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Framework for Integrated Sustainability, Reliability and Resilience Risk Assessment in Water Supply Systems

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Framework for Integrated Sustainability, Reliability and Resilience Risk Assessment in Water Supply Systems

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***Abstract*- It is worth noting that there are overload rates in the water plants, and that there are some areas that suffer from lack of access to water due to insufficient disposal or lack of pressure. However, this research offers a framework for water supply system (WSS) that deliver drinkable water to various regions in Cairo. The scope of work consisted of three main parts, at the first part, the common risks in greater Cairo water supply system is defined, and these types of risks are categorized based on its effect on the sustainability, reliability and resilience. While, at the second part, Combination of Analytic Hierarchy Process (AHP) method and Generic Risk Matrix (GRM) method is developed to evaluate the risks. And the third part, risk response alternative strategies are suggested to supply decision support makers on dealing with the WSS risks and evaluated using (RII) analysis. The application of this frame work will increase the efficiency of Mostorud Water Supply Systems (WSS). Additionally, the research provided a base for water utilities to assess the risks and achieve desirable level of service.**

***Keywords*- Analytic Hierarchy Process, Generic Risk Matrix, Multi Criteria Analysis, Water Supply System, Risk Evaluation, Relative Important Index.**

I. Introduction

Egypt's primary source of potable water, the River Nile also collects drainage and wastewater from a variety of activities. The World Health Organization (WHO) has placed particular emphasis on the necessity of a comprehensive risk management strategy for integrating a safe water supply system.

It is known that the Greater Cairo Water Company (CWC) is the largest producer of pure potable water in Egypt. The company has continued throughout its decades of history to produce and distribute water to meet the growing needs of consumers. The efficiency of the provided water service is affected by the risk events and numerous challenges that the water supply systems are subject to. For instance, twenty five percentage of the total water production is lost, Thirty percent of the water network's length is over than thirty years old, some zones have low pressure, it is difficult to easily isolate those zones due to buried water valves, and many WTPs operate inefficiently due to a lack of disinfection and filtration stages [1].

Multi Criteria Analysis (MCA) is a framework that decision-makers can use to evaluate a small number of possibilities in accordance with various features of each program in order to select the best option. Over time, several MCA methods have been developed, each of them with peculiar strengths and weaknesses [2].

This research includes the development of a framework that supposed to evaluate risks of the water supply system (WSS) at all levels of hierarchy. The Analytic Hierarchy Process (AHP) approach of complicated multi attribute decision-making analysis is utilized in this research to assign weights for WSS risks using pair wise comparisons and the perspectives of experts in developing a priority range [3]. Generic Risk Matrix (GRM) method is used to evaluate the risks by identifying the possibility of incident, the impact and risk factors [4].

This research provides a framework that should control risk mitigation and responses for the sustainability, reliability, and resilience of the water delivery system at all hierarchical levels. Sustainability is described as the degree to which the system conserves level of service over the long-term and achieves social, economic and environmental goals [5], Reliability is to provide an adequate level of service with a low probability of failure under both normal and abnormal situations [6]; However, resilience of a system can be measured as the point to which the system decreases the amount of service failure duration and magnitude when it is subject to unusual conditions [7].

II. Study Area

To meet the water needs of Cairo Governorate there are 13 water treatment plants (WTPs) which produce 6,000,000 m^3 of drinkable water per day by the CWC. These WTPs depends on the River Nile and the canals of the river to attain the raw water. The study area includes one of thewater treatment plants along Ismailia Canal, Mostorud, which has Latitude of 30° 09′ 55″ and Longitude 31° 17′ 36″[8] as shown in Figure 1.

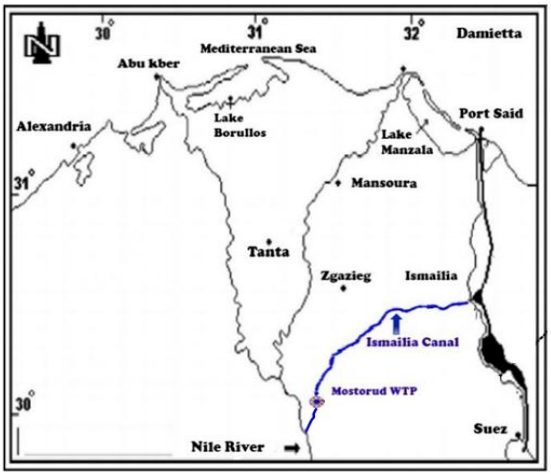

Figure 1. Mostorud WTP geographic location

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This WTP depends on Ismailia canal as a water source, additionally; it produces 950,000 m^3/day, so it is taken into account as a principal water source for many Cairo governorate' Northern and Eastern districts.

