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Critical Factors Influencing Estimation of Egyptian Irrigation Canal Lining Projects

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Abstract

Irrigation Canal Lining Projects (ICLPs) involve complex construction work with various risks and uncertainties. Successful completion requires accurate cost and time estimates, along with effective risk assessment. The project team must identify and address factors that influence these estimates to ensure project success. This paper aims to identify, categorize, and prioritize cost, time, and risk-related factors affecting the estimation of Egyptian Irrigation Canal Lining Projects (EICLPs) contingency to enhance project management outcomes for these projects. In total, 93 factors were divided into three parts. Part (1): 25 factors related to project cost were categorized into 3 groups (Design, Construction, and Overheads) related factors, Part (2): 30 factors related to project time were categorized into 3 groups (Owner, Contractor, and Project) Related Factors, and Part (3): 38 risk related factors categorized into 6 groups (Technical, Environmental, Financial, Operational, Legal and regulatory, and Social) risk related factors were gathered from the literature review and, a brainstorming session with experts in the field was held to focus on the important ones in the first and second phase. In the third phase, a questionnaire including the three parts was created based on these factors identified by 150 respondents. The questionnaire's reliability was tested using SPSS software Ver. 26.

As a result, the 20 most important factors influencing the estimation of Egyptian Irrigation Canal Lining Projects EICLPs' contingency have been identified, which are integrated between the three parts to develop a realistic and achievable project cost estimate as an accurate and acceptable estimation and decision-making tool for stakeholders.

Keywords: Lining, Cost and time, Estimation, Risk, Relative Importance Index (RII)

1. Introduction

1.1 Cost of Irrigation Canals Lining Projects

Canal lining is a costly channel improvement technique, and justifying its installation in an existing system is complicated due to inadequate data and challenges in accurately estimating lining costs. However, estimated costs for design, construction, and maintenance can be forecasted with a significantly better level of precision and certainty [1]. An early planning for canal lining can lead to cost savings and economic justification due to the canal lining which is vital for efficient use of land and water resources, controlling seepage, and preventing groundwater contamination. It also permits higher velocities, reduces maintenance costs, and protects against erosion [2]. Several cost-effective techniques and alternatives have been developed to reduce the expense of constructing watercourses. In light of these facts, an analysis of the efficiency and cost implications of various alternatives, such as lining versus earthen improvements, for developing watercourse improvement techniques is necessary to reduce conveyance losses [3]. Another cost-effective technique for canal lining involves improving the irrigation canals' design to reduce water losses from evaporation and seepage. This can be achieved by determining the irrigation canals' optimal cross-section design to minimize overall costs, including lining, excavation, and loss of water from seepage and evaporation costs [4]. A significant investment is needed based on the length and cross-section of the irrigation canal. Therefore, the cross-sectional design should be optimized to minimize construction costs. This economic design should consider excavation and surface lining costs, as well as labor and maintenance. Open channel design is essential for determining the best dimensions and constructing the canal section with minimal construction cost for conveying the specified discharge [5]. Responsible firms should consider both general and site-specific requirements when selecting the type of lining that significantly affects the estimation of canal lining costs, including soil type and its characteristics, structural stability, economy, availability of construction materials, machinery and equipment, skilled and unskilled labor, ease to maintenance, reparability, weed growth prevention, resistance to burrowing animals, structural stability during and after construction. Additionally, the chosen lining should be economical in its initial cost, and repair and maintenance costs [6]. The compatibility of the lining methods for open channels in permeable soils is the main factor in conserving irrigation water, aiming to minimize water losses during transportation. This included a cost estimate for lining and field analysis of a canal undergoing rehabilitation as part of the Egyptian national project for the rehabilitation of irrigation canals in rural areas [7]. The high cost of rehabilitating irrigation canals poses challenges for implementation processes. Evaluating the impact of lining material's hydraulic properties on flow parameters is crucial for accurately determining the economic value of irrigation canals rehabilitation. Additionally, main factors such as canal size, hydrogeological conditions, and irrigation canal rehabilitation budget aid decision-makers in estimating the overall cost of irrigation canals rehabilitation, especially for irrigation canals lining [8].

1.2 Time of Irrigation Canals Lining Projects

When estimating the time required to reconstruct, lining, and operate the selected tired irrigation canals in Egypt, the overall reconstruction process divided into the following stages: design, preconstruction, construction, and intake headbox reconstruction works [1]. In most instances, major water projects have faced delays and remain unexecuted due to diverse reasons. By identifying and evaluating these various reasons, and the perception of experts involved in the water sector, corrective measures can be considered to alleviate the impact of the extended time frame and delays for implementing large water projects. Consequently, sufficient water may be accessible promptly to meet the water demand [9]. Further, the irrigation channels projects require innovative estimation methods with numerous benefits including accuracy, flexibility, speed, simplicity, and ease of use. While various methods are currently employed to estimate project duration, some of these techniques face significant challenges related to uncertainty, sluggishness, and precision. Additionally, the project duration significantly impacts the project cost, so it's vital to thoroughly evaluate the timeline to ensure a successful irrigation channels projects completion [10]. Moreover, repetitive projects such as canal projects, pipelines, highways, etc., entail ongoing and linear activities that must be built along the facility's horizontal alignment. When scheduling these projects, the Critical Path Method (CPM) breaks down the entire process into distinct activities that are sequenced based on their performance. Nevertheless, the primary challenge in such projects is to evaluate and determine the optimal production rates for timely completion [11]. Therefore, scheduling is essential for irrigation and drainage projects in general and irrigation canals lining projects in particular, as it gathers crucial information about project components, provide a highly accurate project time estimation, and ensures balanced resource distribution, including labor, construction materials, and equipment, for timely execution. This involves utilizing advanced scientific tools and methods to ensure an accurate estimate of project time, guarantee timely implementation and maintenance, ultimately optimizing project scheduling, and achieving their objectives [12].

