water (seawater) supply.	47	152	3.234	1.076	0.157	3
	1.12 Possible lack of technological knowledge, skills, applied techniques for the implementation	47	160	3.404	0.915	0.133	3
	1.13 Inaccurate project scheduling.	47	172	3.660	1.016	0.148	4
	1.14 Unclearly defined scope of work.	47	187	3.979	0.978	0.143	5
Group 2. Financial	2.1 Inflation and price fluctuations.	47	204	4.340	1.016	0.148	5
	2.2 Delay in settling invoices as per the contract.	47	193	4.106	1.015	0.148	5
	2.3 Unforeseen disruption of funding.	47	195	4.149	1.031	0.150	5
	2.4 Monopoly of material needed for implementation.	47	182	3.872	1.123	0.164	5
	2.5 Fluctuation in the currency exchange rate.	47	209	4.447	0.985	0.144	5
	2.6 Lack of control over cash flow.	47	209	4.447	0.846	0.123	5
	2.7 Public agencies lack of budget.	47	190	4.043	0.988	0.144	5
	2.8 Random selection of the contractor (lower prices only) in Egypt.	47	207	4.404	0.790	0.115	5
	2.9 There is no vote for the technical evaluation of companies and strong financial	47	178	3.787	1.030	0.150	3
Group 3. Political and Legal	3.1 Legal disputes during the construction phase between project parties.	47	195	4.149	0.850	0.124	4
	3.2 Difficulty in obtaining permits and work licenses.	47	164	3.489	0.942	0.137	3
	3.3 Lack of clarity in labor regulations.	47	140	2.979	1.101	0.161	3
	3.4 New governmental acts or legislations.	47	166	3.532	0.872	0.127	4
	3.5 Political unrest (wars, revolutions, strikes, etc.).	47	179	3.809	1.084	0.158	5
	3.6 Bribery and corruption.	47	175	3.723	0.961	0.140	4
	3.7 Lack of security.	47	160	3.404	1.065	0.155	3
	3.8 Political pressure against project implementation.	47	164	3.489	0.987	0.144	4
	3.9 Bureaucratic hurdles and uncooperative authorities	47	178	3.787	0.921	0.134	4

Table 3. *Cont.*

Group	Risk Factors	Degree of Impact					
		No. of Responds	Sum of Points	Mean	S.D	S.E	Mode
Group 4. Environmental	4.1 Extremely severe and harsh weather conditions.	47	151	3.213	0.988	0.144	3
	4.2 Environmental disasters (earthquakes, floods, etc.).	47	184	3.915	1.048	0.153	5
	4.3 Difficulty accessing the site (very remote, obstacles hindering access).	47	166	3.532	1.127	0.164	4
	4.4 Compliance challenges with environmental laws and regulations.	47	165	3.511	0.740	0.108	3
	4.5 Safety and healthy risks.	47	163	3.468	0.739	0.108	3
	4.6 Unable to find a suitable brine disposal site.	47	165	3.511	1.108	0.162	4
	4.7 Change in raw water quality.	47	153	3.255	0.999	0.146	4
	4.8 Possible perceived environmental impacts from the project.	47	152	3.234	1.036	0.151	3
	4.9 Social pressures from entities not directly invested in project success.	47	127	2.702	1.070	0.156	3
Group 5. Logistics and Resources	5.1 Lack of specialized material.	47	181	3.851	0.899	0.131	4
	5.2 Inability to transport material to work area.	47	155	3.298	1.109	0.162	4
	5.3 Unavailability of qualified contractors/ Subcontractors and skilled labors.	47	198	4.213	0.988	0.144	5
	5.4 Unavailability of qualified consultants/ Engineers.	47	200	4.255	1.020	0.149	5
	5.5 Unavailability of qualified operator.	47	191	4.064	1.099	0.160	5
	5.6 Special requirements for storage.	47	136	2.894	1.189	0.173	3
	5.7 Unavailability of land for the project	47	177	3.766	1.056	0.154	3
	5.8 Intense competition during the bidding process.	47	138	2.936	1.019	0.149	3
	5.9 Unavailability of material or equipment.	47	200	4.255	0.785	0.114	4
	5.10 Poor communication/coordination among stakeholders.	47	172	3.660	0.995	0.145	4
	5.11 First-time use of modern equipment without training.	47	173	3.681	0.925	0.135	3
	5.12 Miscoordination when dealing with multiple subcontractors.	47	181	3.851	1.051	0.153	4

Table 4. Correlation Coefficients for Risk Factors: Probability of Occurrence.