The Ismailia Canal, which is the main River Nile downstream, extends for about one hundred twenty five kilometer eastward from the River Nile at Shubra and reaches the Suez Canal at Ismailia. Many Egyptians rely on it as their primary source of potable water; however, the water there contains all the contaminants that flow into the River Nile [9].

Mostorud WTP relies on the delivery of water in a traditional way, which consists of three stages, starting from the water intake source then treatment plants and water distribution networks. The WSS is typically subject to a variety of risks along these three stages.

III. METHODOLOGY

Figure 2 shows the methodology in this research.First, the risks at source, treatment and distribution stages are identified, then these risks are categorized based on their effect on the indicators: reliability, resilience and sustainability.Then, we use an AHP analysis in risk rating (Weight) and GRM analysis to get a score of risks and calculate weighted score of risks. Finally, an alternative strategies are suggested and evaluated by RII analysis.

A. Identification of Risks and Categorization

Identification of risks in this research is done by brainstorming and interviewing stakeholders (experts) to collect all possible risks that may happen from mentioned experts. Risks are needed to be categorized depend on their effect on sustainability, reliability and resilience. The essential difference between these indicators on which this classification is based on that sustainability of the WSS is to maximize social, economic and environmental goals [10], reliability of the WSS is its possibility of successful process [11] and resilience is to attain least magnitude and period of failure on the WSS.

B. Analytic Hierarchy Process (AHP)

AHP is a multi criteria analysis method which used to manage and analyze complicated judgments referring to mathematics and sensibility. This research uses the AHP analysis to get a weight of various risks in the WSS. The steps for AHP method are as follows [12]:

I. Create a hierarchical form divided to three levels. First level is the objective, the second is the criteria (standards), and the third level is the attribute levels.

II. Create the comparison matrix $A_{n\times n}$ (which n represents the number of alternatives) and assign each part a_{ij} with the nine-scale technique, which is defined in Table 1.