1.3 Risk Faced Irrigation Canals Lining Projects

Risk assessment is essential during the design development stage of irrigation projects for their success. A risk assessment procedure was developed to determine the best design alternative for these projects that are funded and managed by the State Hydraulic Works. The planning report was also a crucial document that was prepared and approved before the design tender and used during the design phase, providing information on economic feasibility and technical aspects such as irrigation module, type, water conveying method (lined open channel or pipe network), and preliminary drawings [13]. According to [14] comprehensive feasibility studies were conducted for the rehabilitation of the Nubaria and Ismailia Canals in Egypt, two major multipurpose canals in the Nile Delta serving approximately one-third of the local population. The studies explored potential alternative canal lining technologies and addressed various risks such as poorly functioning infrastructure, seepage, water logging, insufficient water conveyance capacity, unauthorized abstractions, and environmental degradation from pollution. Moreover, water sector projects encompassed public, investment, and infrastructural aspects, serving public interests and achieving public objectives. These projects necessitated significant resources, time, and a skilled professional team that carried high-risk and had wide-ranging economic, social, and environmental impacts. Additionally, incorporating environmental and social aspects in the planning of these projects involved assessing potential risks during implementation [15]. Based on [16] the rehabilitation and improvement of irrigation networks will encourage the shift from traditional low-yielding grain crops to high-value cash crops. It will also enhance farmers' ability to manage water and irrigation more effectively. Given the potential risks, a risk assessment and management plan will be developed to identify significant risks and implement mitigating measures. Precast concrete canals were employed when field concrete construction faced challenges like severe weather, and poor soil conditions. They were also utilized to manage work time constraints during irrigation network installation. The adoption of precast concrete canals was increasingly prevalent in irrigation projects, often conducted in uncertain environments. Investigating the risks associated with precast concrete canal construction was crucial to ensure high standards and safety [17]. Irrigation canal lining projects may pose a risk to water quality, which is a cause for concern. The potential impact on water quality depended on the characteristics of the lining material, the water, and the construction process. Findings showed that water samples from lined sites had lower bacterial counts compared to unlined ones, meeting the permissible limits for irrigation water classes in WHO guidelines. Further, the cement lining of the Nubaria irrigation canal in Egypt could potentially reduce bacterial growth and heavy metal pollution, and prevented the discharge of wastewater into the canal [18]. Additionally, Egypt faces water scarcity and limited public funds, necessitating increased investments in unconventional water supply projects through public-private partnerships (PPPs). The allocation of risk is crucial to the success of these partnerships, with a preference for discussed risk allocation for domestic wastewater treatment and seawater desalination projects. These findings have helped develop an efficient risk allocation framework for water sector partnerships in Egypt, and compared results to similar findings in China to aid foreign investors in adjusting their investment strategies [19]. Managing risk in the construction industry, particularly in Egyptian working conditions, is essential for identifying potential risk categories, their causes, probability of occurrence, and impact on project objectives. Success in meeting schedule, cost, quality, and other objectives depend heavily on an effective risk management approach. Project risk refers to uncertain events or conditions that can have a positive or negative effect (opportunities or threats) on project objectives such as scope, schedule, cost, and quality. It also involves exposure to loss or gain, or the probability of loss or gain occurring. Risks are categorized as certain if the probability of occurrence is 100% or uncertain if the probability of occurrence is 0% [20].

Irrigation canal lining projects faced challenges due to the high costs, cost overrun, delays, numerous risks and uncertainties. To address these challenges, estimators must have the ability to identify, and prioritize the various factors related to cost, time, and risk affecting contingency estimation of these projects. Despite the existence of several factors outlined in the literature, there is still a lack of clarity on how to accurately estimate the project cost for ICLPs. This has led researchers to focus on individual factors rather than grouping them based on specific criteria to facilitate a more comprehensive analysis. Therefore, there is an ongoing necessity to identify and categorize these factors. Consequently, the main objective of this research is to pinpoint the critical factors affecting the contingency estimation for Egyptian Irrigation Canal Lining Projects (EICLPs).

2. Literature review

2.1 Relevant cost factors affecting the estimation of ICLPS' contingency

Various factors related to cost that have an immediate impact on the estimation of ICLPs' contingency were identified and backed by multiple references as [21] identified the key cost parameters for Field Canal Improvement

Projects (FCIPs), and they also developed a reliable and practical model for a conceptual cost estimate that organizations can use to plan and construct irrigation improvement projects. [22] determined Continuous Flight Aguer (CFA) piles cost components using a prompt list, utilized an affinity diagramming technique to categorize the cost elements, and established a comprehensive cost breakdown structure (CBS) for CFA piles construction. [4] studied how the geometric shape of the canal cross-section affects cost estimation. [6] listed the factors that the responsible engineers should consider when gathering information about the main impacts on the economic canal. [7] suggested three alternative engineering methods for Egyptian irrigation canal rehabilitation with the feasibility and economic study that was carried out to estimate irrigation canal lining cost for each one. [23] estimated the cost of a canal lining with various cross-sections and broke down lining works into several factors that had significantly affected the cost. [8] revealed that the perimeter values of the channel's cross-section are crucial in estimating construction costs. [5] developed a nonlinear optimization model to minimize construction cost per unit length for lining irrigation canal, considering constraints and determining minimum dimensions.

2.2 Relevant time factors affecting the estimation of ICLPS' contingency

Time-related factors that affected the estimation of ICLPs' contingency were identified and supported by references as [24] developed a time management module utilizing historical data from forty projects to estimate the project duration for constructing Continuous Flight Auger (CFA) piles in Egypt. [11] compared between using the Critical Path Method (CPM) and Linear Scheduling Method (LSM) for a precast water canal project. [12] identified (26) factors affecting the estimation of execution periods for irrigation and drainage projects. [25] identified and listed 15 factors affecting the periods of the irrigation project, and developed a mathematical equation using modern technologies for prediction and validating the model.

2.3 Relevant risk factors affecting the estimation of ICLPs' contingency

Factors related to risk that face the estimation of ICLPs' contingency were identified and supported by references as [20] established a comprehensive list of forty-five common risks specific to Continuous Flight Auger CFA pile construction in Egyptian operating conditions, detailing causes, risk events, and effects for each. [26] identified and categorized major risks in rehabilitating irrigation networks into technical, economic, financial, governance, safeguards, environment, resettlement, and Indigenous peoples. [27] designed a survey with 51 factors related to risks in water supply projects, grouped into five categories: 10 for design and contract, 21 for construction and management, 3 for finance, 5 for politics, 5 for environment, and 7 for resources and procurement. [28] developed and validated a modified Fuzzy Group Decision-Making Approach (FGDMA) for 57 potential risks grouped into 9 categories to identify and assess risks in power plant projects. [19] examined risk allocation preferences in Egyptian water sector Private Public Partnership (PPP) projects, divided 49 risks into three levels (Macro, Meso, Micro), and classified them into thirteen categories each with sub-risks. [7] investigated the compatibility risks between canal lining methods and site conditions for rehabilitating the Egyptian irrigation canal. [29] created a survey with 51 risk-related factors for construction work in Water Supply Projects. [17] utilized the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to identify critical construction risks, eight potential risks were pinpointed in precast concrete canal construction: financial, time, equipment and material, technical, contractor, employer, consulting, and climate risks.

According to the literature, various factors related to cost, time, and risk that have an immediate impact on the estimation of ICLPs' contingency identified and backed by multiple references, as depicted in **Table 1**.

Table 1. Summary of past studies of relevant cost, time, and risk factors influencing estimation of ICLPs' contingency

Past studies of relevant cost factors influencing estimation of ICLPs' contingency		
References	**Year**	**Key Notes**

[22]	2016	▪ Identified CFA cost components using a prompt list, utilized an affinity diagramming technique to categorize the cost elements, and established a comprehensive cost breakdown structure (CBS)
[21]	2018	▪ Identified 35 parameters and grouped them into five categories: civil, mechanical, electrical, location, and miscellaneous parameters.
[4]	2020	▪ Studied how the geometric shape of the canal cross-section affects
[6]	2021	▪ Listed the factors the responsible engineers should consider when gathering information about the
[7]	2021	▪ Suggested three alternative engineering methods for Egyptian irrigation canal rehabilitation with the feasibility and economic study that was
[23]	2023	▪ Estimated the cost of a canal lining with various cross-sections and broke down lining works into several factors that had significantly affected the
[8]	2023	▪ Revealed that the perimeter values of the channel's cross-section are crucial in estimating construction costs
[5]	2023	▪ Developed a nonlinear optimization model to minimize construction cost per unit length for lining irrigation canal, considering constraints and

Past studies of relevant time factors influencing estimation of ICLPs' contingency