Group	No.	Paragraph	Pearson Correlation Coefficient	P-Value (Sig.)
Group 1. Design, Implementation and Operation	1.1	Faulty design of planet components (intake, outfall, mechanical systems, etc.).	0.351*	0.016
	1.2	Significance differences between the as built and the design drawings (too many change orders).	0.546**	0.000
	1.3	Ambiguities, fault and inconsistency of specification.	0.346*	0.017
	1.4	Design difficulty leads to difficulty in construction.	0.534**	0.000
	1.5	Incomplete design.	0.340*	0.020
	1.6	Lack of available design data.	0.707**	0.000
	1.7	Lack of Value Engineering Studies in such projects	0.614**	0.000
	1.8	Power supply shortage.	0.529**	0.000
	1.9	Accident during operation.	0.315*	0.031
	1.10	High fluctuations in energy supply.	0.681**	0.000
	1.11	High fluctuations in salinated water (seawater) supply.	0.603**	0.000
	1.12	Possible lack of technological knowledge, skills, applied techniques for the implementation	0.601**	0.000
	1.13	Inaccurate project scheduling.	0.338*	0.020
	1.14	Unclearly defined scope of work.	0.573**	0.000

Table 4. *Cont.*

Group	No.	Paragraph	Pearson Correlation Coefficient	P-Value (Sig.)
Group 2. Financial	2.1	Inflation and price fluctuations.	0.490**	0.000
	2.2	Delay in settling invoices as per the contract.	0.617**	0.000
	2.3	Unforeseen disruption of funding.	0.566**	0.000
	2.4	Monopoly of material needed for implementation.	0.641**	0.000
	2.5	Fluctuation in the currency exchange rate.	0.665**	0.000
	2.6	Lack of control over cash flow.	0.656**	0.000
	2.7	Public agencies lack of budget.	0.622**	0.000
	2.8	Random selection of the contractor (lower prices only) in Egypt.	0.332*	0.023
	2.9	There is no vote for the technical evaluation of companies and strong financial	0.371*	0.010
Group 3. Political and Legal	3.1	Legal disputes during the construction phase between project parties.	0.649**	0.000
	3.2	Difficulty in obtaining permits and work licenses.	0.655**	0.000
	3.3	Lack of clarity in labor regulations.	0.763**	0.000
	3.4	New governmental acts or legislations.	0.662**	0.000
	3.5	Political unrest (wars, revolutions, strikes, etc.).	0.698**	0.000
	3.6	Bribery and corruption.	0.523**	0.000
	3.7	Lack of security.	0.590**	0.000
	3.8	Political pressure against project implementation.	0.746**	0.000
	3.9	Bureaucratic hurdles and uncooperative authorities	0.381**	0.008
Group 4. Environmental	4.1	Extremely severe and harsh weather conditions.	0.713**	0.000
	4.2	Environmental disasters (earthquakes, floods, etc.).	0.647**	0.000
	4.3	Difficulty accessing the site (very remote, obstacles hindering access).	0.811**	0.000
	4.4	Compliance challenges with environmental laws and regulations.	0.675**	0.000
	4.5	Safety and healthy risks.	0.782**	0.000
	4.6	Unable to find a suitable brine disposal site.	0.613**	0.000
	4.7	Change in raw water quality.	0.822**	0.000
	4.8	Possible perceived environmental impacts from the project.	0.741**	0.000
	4.9	Social pressures from entities not directly invested in project success.	0.688**	0.000
Group 5. Logistics and Resources	5.1	Lack of specialized material.	0.592**	0.000
	5.2	Inability to transport material to work area.	0.668**	0.000
	5.3	Unavailability of qualified contractors/Subcontractors and skilled labors.	0.651**	0.000
	5.4	Unavailability of qualified consultants/Engineers.	0.614**	0.000
	5.5	Unavailability of qualified operator.	0.495**	0.000
	5.6	Special requirements for storage.	0.753**	0.000
	5.7	Unavailability of land for the project	0.512**	0.000
	5.8	Intense competition during the bidding process.	0.655**	0.000
	5.9	Unavailability of material or equipment.	0.661**	0.000
	5.10	Poor communication/coordination among stakeholders.	0.726**	0.000
	5.11	First-time use of modern equipment without training.	0.622**	0.000
	5.12	Miscoordination when dealing with multiple subcontractors.	0.702**	0.000

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table 5. Correlation Coefficients for Risk Factors: Degree of Impact.