III. Calculate r_i (the significance ranking indicator) as Eq. 1:

$$r_i = \sum_{j=1}^{n} a_{ij} \qquad (i = 1,2, \dots \dots, n) \qquad (1)$$

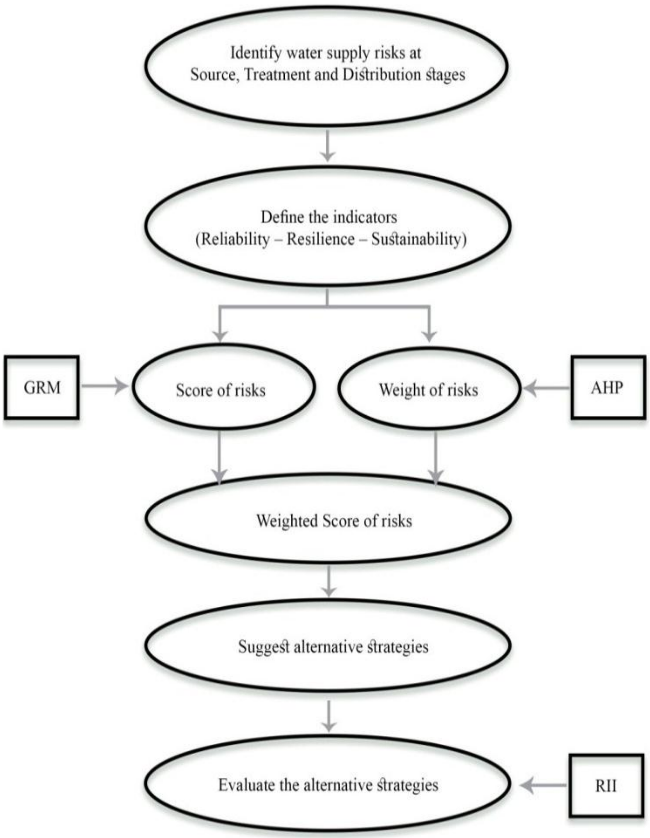

Figure 2. Research process flowchart

Table 1. Nine-scale technique assignment concept

Intensity of significance	Definition	
1	Equivalent Importance	The objective is equally enhanced by the two activities.
2	Weak or Slight	
3	Moderate Importance	One activity is slightly preferred over another by experience and judgment.
4	Moderate Plus	
5	Strong Importance	One activity is greatly preferred over another by experience and judgment.
6	Strong Plus	
7	Very Strong	Strongly favoring one activity over another
8	Very, very Strong	
9	Extreme Importance	The strongest potential order of affirmation can be found in the data supporting one activity over another.

IV. Analyze the decision matrix $B_{n\times n}$, and assign each matrix part b_{ij} as the following way:

$$b_{ij} = \begin{cases} \dfrac{r_i - r_j}{r_{max} - r_{min}} \times (k_m - 1) + 1 & r_i \geq r_j \\ \left[\dfrac{|r_i - r_j|}{r_{max} - r_{min}} \times (k_m - 1) + 1\right]^{-1} & r_i < r_j \end{cases}$$

$$(i, j = 1,2, \dots \dots, n) \qquad (2)$$

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$$(i, j = 1,2, \dots \dots, n) \qquad (2)$$

where r_j is the ranking indicator of indicator j, r_{max} is the maximum amount of the ranking indicator, and r_{min} is the minimum amount of the ranking indicator. K_m is defined as Eq. 3:

$$k_m = \frac{\max(r_i)}{\min(r_i)} (i = 1,2, \dots \dots, n) (3)$$

V. Create the optimum transferal matrix $C_{n\times n}$, and each matrix part is C_{ij}, as Eq. 4:

$$C_{ij} = \frac{1}{n}\sum_{k=1}^{n}\left(lg\frac{b_{ik}}{b_{jk}}\right)(i, j = 1,2, \dots \dots, n) \qquad (4)$$

VI. Create the quasi-optimum consistent matrix $\mathrm{D}_{n\times n}$, which every matrix part is d_{ij} as Eq. 5:

$$d_{ij} = 10^{c_{ij}}(i, j = 1,2, \dots \dots, n) \qquad (5)$$

VII. Calculate the eigenvector of the maximum eigen value for matrix $\mathrm{D}_{n\times n}$. Later, the weight ω_i of a piece factor can be gotten after standardization. The weight vector that is combined of the weight of every factor is as Eq. 6:

$$\omega = (\omega_1, \omega_2, \dots, \omega_n)^T \qquad (6)$$

VIII. Calculate λ_{max} (the highest eigen value of the matrix) as Eq. 7:

$$\lambda_{max} = \sum_{j=1}^{n}\frac{(S.\omega)_j}{m.\omega_j}(j = 1,2, \dots \dots, n) \qquad (7)$$

where S means matrix of pairwise comparison and ω is the eigenvector of the matrix.

IX: Calculate consistency index (CI) as Eq. 8:

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad (8)$$

X. Calculate Consistency ratio CR is calculated as Eq. 9:

$$CR = \frac{CI}{RI} (9)$$

where RI is determined by averaging the CI values gathered from a Saaty pair-wise comparison matrix random model CIs as shown in Table 2.

C. Generic Risk Matrix (GRM)

Generic Risk Matrix (GRM) method is used to evaluate the risks by identifying the possibility of incident, the impact and risk factors. In this study, for the development of GRM, appropriate impact and probability values were selected.

Table 2. RI values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 3. Impact, probability and risk score

Probability	Risk Score				
0.90	0.05	0.09	0.18	0.36	0.72
0.70	0.04	0.07	0.14	0.28	0.56
0.50	0.03	0.05	0.10	0.20	0.40
0.30	0.02	0.03	0.06	0.12	0.24
0.10	0.01	0.01	0.02	0.04	0.08
Impact	0.05	0.10	0.20	040	0.80

Table 4. Importance level categorization

RII	0:0.20	0.21:0.40	0.41:0.60	0.61:0.80	0.81:1.00
Importance Level	Low	Medium Low	Medium	Medium high	High

At the same time, the risk score is estimated as the multiply of probability and impact value. Then the risk category is determined (high, medium and low). Table 3 shows the impact, probability and risk score category.