References	Year	Key Notes
[24]	2015	▪ Listed 25 factors to calculate the equipment performance ratio.
[11]	2022	▪ Compared the use of Critical Path Method (CPM) and Linear Scheduling Method (LSM) for a precast water canal project.
[12]	2022	▪ Identified (26) factors affecting the estimation of execution periods for irrigation and drainage projects
[25]	2023	▪ Identified and listing 15 factors affecting the periods of the irrigation project, developing a mathematical equation, using modern technologies for

Past studies of relevant risk factors influencing estimation of ICLPs' contingency

References	Year	Key Notes
[20]	2018	▪ Compiled a comprehensive list of forty-five common risks specific to Continuous Flight Auger CFA pile construction in Egyptian operating conditions, detailing causes, risk events, and effects
[16]	2019	▪ Identified and categorized major risks in rehabilitating irrigation networks into technical, economic, financial, governance, safeguards, environment, resettlement, and Indigenous
[27]	2019	▪ Designed a survey with 51 factors for risks in water supply projects, grouped into 5 categories: 10 for design and contract, 21 for construction and management, 3 for finance, 5 for politics, 5 for
[28]	2019	▪ Developed and validated a modified fuzzy group decision-making approach (FGDMA) for 57 potential risks grouped into 9 categories to identify and assess
[19]	2020	▪ Examined risk allocation preferences in Egyptian water sector PPP projects, dividing 49 risks into three levels (Macro, Meso, Micro), and classifying
[7]	2021	▪ Investigated the compatibility risks between canal lining methods and site conditions for the rehabilitation of Egyptian
[29]	2021	▪ Created a survey with 51 risk factors for construction work in Water Supply Projects
[17]	2022	▪ Utilized the Decision-Making Trial and Evaluation Laboratory (DEMATEL) to identify critical construction risks, eight potential risks were pinpointed in precast concrete canal construction: financial, time, equipment and

3. Research methodology

The methodology employed in this study is outlined in 6 phases as follows and depicted in **Figure 1**.

1. Review previous studies to identify factors affecting cost, time, and risk-related factors and categorize them based on their characteristics.
2. Conducting a brainstorming session with experts in the field to refine and reduce these factors.
3. Creating a questionnaire.
4. Collecting and analyzing data.
5. Determining the most influential factors affecting cost, time, and risk-related factors affecting the estimation of ICLPS' contingency.
6. Presenting the conclusions.

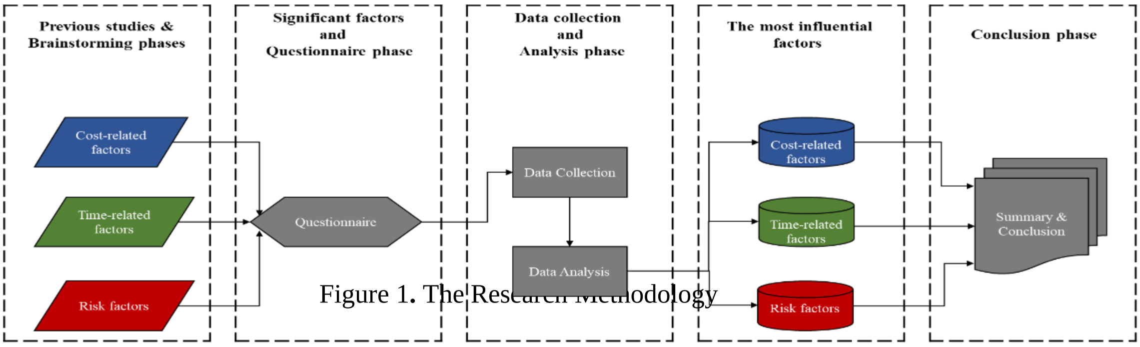

Figure 1. The Research Methodology

4. Questionnaire stage

Previous research identified and categorized various factors that affect the estimation of EICLPs' contingency. These factors were then refined, resulting in a total of 93 factors gathered from prior literature reviews and classified into three main groups: cost, time, and risk-related factors; and divided into 12 subgroups including 3 cost-related factors (design, construction, and overheads)-related factors; 3 time-related factors (owner, contractor, and project)-related factors; and 6 risk-related factors (technical, environmental, financial, operational, legal and regulatory, and social)-related factors as shown in **Figure 2** and **Table 2**.

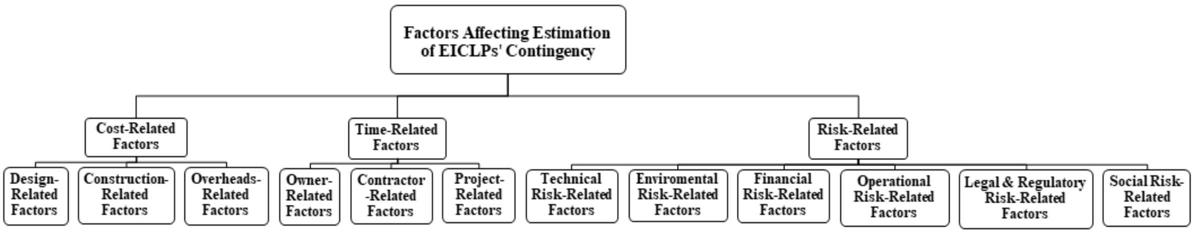

Figure 2. Hierarchy of cost, time, and risk-related factors groups and subgroups.

Table 2. Summarized list of 93 factors affecting the estimation of EICLPs' contingency from the literature.

Groups	Subgroups	Factors	References
Cost-Related Factors	Design-Related Factors	Type of irrigation canals' cross-section such as (Trapezoidal, Rectangle, ...)	[1, 2, 30, 31]
		Area of irrigation canals' cross-section [Hydraulic cross-sectional area] (m^2)	[1, 8, 23, 30, 32]
		Type of irrigation canals' lining	[1, 8, 23, 30-33]
		Irrigation canals' lining length (m run)	[1, 5, 8, 23, 30, 33]
		Area of irrigation canals' cross-section with rubble stone lining (m^2)	[8, 31]
		Area of irrigation canals' cross-section with plain concrete lining (m^2)	[23, 30, 32]
	Construction-Related Factors	Methods of irrigation canals' dewatering, and drying such as (Pumps, WPS, ….)	[1, 23]
		Appropriate means used for aquatic weed cleansing	[1]
		Irrigation canals' survey works such as (reshaping, levels' adjustments, ...)	[1, 23]
		Excavation works to adjust irrigation canals' cross-section dimensions and to reach the required levels	[1, 23, 32, 33]
		Backfill works to adjust irrigation canals' cross-section dimensions and to reach the required levels	[1, 32, 33]