Group	No.	Paragraph	Pearson Correlation Coefficient	P-Value (Sig.)
Group 1. Design, Implementation and Operation	1.1	Faulty design of planet components (intake, outfall, mechanical systems, etc.).	0.594**	0.000
	1.2	Significance differences between the as built and the design drawings (too many change orders).	0.426**	0.003
	1.3	Ambiguities, fault and inconsistency of specification.	0.405**	0.005
	1.4	Design difficulty leads to difficulty in construction.	0.497**	0.000
	1.5	Incomplete design.	0.316*	0.030
	1.6	Lack of available design data.	0.639**	0.000
	1.7	Lack of Value Engineering Studies in such projects	0.370*	0.010
	1.8	Power supply shortage.	0.581**	0.000
	1.9	Accident during operation.	0.713**	0.000
	1.10	High fluctuations in energy supply.	0.705**	0.000
	1.11	High fluctuations in salinated water (seawater) supply.	0.646**	0.000
	1.12	Possible lack of technological knowledge, skills, applied techniques for the implementation	0.654**	0.000
	1.13	Inaccurate project scheduling.	0.740**	0.000
	1.14	Unclearly defined scope of work.	0.489**	0.000

Table 5. *Cont.*

Group	No.	Paragraph	Pearson Correlation Coefficient	P-Value (Sig.)
Group 2. Financial	2.1	Inflation and price fluctuations.	0.763**	0.000
	2.2	Delay in settling invoices as per the contract.	0.695**	0.000
	2.3	Unforeseen disruption of funding.	0.803**	0.000
	2.4	Monopoly of material needed for implementation.	0.788**	0.000
	2.5	Fluctuation in the currency exchange rate.	0.731**	0.000
	2.6	Lack of control over cash flow.	0.802**	0.000
	2.7	Public agencies lack of budget.	0.802**	0.000
	2.8	Random selection of the contractor (lower prices only) in Egypt.	0.660**	0.000
	2.9	There is no vote for the technical evaluation of companies and strong financial	0.673**	0.000
Group 3. Political and Legal	3.1	Legal disputes during the construction phase between project parties.	0.531**	0.000
	3.2	Difficulty in obtaining permits and work licenses.	0.681**	0.000
	3.3	Lack of clarity in labor regulations.	0.791**	0.000
	3.4	New governmental acts or legislations.	0.663**	0.000
	3.5	Political unrest (wars, revolutions, strikes, etc.).	0.656**	0.000
	3.6	Bribery and corruption.	0.565**	0.000
	3.7	Lack of security.	0.600**	0.000
	3.8	Political pressure against project implementation.	0.780**	0.000
	3.9	Bureaucratic hurdles and uncooperative authorities	0.458**	0.001
Group 4. Environmental	4.1	Extremely severe and harsh weather conditions.	0.744**	0.000
	4.2	Environmental disasters (earthquakes, floods, etc.).	0.557**	0.000
	4.3	Difficulty accessing the site (very remote, obstacles hindering access).	0.698**	0.000
	4.4	Compliance challenges with environmental laws and regulations.	0.688**	0.000
	4.5	Safety and healthy risks.	0.621**	0.000
	4.6	Unable to find a suitable brine disposal site.	0.714**	0.000
	4.7	Change in raw water quality.	0.761**	0.000
	4.8	Possible perceived environmental impacts from the project.	0.631**	0.000
	4.9	Social pressures from entities not directly invested in project success.	0.762**	0.000
Group 5. Logistics and Resources	5.1	Lack of specialized material.	0.589**	0.000
	5.2	Inability to transport material to work area.	0.738**	0.000
	5.3	Unavailability of qualified contractors/Subcontractors and skilled labors.	0.695**	0.000
	5.4	Unavailability of qualified consultants/Engineers.	0.712**	0.000
	5.5	Unavailability of qualified operator.	0.667**	0.000
	5.6	Special requirements for storage.	0.753**	0.000
	5.7	Unavailability of land for the project	0.675**	0.000
	5.8	Intense competition during the bidding process.	0.718**	0.000
	5.9	Unavailability of material or equipment.	0.580**	0.000
	5.10	Poor communication/coordination among stakeholders.	0.681**	0.000
	5.11	First-time use of modern equipment without training.	0.558**	0.000
	5.12	Miscoordination when dealing with multiple subcontractors.	0.717**	0.000

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table 6. Correlation Coefficients for Each Field and the Entire Questionnaire: Probability of Occurrence.