The upper right cells of the matrix (shaded in red) are the highest priority, so this High-Risks (HR) should receive majority of the risk management. The second priority is for the Medium Risk category (MR) that lies on the middle of the matrix (shaded in yellow). And the lowest priority is for the Low Risk category (LR) which lies on the lower left of the matrix (green shaded).

D. Relative Importance Index (RII)

Relative Importance Index (RII) Is calculated as Eq. 10 [13]:

$$RII = \frac{\sum W}{A \times N} (10)$$

where, W is the given weight (ranging from 1 to 5), A is the maximum weight, and N is the number of survey experts. Andimportance level iscategorized as shown in Table 4 [14]:

IV. Analysis And Discussion

A. Risk Breakdown Structure (RBS) Results

Figure 3 shows the developed hierarchical RBS that categorized risks.

B. Risk Analysis

A questionnaire was developed and data was collected from(8) experts including (5) academic stuff in Hydraulics and Irrigation, (3) academic stuff in Sanitary and Environmental Engineering; in order to evaluate the severity through AHP methodology and the frequency of occurrence and impact through GRM methodology.

After the risks were defined in each phase of WSS and categorized depend on its effect on sustainability, reliability and resilience. AHP is done to give a weight to each risk affects the WSSs. A hierarchy model for AHP analysis is as shown in Fig.4.First, a matrix of Source stage, treatment stage and distribution stage [S, T, D] is done to produce a weight of each stage depend on the importance of each respect to other stages (on scale from 1 to 9) as shown in Table 5.

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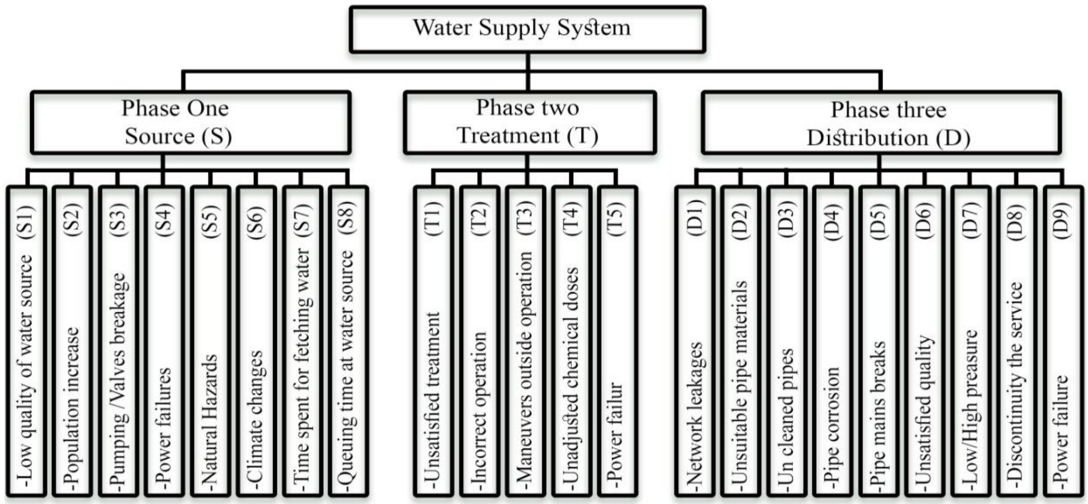