		Construction works of rubble stones for irrigation canals' beds, side slopes, and feet	[23, 31]
		Pouring works of plain concrete mortar consisting of (gravel, sand, cement, and water) for irrigation canals' beds, side slopes, and feet	[1, 32, 33]
		Use of additive materials in the concrete mixture such as fiber needed for irrigation canals' lining works	[32]
		Use ready-mix plain concrete from the central mixing station for pouring irrigation canals' beds, side slopes, and feet	[1]
		Use plain concrete mixed on-site to pour irrigation canals' beds, side slopes, and feet	[1, 33]
		Using chemicals to treat the surface of concrete slabs for irrigation canals' beds, side slopes, and feet	[23, 32]
		Use insulating materials such as (Bitumen, ….) necessary for moisture insulation work for concrete slabs and filling joints	[1, 23, 32]
		Use filter pipes with the required dimensions (diameter, and length) needed for irrigation canals' lining works	[7]
	Overheads-Related Factors	Administrative expenses such as (office rent, utilities, insurance, salaries, and professional fees)	[22]
		Advertising expenses such as (billboards, online ads, flyers, mailers, and business cards)	[22]
		Vehicle expenses as (leased vehicles, owned vehicles, fuel, maintenance, and repairs)	[22]
		Bonding and insurance expenses as (bonding premiums, general permits, and insurance premiums)	[22]
		Equipment expenses as (leased equipment, owned equipment, and maintenance and repairs)	[22]
		Labor burden as (payroll taxes, workers' compensation insurance, and other labor-related costs)	[22]
Groups	**Subgroups**	**Factors**	**References**
Time-Related Factors	Owner-Related Factors	Existence of a database for similar projects (historical data)	[10, 12, 24]
		Owner's policy in evaluating bids and awarding	[1]
		Owner's payment policy (such as Initial payment and invoices)	[1]
		Selecting the appropriate type of lining	[1]
		Design drawings for irrigation canals and their modifications	[9 ,1]
		Time estimating team's experience	[1, 12]
		The time limit for project to apply and calculate price differences equation	[34]
		Methods used for time estimation such as (Critical Path Method (CPM), ….)	[11]
		Scheduling software such as (MS Project, Primavera, ...)	[11, 12]
	Contractor-Related Factors	Financing sources for irrigation canals lining projects	[9]
		Soil type and investigations such as (boreholes, tests, ...)	[1, 9, 24, 25]
		Efficiency of irrigation canals' drying systems used	[1, 12]
		Availability of materials for irrigation canals lining works	[1, 9]
		Availability of skilled labor participating in irrigation canals lining projects	[1, 9]
		Delay in receiving irrigation canals' sites, and thus delay in executing irrigation canals lining works	[9]
		Delays in obtaining the required approvals, licenses, and permits	[9]
		Efficiency of subcontractors involved in the execution of irrigation canals lining works	[9, 12]
	Project-Related Factors	The geographical location of the irrigation canals required to line	[1, 11, 12, 25]
		Size of irrigation canals lining projects in terms of (canal lengths in kilometers, and number of canals) in one project or operation	[1, 10]

		Efficiency of irrigation canals' surveying works that need to be lined	[1, 24]
		Methods of executing lining's construction works for irrigation canals	[1, 11]
		Water turn rotation in irrigation canals (on and off turns)	[1]
		Efficiency of site management for canals required to be lined	[11, 24, 25]
		Equipment efficiency used in the execution of irrigation canals' lining works	[1, 12, 24]
		Equipment age used in the execution of irrigation canals' lining works	[24]
		Equipment drivers' efficiency used in the execution of irrigation canals' lining works	[1, 24, 25]
		Labor productivity participating in irrigation canals lining projects	[1]
		Productivity of plain concrete ready-mix used for pouring beds, side slopes, and feet for irrigation canals that required lining them	[1]
		Productivity of plain concrete mixer in site used for pouring beds, side slopes, and feet for irrigation canals that required lining them	[1]
		The extent of the efficiency of communication between the parties concerned with irrigation canal lining projects is represented by (the Ministry of Water Resources and Irrigation, contractors, stakeholders, ...)	[1, 12]
Groups	**Subgroups**	**Factors**	**References**
Risk-Related Factors	Technical Risk-Related Factors	Lack of appropriate engineering design for the irrigation canals to be lined	[13, 19, 20, 27, 29]
		Use of low-quality or inappropriate materials in executing irrigation canals' lining works	[14, 27]
		Selecting inappropriate lining methods for the irrigation canals to be lined	[7, 14]
		Lack of sufficiently skilled and trained labor	[20, 27, 29]
		Inadequate soil conditions for the irrigation canals to be lined	[13, 20, 27]
		Non-compliance with local and international technical standards and directives	[13, 29]
	Environmental Risk-Related Factors	Contamination of soil and water as a result of the use of harmful or inappropriate lining materials	[13, 14, 16]
		Climate changes such as (High temperatures, and lack of rainfall)	[13-15, 19, 20, 27, 29]
		High seepage from the bed, and side slopes of irrigation canals that need to be lined	[7, 14, 17]
		Low water and soil quality of irrigation canals to be lined	[13, 14, 18]
		Effects of irrigation canals lining projects on plant and animal life	[14, 19]
		Sound and vibration effects during execution and maintenance of irrigation canal lining projects on local residents and animals	[14, 16]
		Effects of agricultural and sanitary wastewater drainage in lined irrigation canals on water quality and lining	[18]
	Financial Risk-Related Factors	Inaccurate project cost estimate	[15, 27]
		High costs of materials and equipment needed for irrigation canals lining works	[13, 27]
		Increased shipping and supply costs for materials and equipment needed for irrigation canals' lining works	[13]
		Delay in the project schedule	[13, 15, 19, 27]
		Changes in the prices of materials and services needed for irrigation canals' lining works, and costs inflation for these projects	[19, 20, 27]

		Lack of adequate sources of funding for irrigation canals' lining projects	[15, 19, 20, 29]
		Changes in required financial and tax policies and legislation	[16, 19, 20, 29]
	Operational Risk-Related Factors	Lack of skills and expertise necessary to study, execute, and maintain irrigation canals' lining projects	[13, 15, 29]
		Inefficient implementation of lining operations	[13, 19, 29]
		Problems in project management such as (inadequate planning - inefficient allocation of resources, and lack of appropriate monitoring and evaluation mechanisms)	[13, 19, 20, 27, 29]
		Incompatibility in use of appropriate technology	[15, 19, 29]
		Neglecting maintenance of lined irrigation canals	[13, 16]
		Unexpected natural effects such as (floods or earthquakes)	[19, 20, 27, 29]
	Legal and Regulatory-Related Factors	Non-compliance with local legislation such as (environmental and water resources laws, required licenses and permits)	[14, 15, 27]
		Project interruption or imposition of legal fines	[14]
		Land restrictions and property rights	[19]
		Availability of access and use rights and financial compensation for original owners	[16]
		Regulatory and environmental obligations	[16]
		Cooperation and communication with relevant regulatory authorities such as the Ministry of Water Resources and Irrigation, local authorities and environmental bodies	[14, 15]
		Coordinate with other participants such as farmers and local residents to deal with entitlement issues and potential problems	[14, 16]
		Other legal risks related to contracts, damages, and potential disputes	[13, 15, 29]
	Social Risk-Related Factors	Impact on residents of neighboring areas and communities (The original land owners may be compensated)	[13, 14, 16]
		Changes in water quality and negative impacts on surrounding aquatic ecosystems	[13, 14]
		Continuous communication and provision of appropriate information and awareness	[15, 20]
		Create local jobs opportunities and improve the economic conditions of the region	[14, 16]

4.1 Questionnaire design

The questionnaire was designed for EICLPs within the national project for rehabilitating irrigation canals in Egypt by utilizing a common lining type of rubble stone with a determined thickness topped by a layer of plain concrete with a specified thickness. This framework is implemented in a wide network of irrigation canals most of them located in villages throughout the Egyptian countryside. It includes three parts: cost, time, and risk-related factors. The goal is to identify key cost, time, and risk-related factors that influence the estimation of these projects' contingency. 150 respondents rated each factor based on their experience, using a scale of 1 to 10 to assess frequency and impact as shown in **Table 3**.