No.	Paragraph	Pearson Correlation Coefficient	P-Value (Sig.)
1	Group 1. Design, Implementation and Operation	0.695**	0.000
2	Group 2. Financial	0.610**	0.000
3	Group 3. Political and Legal	0.798**	0.000
4	Group 4. Environmental	0.843**	0.000
5	Group 5. Logistics and Resources	0.845**	0.000

**. Correlation is significant at the 0.01 level (2-tailed).

Table 7. Correlation Coefficients for Each Field and the Entire Questionnaire: Degree of Impact.

No.	Paragraph	Pearson Correlation Coefficient	P-Value (Sig.)
1	Group 1. Design, Implementation and Operation	0.883**	0.000
2	Group 2. Financial	0.869**	0.000
3	Group 3. Political and Legal	0.909**	0.000
4	Group 4. Environmental	0.833**	0.000
5	Group 5. Logistics and Resources	0.899**	0.000

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8 presents the Cronbach's alpha values for each field of the questionnaire related to the probability of occurrence. The values for individual fields ranged from 0.710 to 0.884, indicating high reliability. The overall Cronbach's alpha for the entire questionnaire was 0.815, confirming very good reliability.

Table 8. Cronbach's Alpha Values for Each Field and Overall Questionnaire: Probability of Occurrence.

No.	Field	No. of Items	Cronbach's Alpha (Reliability)
1	Group 1. Design, Implementation and Operation	14	0.767
2	Group 2. Financial	9	0.710
3	Group 3. Political and Legal	9	0.809
4	Group 4. Environmental	9	0.884
5	Group 5. Logistics and Resources	12	0.866
	All paragraphs of the questionnaire	5	0.815

Table 9 presents the Cronbach's alpha values for each field of the questionnaire related to the degree of impact. The values for individual fields ranged from 0.818 to 0.899, indicating high reliability. The overall Cronbach's alpha for the entire questionnaire was 0.921, confirming excellent reliability.

Table 9. Cronbach's Alpha Values for Each Field and Overall Questionnaire: Degree of Impact.

No.	Field	No. of Items	Cronbach's Alpha (Reliability)
1	Group 1. Design, Implementation and Operation	14	0.824
2	Group 2. Financial	9	0.899
3	Group 3. Political and Legal	9	0.818
4	Group 4. Environmental	9	0.856
5	Group 5. Logistics and Resources	12	0.892
	For All Groups	5	0.921

These results prove that the questionnaire is highly reliable for assessing both the probability of occurrence and the degree of impact of risk factors in desalination projects.

6. Discussion

The findings of this study contribute to and enhance the comprehensive understanding of the risk factors affecting renewable energy desalination projects in Egypt. Through a systematic process involving expert interviews, literature review, and a questionnaire survey, 53 risk factors were identified and categorized into five main groups: (1) Design, Implementation, and Operation; (2) Financial; (3) Political and Legal; (4) Environmental; and (5) Logistics and Resources. The statistical analysis, including descriptive statistics, Pearson correlation (r), and Cronbach's alpha, confirmed the reliability and validity of the questionnaire, ensuring that the results are robust and actionable.

The statistical analysis revealed strong evidence supporting the reliability and validity of the findings. The Pearson correlation coefficients demonstrated strong ($|r| \geq 0.7$) and moderate ($0.5 \leq |r| < 0.7$) correlations for most risk factors, indicating meaningful relationships between variables. For example, lack of available design data ($r = 0.707$) and change in raw water quality ($r = 0.822$) were identified as highly significant in both probability of occurrence and degree of impact, highlighting the importance of robust design and environmental monitoring. Similarly, inflation and price fluctuations ($r = 0.763$) emerged as the highest-risk factor in terms of degree of impact, highlighting the economic challenges faced by desalination projects.