Figure 4. AHP hierarchy model structure

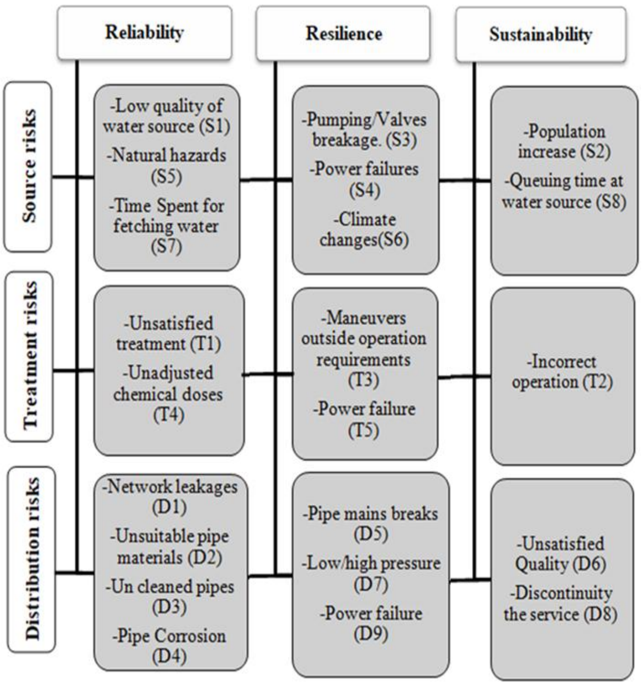

Figure 3. Water supply system risks

Table 5. Pair-wise Comparison Matrix for the stages

Code	S	T	D
S	1.00	0.25	1.00
T	4.00	1.00	2.00
D	1.00	0.50	1.00

Table 6. Calculation of Eigen Vector for the stages

Code	Geometric Mean	Eigen Vector (ω)	A*ω	λ_{max}
S	0.63	0.19	0.56	3.05
T	2.00	0.58	1.78	3.05
D	0.79	0.23	0.71	3.05
SUM	**3.42**	**1.00**		**λ_{max} = 3.05**

To compute the consistency of the experts when they evaluate the judgments, Consistency ratio (CR) is calculated and checked to be less than or equal 10% to be accepted, if it is more than 10% the judgments are not accepted and the subject judgment must be adjust [15].

For the stages matrix CR equals 0.04 then the matrix is consistent. As shown in Table 5, the treatment stage (T) has the largest weight which equals 0.58, then the stage of distribution (D) has a weight of 0.23, otherwise the source stage (S) has the lowest weight which equals 0.19.

In the same context, Risk matrices [S1, S2, …., S8] for source stage, [T1, T2, T3, T4] for treatment stage and [D1, D2, D3,….D9] for distribution stage were created for the source, treatment and distribution risks in Mostorud WSS as shown in Tables7,8 and9 and consistency ratio is checked for each matrix to compute the consistency.

Table 7. Pair-wise Comparison Matrix for source risks

Code	S1	S2	S3	S4	S5	S6	S7	S8
S1	1.00	1.00	3.00	3.00	5.00	2.00	4.00	5.00
S2	1.00	1.00	4.00	2.00	3.00	2.00	2.00	4.00
S3	0.33	0.25	1.00	1.00	1.00	2.00	5.00	5.00
S4	0.33	0.50	1.00	1.00	2.00	1.00	3.00	4.00
S5	0.20	0.33	1.00	0.50	1.00	2.00	1.00	3.00
S6	0.50	0.50	0.50	0.50	0.50	1.00	2.00	2.00
S7	0.25	0.50	0.50	0.50	1.00	0.50	1.00	1.00
S8	0.20	0.25	0.20	0.25	0.33	0.50	1.00	1.00
∑	3.82	4.33	11.20	8.75	13.83	11.00	19.00	25.00

CR= 0.07 < 0.1 then the matrix is consistent.

Table 8. Pair-wise Comparison Matrix for treatment risk

Code	T1	T2	T3	T4	T5
T1	1.00	3.00	4.00	3.00	3.00
T2	0.33	1.00	1.00	2.00	5.00
T3	0.25	1.00	1.00	1.00	3.00
T4	0.33	0.50	1.00	1.00	4.00
T5	0.33	0.20	0.33	0.25	1.00
∑	2.25	5.70	7.33	7.25	16.00

CR= 0.08 < 0.1 then the matrix is consistent.

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Table 9. Pair-wise Comparison Matrix for distribution risks

Code	D1	D2	D3	D4	D5	D6	D7	D8	D9
D1	1.00	3.00	2.00	3.00	4.00	5.00	4.00	3.00	2.00
D2	0.33	1.00	1.00	1.00	2.00	2.00	3.00	5.00	4.00
D3	0.50	1.00	1.00	2.00	5.00	3.00	4.00	3.00	2.00
D4	0.33	1.00	0.50	1.00	3.00	2.00	2.00	5.00	1.00
D5	0.25	0.50	0.20	0.33	1.00	1.00	1.00	4.00	3.00
D6	0.20	0.50	0.50	0.50	1.00	1.00	5.00	6.00	4.00
D7	0.25	0.33	0.33	0.33	1.00	0.20	1.00	2.00	3.00
D8	0.33	0.20	0.33	0.20	0.25	0.17	0.50	1.00	1.00
D9	0.20	0.33	0.20	0.25	0.17	0.50	1.00	1.00	1.00
Σ	3.40	7.87	6.07	8.62	17.42	14.87	21.50	30.00	21.00

CR= 0.08 < 0.1 then the matrix is consistent.