Table 3. Questionnaire of cost, time, and risk-related factors affecting the estimation of EICLPs' contingency.

Group Name	Code	Cost-Related Factors	Frequency	Impact (1-10)
Design-Related Factors	CD1	Type of irrigation canals' cross-section such as (Trapezoidal, Rectangle, ...)		
	CD2	Area of irrigation canals' cross-section [Hydraulic cross-sectional area] (m^2)		
	CD3	Type of irrigation canals' lining		

	CD4	Irrigation canals' lining length (m run)		
	CD5	Area of irrigation canals' cross-section with rubble stone lining (m^2)		
	CD6	Area of irrigation canals' cross-section with plain concrete lining (m^2)		
Construction-Related Factors	CC1	Methods of irrigation canals' dewatering, and drying such as (Pumps, WPS, ….)		
	CC2	Appropriate means used for aquatic weed cleansing		
	CC3	Irrigation canals' survey works such as (reshaping, levels' adjustments, ...)		
	CC4	Excavation works to adjust irrigation canals' cross-section dimensions and to reach the required levels		
	CC5	Backfill works to adjust irrigation canals' cross-section dimensions and to reach the required levels		
	CC6	Construction works of rubble stones for irrigation canals' beds, side slopes, and feet		
	CC7	Pouring works of plain concrete mortar consisting of (gravel, sand, cement, and water) for irrigation canals' beds, side		
	CC8	Use of additive materials in the concrete mixture such as fiber needed for irrigation canals' lining works		
	CC9	Use ready-mix plain concrete from the central mixing station for pouring irrigation canals' beds, side slopes, and feet		
	CC10	Use plain concrete mixed on-site to pour irrigation canals' beds, side slopes, and feet		
	CC11	Using chemicals to treat the surface of concrete slabs for irrigation canals' beds, side slopes, and feet		
	CC12	Use insulating materials such as (Bitumen, ….) necessary for moisture insulation work for concrete slabs and filling joints		
	CC13	Use filter pipes with the required dimensions (diameter, and length) needed for irrigation canals' lining works		
Overheads-Related Factors	CO1	Administrative expenses such as (office rent, utilities, insurance, salaries, and professional fees)		
	CO2	Advertising expenses such as (billboards, online ads, flyers, mailers, and business cards)		
	CO3	Vehicle expenses as (leased vehicles, owned vehicles, fuel, maintenance, and repairs)		
	CO4	Bonding and insurance expenses as (bonding premiums, general permits, and insurance premiums)		
	CO5	Equipment expenses as (leased equipment, owned equipment, and maintenance and repairs)		
	CO6	Labor burden as (payroll taxes, workers' compensation insurance, and other labor-related costs)		
Group Name	**Code**	**Time-Related Factors**	**Frequency**	**Impact (1-10)**
Owner-Related Factors	TO1	Existence of a database for similar projects (historical data)		
	TO2	Owner's policy in evaluating bids and awarding		
	TO3	Owner's payment policy (such as Initial payment and invoices)		
	TO4	Selecting the appropriate type of lining		
	TO5	Design drawings for irrigation canals and their modifications		
	TO6	Time estimating team's experience		
	TO7	The time limit for project to apply and calculate price differences equation		
	TO8	Methods used for time estimation such as (Critical Path Method (CPM), ….)		
	TO9	Scheduling software such as (MS Project, Primavera, ...)		
Contractor-Related	TC1	Financing sources for irrigation canals lining projects		

Factors	TC2	Soil type and investigations such as (boreholes, tests, ...)		
	TC3	Efficiency of irrigation canals' drying systems used		
	TC4	Availability of materials for irrigation canals lining works		
	TC5	Availability of skilled labor participating in irrigation canals lining projects		
	TC6	Delay in receiving irrigation canals' sites, and thus delay in executing irrigation canals lining works		
	TC7	Delays in obtaining the required approvals, licenses, and		
	TC8	Efficiency of subcontractors involved in the execution of irrigation canals lining works		
Project-Related Factors	TP1	The geographical location of the irrigation canals required to		
	TP2	Size of irrigation canals lining projects in terms of (canal lengths in kilometers, and number of canals) in one project or		
	TP3	Efficiency of irrigation canals' surveying works that need to be lined		
	TP4	Methods of executing lining's construction works for irrigation canals		
	TP5	Water turn rotation in irrigation canals (on and off turns)		
	TP6	Efficiency of site management for canals required to be lined		
	TP7	Equipment efficiency used in the execution of irrigation canals' lining works		
	TP8	Equipment age used in the execution of irrigation canals' lining works		
	TP9	Equipment drivers' efficiency used in the execution of irrigation canals' lining works		
	TP10	Labor productivity participating in irrigation canals lining		
	TP11	Productivity of plain concrete ready-mix used for pouring beds, side slopes, and feet for irrigation canals that required lining		
	TP12	Productivity of plain concrete mixer in site used for pouring beds, side slopes, and feet for irrigation canals that required		
	TP13	The extent of the efficiency of communication between the parties concerned with irrigation canal lining projects is represented by (the Ministry of Water Resources and Irrigation, contractors, stakeholders, ...)		
Group Name	**Code**	**Risk-Related Factors**	**Frequency**	**Impact (1-10)**
Technical Risk-Related Factors	TR1	Lack of appropriate engineering design for the irrigation canals to be lined		
	TR2	Use of low-quality or inappropriate materials in executing irrigation canals' lining works		
	TR3	Selecting inappropriate lining methods for the irrigation canals to be lined		
	TR4	Lack of sufficiently skilled and trained labor		
	TR5	Inadequate soil conditions for the irrigation canals to be lined		
	TR6	Non-compliance with local and international technical standards and directives		
Environmental Risk-Related Factors	ER1	Contamination of soil and water as a result of the use of harmful or inappropriate lining materials		
	ER2	Climate changes such as (High temperatures, and lack of		
	ER3	High seepage from the bed, and side slopes of irrigation canals that need to be lined		
	ER4	Low water and soil quality of irrigation canals to be lined		

	ER5	Effects of irrigation canals lining projects on plant and animal life		
	ER6	Sound and vibration effects during execution and maintenance of irrigation canal lining projects on local residents and animals		
	ER7	Effects of agricultural and sanitary wastewater drainage in lined irrigation canals on water quality and lining		
Financial Risk-Related Factors	FR1	Inaccurate project cost estimate		
	FR2	High costs of materials and equipment needed for irrigation canals lining works		
	FR3	Increased shipping and supply costs for materials and equipment needed for irrigation canals' lining works		
	FR4	Delay in the project schedule		
	FR5	Changes in the prices of materials and services needed for irrigation canals' lining works, and costs inflation for these projects		
	FR6	Lack of adequate sources of funding for irrigation canals' lining projects		
	FR7	Changes in required financial and tax policies and legislation		
Operational Risk-Related Factors	OR1	Lack of skills and expertise necessary to study, execute, and maintain irrigation canals' lining projects		
	OR2	Inefficient implementation of lining operations		
	OR3	Problems in project management such as (inadequate planning - inefficient allocation of resources, and lack of appropriate monitoring and evaluation mechanisms)		
	OR4	Incompatibility in use of appropriate technology		
	OR5	Neglecting maintenance of lined irrigation canals		
	OR6	Unexpected natural effects such as (floods or earthquakes)		
Legal and Regulatory-Related Factors	LR1	Non-compliance with local legislation such as (environmental and water resources laws, required licenses and permits)		
	LR2	Project interruption or imposition of legal fines		
	LR3	Land restrictions and property rights		
	LR4	Availability of access and use rights and financial compensation for original owners		
	LR5	Regulatory and environmental obligations		
	LR6	Cooperation and communication with relevant regulatory authorities such as the Ministry of Water Resources and Irrigation, local authorities and environmental bodies		
	LR7	Coordinate with other participants such as farmers and local residents to deal with entitlement issues and potential problems		
	LR8	Other legal risks related to contracts, damages, and potential disputes		
Social Risk-Related Factors	SR1	Impact on residents of neighboring areas and communities (The original land owners may be compensated)		
	SR2	Changes in water quality and negative impacts on surrounding aquatic ecosystems		
	SR3	Continuous communication and provision of appropriate information and awareness		
	SR4	Create local jobs opportunities and improve the economic conditions of the region		