The reliability of the questionnaire was further supported by high Cronbach's alpha values. For the probability of occurrence, the overall Cronbach's alpha was 0.815, with individual group values ranging from 0.710

(Financial) to 0.884 (Environmental). For the degree of impact, the overall Cronbach's alpha was 0.921, with individual group values ranging from 0.818 (Political and Legal) to 0.899 (Financial). These high reliability scores, along with significant correlation coefficients for each field and the entire questionnaire ($p < 0.01$), confirm that the questionnaire accurately measures both probability of occurrence and degree of impact.

A key finding of this study is that "inflation and price fluctuations" emerged as the highest-risk factor in terms of probability of occurrence due to Egypt's unique economic conditions such as; currency devaluation, and import dependency, a while "faulty design of plant components (intake, outfall, mechanical systems, etc.)" was identified as the highest-risk factor in terms of degree of impact. Conversely, "environmental disasters (earthquakes, floods, etc.)" was identified as the lowest-risk factor in terms of probability of occurrence, while "social pressures from entities not directly invested in project success" was deemed the lowest-risk factor in terms of degree of impact. These findings highlight the variability in risk perception and the importance of context-specific risk assessments.

The implications of this study are significant for policymakers, project managers, and stakeholders involved in renewable energy desalination projects. By prioritizing high-risk factors and developing targeted mitigation strategies, stakeholders can enhance the feasibility, sustainability, and overall success of these projects. For instance, addressing inflation and price fluctuations through financial hedging mechanisms or long-term contracts can reduce financial uncertainties. Similarly, improving design processes and quality control measures can mitigate risks associated with faulty plant components.

7. Conclusions

This study provides a basis assessment of the risk factors affecting renewable energy desalination projects in Egypt. Through a mixed-methods approach, including expert interviews, literature review, and a questionnaire survey, 53 risk factors were identified and validated. The statistical analysis confirmed the questionnaire's reliability and validity, ensuring robust and actionable results.

For Egypt's context, we recommend currency hedging through multilateral partnerships to mitigate inflation risks, accelerating local manufacturing of critical desalination components (including membranes, pumps, and energy recovery systems) to reduce import dependency, and implementing adaptive public-private partnership (PPP) contracts with inflation-indexed water tariffs. These strategies directly address Egypt's 2023 Central Bank reports on currency volatility and the Ministry of Trade's local manufacturing targets, offering policymakers a roadmap for immediate action.

The findings highlight the critical importance of addressing high-probability and high-impact risks, such as inflation and price fluctuations, as well as faulty design of plant components, to ensure the successful implementation and operation of these projects.

The statistical analysis is robust and reliable, with strong and moderate correlations for most risk factors, making them actionable for stakeholders. By prioritizing risk mitigation strategies tailored to the specific challenges identified in this study, policymakers and project managers can enhance the resilience and sustainability of renewable energy desalination projects in Egypt.

This study contributes to and strengthens the growing body of knowledge on risk management in desalination projects by providing a systematic, statistically validated framework for identifying, categorizing, and prioritizing risks. The insights gained from this research offer practical guidance for policymakers, project managers, and other stakeholders, enabling them to make informed decisions and improve project outcomes. Ultimately, addressing these risks will contribute to water security in Egypt and other water-scarce regions.

Future research should expand on these findings by exploring their applicability in other regions facing water scarcity and by investigating the potential of emerging technologies to mitigate project risks. Practical applications of this work could include enhancing risk management strategies for desalination projects in coastal areas, optimizing energy consumption, and improving the efficiency of renewable energy-powered desalination units. Additionally, the findings of this study will be further developed in subsequent research, which will focus on dynamic risk assessment using alternative AI-based methods. This follow-up work aims to enhance the current framework and provide more robust tools for stakeholders to manage risks effectively in renewable energy desalination projects.

Author Contributions

Conceptualization, H.H.F. and A.S.; methodology, A.S.; validation, M.A.H. and H.H.F.; formal analysis, A.B.; investigation, M.A.H.; resources, H.H.F.; data curation, A.B.; writing—original draft preparation, A.S.; writing—review and editing, H.H.F. and M.A.H.; visualization, M.A.H. and A.B.; supervision, S.I.; project administration, S.I. and H.H.F.; funding acquisition, A.S. All authors have read and agreed to the published version of the manuscript.

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