Table 10. Rank and Global weight calculation

	Weight	Code	Relative Weight	Global Weight	Global Rank
Source	**0.19**	**S1**	0.27	0.051	6
		S2	0.22	0.042	7
		S3	0.12	0.023	12
		S4	0.12	0.023	12
		S5	0.09	0.017	15
		S6	0.08	0.015	17
		S7	0.06	0.011	19
		S8	0.04	0.008	21
Treatment	**0.58**	**T1**	0.42	0.244	1
		T2	0.21	0.122	2
		T3	0.16	0.093	3
		T4	0.15	0.087	4
		T5	0.06	0.035	9
Distribution	**0.23**	**D1**	0.25	0.058	5
		D2	0.15	0.035	9
		D3	0.18	0.041	8
		D4	0.12	0.028	11
		D5	0.07	0.016	16
		D6	0.10	0.023	12
		D7	0.06	0.014	18
		D8	0.03	0.007	22
		D9	0.04	0.009	20

After the Eigen Vector (ω), relative weight, is calculated, the global weight is calculated by multiply the relative weight of each risk and the weight of its stage as shown in Table10.

Regarding AHP results in Table 10, T1, Unsatisfied treatment, recorded the highest weight then T2, Incorrect operation, which means that two risks are considered more important than other risks in the opinion of the experts; however, D8, Discontinuity the service, is the smallest weight between the risks, which mean that this risk is the least important.

The importance of each risk relative to other risks is determined from the weight calculated for risks, and then GRM analysis is a must to assign a score to each risk based on its probability of occurrence and its impact. For score > 0.14 then the risk is High risk, the risk is medium if the score is more than 0.05 and not exceed 0.14. The risk considered a slow risk if the score is equal or less than 0.05 as shown in Table 11.

To take into consideration the weight of each risk, its probability and impact, the weighted score is calculated for each risk by multiply the weight of the risk and the score as shown in Table 12 and Figure 5.

Table 11. GRM analysis for risks

	Code	Risk Probability	Risk impact	Risk Score	Risk Category
Source	**S1**	0.9	0.4	0.36	HR
	S2	0.9	0.4	0.36	HR
	S3	0.9	0.4	0.36	HR
	S4	0.5	0.4	0.20	HR
	S5	0.9	0.2	0.18	HR
	S6	0.7	0.4	0.28	HR
	S7	0.3	0.2	0.06	LR
	S8	0.5	0.4	0.20	HR
Treatment	**T1**	03	0.4	0.12	LR
	T2	0.5	0.4	0.20	HR
	T3	0.9	0.2	0.18	HR
	T4	0.7	0.4	0.28	HR
	T5	0.5	0.4	0.20	HR
Distribution	**D1**	0.7	0.1	0.07	MR
	D2	0.5	0.8	0.40	HR
	D3	0.9	0.4	0.36	HR
	D4	0.3	0.4	0.12	LR
	D5	0.5	0.4	0.20	HR
	D6	0.9	0.2	0.18	HR
	D7	0.7	0.4	0.28	HR
	D8	0.6	0.4	0.24	HR
	D9	0.9	0.4	0.36	HR

The results in Table 12 and Figure 5 showed that:
- The weighted score of T1, Unsatisfied treatment, have the highest weighted score which means that risk has the priority although the GRM analysis categorized this risk

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as (LR) but it has a highest weight in AHP analysis which cause a high weighted score.

- T4, Unadjusted chemical doses, and T2, Incorrect operation; Have the second priority relative to other risks.
- S7, Time Spent for fetching water is the lowest risk in weighted score, which was categorized as (LR) in GRM analysis.

C. Risk Response Alternatives Strategies

Results from risk analysis and risk evaluation are a helpful guide for decisions needed to manage risks. To mitigate the probability and/or the consequence of the risks it is essential to search for alternatives, the HRs have the major priority on suggesting effective strategies to reduce the risks on the system. The experts can study the current situation of the system and think about new strategies to apply on the system.