4.2 Questionnaire analysis

4.2.1 Required sample size determination

We utilized the following formula as [35] that was developed by Bartlet, Kotrlik et al. (2001) to compute the sample size required for an infinite population:

$$\boldsymbol{n} = \boldsymbol{K}^2 * \boldsymbol{P} * (\mathbf{1} - \boldsymbol{P})/\boldsymbol{E}^2 \quad \textbf{(1)}$$

Where n represents the necessary sample size for an infinite population, the K-value is 1.645 at a confidence level of 90%, P is the population proportion, and E is the acceptable margin of error = 10% for a 90% confidence level. The value of P ranges from 0 to 1.0. By substituting these values into Equation **(1)** to determine the needed sample size (with the crucial value of P being 0.5), n was calculated to be 68 as the minimum value.

This questionnaire was designed for the EICLPs' main stakeholders. It was distributed online and through interviews with professionals working on ICLPs in Egypt with experience ranging from less than 5 to more than 15 years as shown in **Table 4**. A total of 150 questionnaires were gathered from four groups (department heads, project managers, technical office engineers, and site engineers), of these, 76 represented the Owner's point of view, 32 represented the Consultant's point of view, and 42 represented the Contractor's point of view involved in these projects as shown in **Figure 3**, and **Figure 4**.

Table 4 Details of respondents' classifications and expertise.

Experience Years		Less than	Between (5 – 10)	Between (11 – 15)	More	Total
The entity	**The state of Position**	**5 years**	**years**	**years**	**than 15**	
Owner	Department head	0	1	1	7	**9**
	Project manager	1	1	0	8	**10**
	Technical office	4	8	1	2	**15**
	Site engineer	18	20	2	2	**42**
	Total	**23**	**30**	**4**	**19**	**76**
Consultant	Department head	0	1	0	2	**3**
	Project manager	1	1	4	6	**12**
	Technical office	2	0	0	0	**2**
	Site engineer	8	7	0	0	**15**
	Total	**11**	**9**	**4**	**8**	**32**
Contractor	Department head	0	0	2	2	**4**
	Project manager	1	10	1	5	**17**
	Technical office	3	2	0	1	**6**
	Site engineer	12	3	0	0	**15**
	Total	**16**	**15**	**3**	**8**	**42**
	Total	**50**	**54**	**11**	**35**	**150**

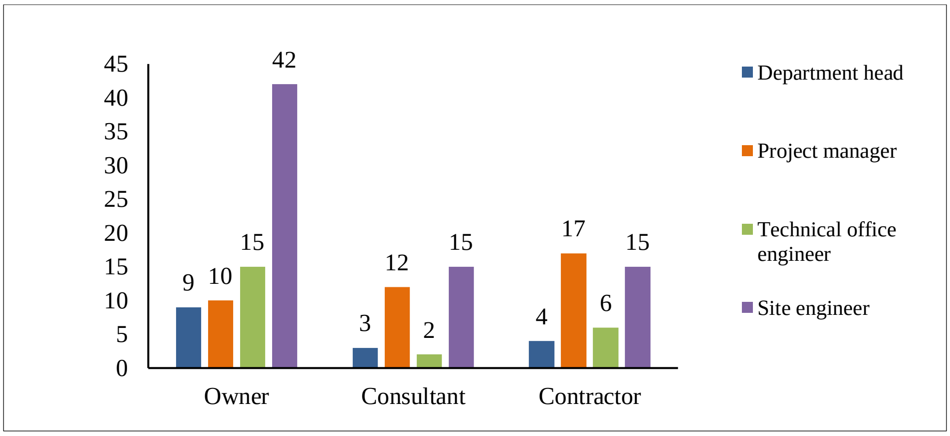

Figure 3. Number of respondents' classifications based on their state of position.

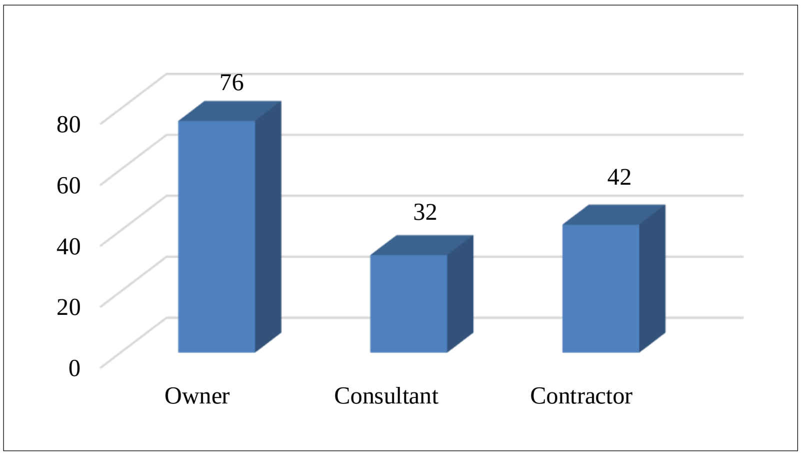

Figure 4. Number of respondents' classifications based on their entity.

The questionnaire's reliability was tested by using Statistical Package for Social SPSS software Ver. 26 [36]. The Cronbach's Alpha test was used to check the reliability of this questionnaire. According to [37] scores were evaluated for stability and consistency on a scale from 0 to 1. The alpha coefficient value was 0.802, and Cronbach's alpha values for this questionnaire exceeded 0.7, indicating acceptable internal consistency, which signifies that the questionnaire is reliable.

4.2.2 Determination of indices

As mentioned above, the purpose of the questionnaire was to rate two fundamental metrics on a scale of 1 to 10. The first scale indicated how frequently each component was related to cost, time, and risk affecting the estimation of EICLPs' contingency, while the second scale stated the impact of these factors on the estimation of these projects' contingency. After computing the first two metrics, the next three indices are calculated based on the RII method: the Frequency Index (FI) represented by Equation **(2)**, the Impact Index (II) represented by Equation **(3)**, and the Final Index (F.I) represented by Equation **(4)** which is the product of the two previous indices and is used to evaluate and identify the most important factors [35].

$$\boldsymbol{Frequency\ Index\ (FI)} = \frac{\sum_{i=1}^{n} \boldsymbol{F_i}}{\boldsymbol{a \times n}} \qquad \textbf{(2)}$$

$$\boldsymbol{Impact\ Index\ (II)} = \frac{\sum_{i=1}^{n} \boldsymbol{I_i}}{\boldsymbol{a \times n}} \qquad \textbf{(3)}$$

where

$\sum_{i=1}^{n} F_i$ total frequency scores of each factor from the respondents
$\sum_{i=1}^{n} I_i$ total impact scores of each factor from the respondents
the scoring ranges from 1 to 10

n the total number of participating respondents is 150
a the upper scale for each measure equals 10

$$\boldsymbol{Final\ Index\ (F.I)} = \boldsymbol{FI \times II} \qquad \textbf{(4)}$$

To determine factors related to cost, time, and risk that have the most importance affecting the estimation of EICLPs' contingency the relative weight is estimated using the final index, which is the product of the frequency index and the impact index with a value of 100%, and the remaining values are assigned based on this calculation. The factors that have a relative weight of over 70% are the most important [35].

4.2.3 The most important factors affecting the estimation of EICLPs' contingency

Table 5 shows that we determined 20 out of 93 had the most important cost, time, and risk-related factors impacting the estimation of EICLPs' contingency, and their relative weight exceeds 70%. **Table 6** shows that a condensed list of main groups pre- and post-ranking that affected the estimation of EICLPs' contingency that included the total number of cost-related factors dropped from 25 to only 8, the total number of time-related factors dropped from 30 to only 7, and the total number of risk-related factors dropped from 38 to only 5. **Figure 5** shows the total number of factors in the main groups' pre- and post-questionnaire ranking. Additionally, **Figure 6** shows the weight of each main group post-ranking and questionnaire findings. **Figure 7** depicts the 20 most influential factors associated with project cost, time, and risk affecting the estimation of EICLPs' contingency and their groups and subgroups.

Table 5. The 20 most important factors affecting the estimation of EICLPs' contingency.

Code	Name of factor	Group	Sub-Group	Frequency Index (FI)	Impact Index (II)	Final Index (F.I)	Relative Weight	Rank
CC7	Pouring works of plain concrete mortar consisting of (gravel, sand, cement, and water) for irrigation canals' beds, side slopes, and feet.	Cost-Related Factors	Construction-Related Factors	0.3320	0.3433	0.1140	100.00%	1
TP5	Water turn rotation in irrigation canals (on and off turns)	Time-Related Factors	Project-Related Factors	0.3333	0.3373	0.1124	98.60%	2
TP10	Labor productivity participating in irrigation canals lining projects	Time-Related Factors	Project-Related Factors	0.3173	0.34 13	0.1083	95.00%	3
CD2	Area of irrigation canals' cross-section [Hydraulic cross-sectional area] (m^2)	Cost-Related Factors	Design-Related Factors	0.3267	0.3260	0.1065	93.42%	4
TO3	Owner's payment policy (such as Initial payment and invoices)	Time-Related Factors	Owner-Related Factors	0.3240	0.3280	0.1063	93.25%	5
CD6	Area of irrigation canals cross-section with plain concrete lining (m^2)	Cost-Related Factors	Design-Related Factors	0.3200	0.3273	0.1047	91.84%	6
CD4	Irrigation canals lining length (m run)	Cost-Related Factors	Design-Related Factors	0.3147	0.3113	0.0980	85.96%	7
FR1	Inaccurate project cost estimate	Risk-Related Factors	Financial Risk-Related Factors	0.3007	0.3207	0.0964	84.56%	8
CO5	Equipment expenses as (leased equipment, owned equipment, and maintenance and repairs)	Cost-Related Factors	Overheads-Related Factors	0.3187	0.3013	0.0960	84.21%	9
TP3	Efficiency of irrigation canals' surveying works that need to be lined	Time-Related Factors	Project-Related Factors	0.3180	0.2993	0.0952	83.51%	10
TP12	Productivity of plain concrete mixer in site used for pouring beds, side slopes, and feet for irrigation canals that required lining them	Time-Related Factors	Project-Related Factors	0.3060	0.3087	0.0945	82.89%	11
CC6	Construction works of rubble stones for irrigation canals' beds, side slopes, and feet.	Cost-Related Factors	Construction-Related Factors	0.3167	0.2967	0.0940	82.46%	12
TP7	Equipment efficiency used in the execution of irrigation canals lining works	Time-Related Factors	Project-Related Factors	0.3067	0.3053	0.0936	82.11%	13
TR4	Lack of sufficiently skilled and trained labor	Risk-Related Factors	Technical Risk-Related Factors	0.3000	0.3020	0.0906	79.47%	14
CD5	Area of irrigation canals cross-section with rubble stone lining (m^2)	Cost-Related Factors	Design-Related Factors	0.2960	0.3033	0.0898	78.77%	15

FR2	High costs of materials and equipment needed for irrigation canals lining works	Risk-Related Factors	Financial Risk-Related Factors	0.2727	0.3247	0.0885	77.63%	16
CC3	Irrigation canals survey works such as (reshaping, levels' adjustments, ...)	Cost-Related Factors	Construction-Related Factors	0.3440	0.2500	0.0860	75.44%	17
TC1	Financing sources for irrigation canals lining projects	Time-Related Factors	Contractor-Related Factors	0.2720	0.3080	0.0838	73.51%	18
ER5	Effects of irrigation canals lining projects on plant and animal life	Risk-Related Factors	Environmental Risk-Related Factors	0.2840	0.2933	0.0833	73.07%	19
SR4	Create local jobs opportunities and improve the economic conditions of the region	Risk-Related Factors	Social Risk-Related Factors	0.2760	0.2920	0.0806	70.70%	20

Table 6. The main groups affecting the estimation of EICLPs' contingency pre- and post-findings of ranking from the questionnaire.

Group No.	Group Name	Factors in each group pre-		Factors in each group post-	
		Sum	Weight	Sum	Weight
1	Cost-Related Factors	25	26.88 %	8	40 %
2	Time-Related Factors	30	32.26 %	7	35 %
3	Risk-Related Factors	38	40.86 %	5	25 %
Total		**93**	**100.00%**	**20**	**100.00%**

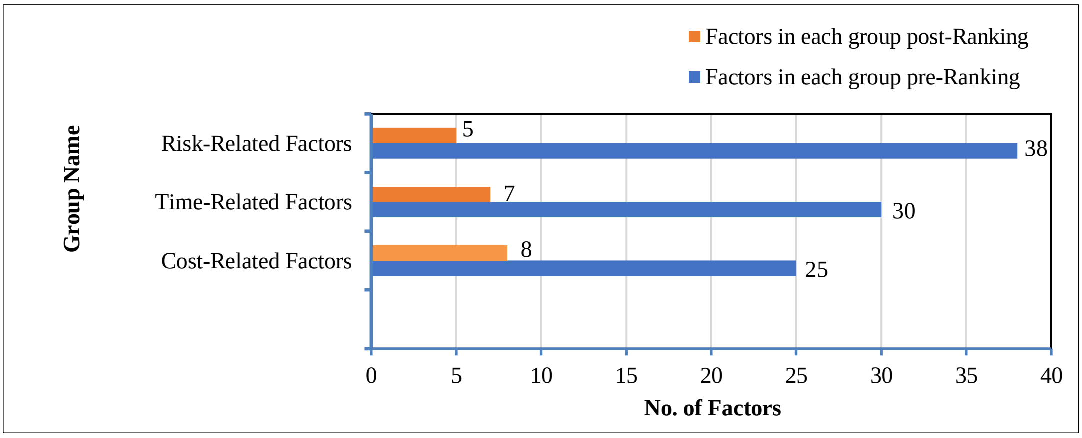

Figure 5. Total number of factors in the main groups' pre- and post-questionnaire ranking.

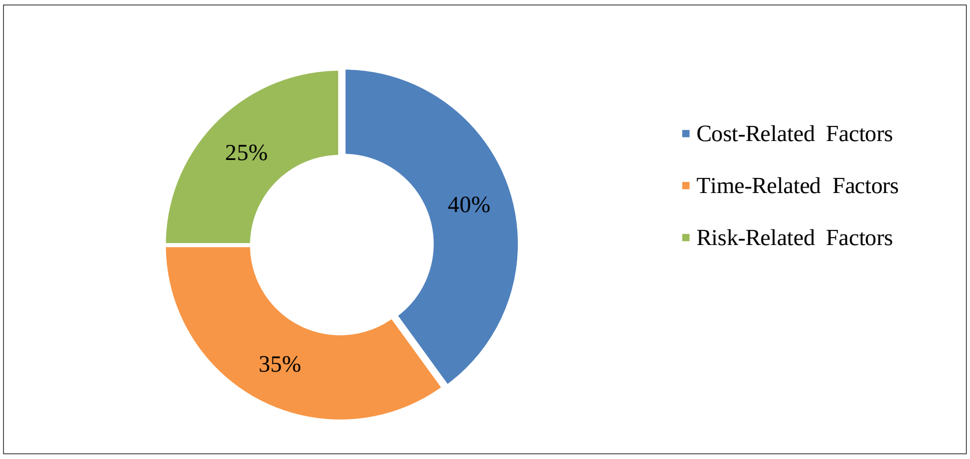

Figure 6. The weight of each main group post-analyzing the questionnaire responses and ranking.

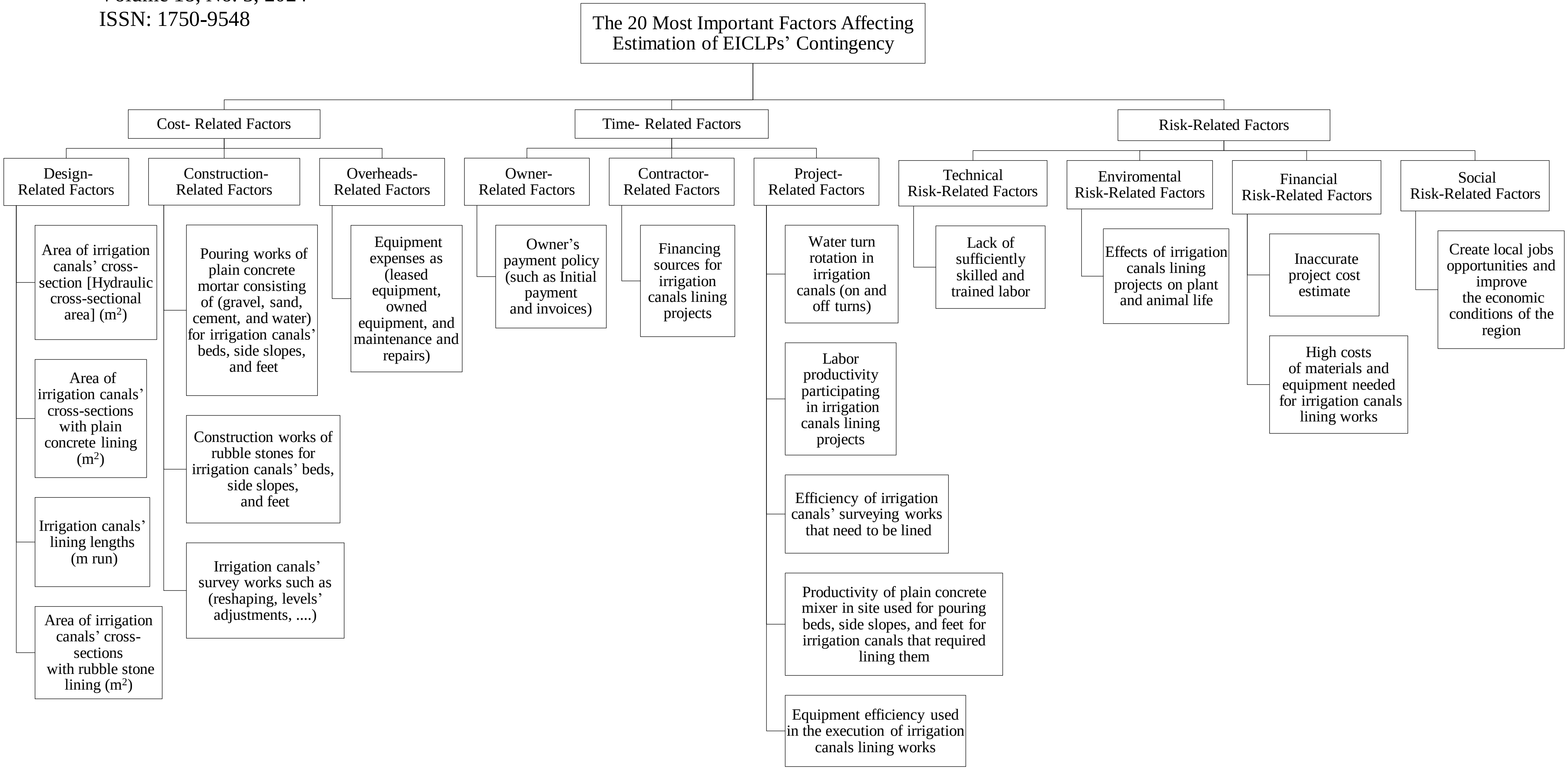

Figure 7. Hierarchy of 20 most important factors related to cost, time, and risk groups and subgroups.

5. Conclusions

This study aimed to identify and prioritize the most significant factors related to cost, time, and risk that influence the estimation of EICLPs' contingency within the national project for rehabilitating irrigation canals in Egypt. In this research, a questionnaire with three parts was conducted by 150 participants from Egyptian experts and construction companies in this field to evaluate these factors. It focused on a common lining type of rubble stone with a specific thickness, covered by a layer of plain concrete with a set thickness used in these projects. Each factor was identified and grouped for each part into 25 factors related to project cost were categorized into 3 groups (6 Design, 13 Construction, and 6 Overheads)-related factors; 30 factors related to project time were categorized into 3 groups (9 Owner, 8 Contractor, and 13 Project)-related factors; and 38 factors related to risk categorized into 6 groups (6 Technical, 7 Environmental, 7 Financial, 6 Operational, 8 Legal and regulatory, and 4 Social) risk-related factors. In total, 93 factors were gathered from the literature review and a brainstorming session to reduce the number of those factors and focus on the most important factors that influence estimation of these projects in the first stage and the second stage. In the third stage, a questionnaire including the three parts was created based on the significant factors identified by a total of 150 respondents. As a result, the 20 most important factors 8 factors related to project cost, 7 factors related to project time, and 5 factors related to risk affecting the estimation of ICLPs' contingency to achieve success of completing irrigation canal lining projects have been identified. This study did not account for the relative weights among categories, subcategories, and factors, and investigating alternative methods for estimation, such as using artificial intelligence for modeling, to achieve even greater accuracy. Moreover, incorporating digital construction technologies like advanced data analytics which could be explored in future research.

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