To reduce the risks of the WSS at the source, treatment and distribution stages, some alternative strategies are recommended for example:

C.1 Water Source Risks Response Strategies

Strategy 1 (AS1): Online measurement of quality of raw water: by connecting a remote data transfer device to an automatic turbidity meter.

Strategy 2 (AS2): Unusual sources of water: such as collecting storm water and rainwater from rooftops and installing a new deep well system as a substitute for groundwater.

Strategy 3 (AS3): Sludge treatment: This suggested strategy concentrates on applying a sludge treatment alternative and stopping the sludge disposal effluent from WTPs in the water source.

Strategy 4 (AS4): Installation of water meters: The installation of the meter must be performed to ensure that there is always a full flow of water in the pipe at the meter and regulate the demand. It must be placed so that all water produced by the well is measured [16].

Strategy 5 (AS5): Automatic water quality and level,to track tiers in the source of water. The best levelof water temperature fluctuation decision-making is provided by continuous tracking.

C.2 Treatment Plants Risks Response Strategies

Strategy6 (AS6): Emergency operating procedures when emergencies occur, it's important to reduce the systems disruption caused by them.

Table 12. Weighted Score calculation

	Code	Risk Weight	Risk Score	Weighted Score
Source	S1	0.051	0.36	0.018
	S2	0.042	0.36	0.015
	S3	0.023	0.36	0.008
	S4	0.023	0.20	0.005
	S5	0.017	0.18	0.003
	S6	0.015	0.28	0.004
	S7	0.011	0.06	0.001
	S8	0.008	0.20	0.002
Treatment	T1	0.244	0.12	0.029
	T2	0.122	0.20	0.024
	T3	0.093	0.18	0.017
	T4	0.087	0.28	0.024
	T5	0.035	0.20	0.007
Distribution	D1	0.058	0.07	0.004
	D2	0.035	0.40	0.014
	D3	0.041	0.36	0.015
	D4	0.028	0.12	0.003
	D5	0.016	0.20	0.003
	D6	0.023	0.18	0.004
	D7	0.014	0.28	0.004
	D8	0.007	0.24	0.002
	D9	0.009	0.36	0.003

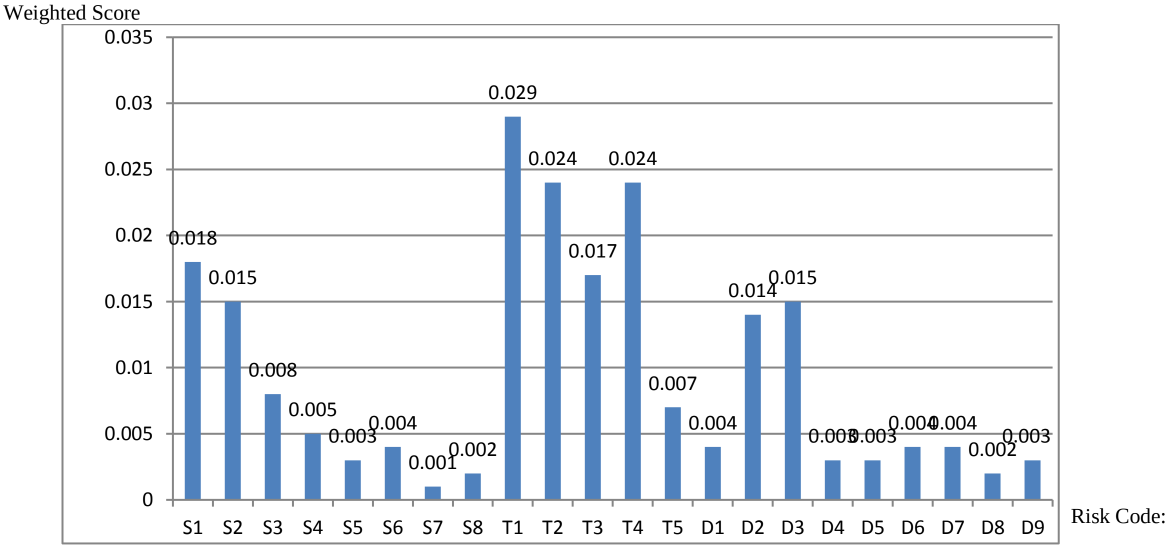

Figure 5. Weighted score of risks monitoring

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Strategy 7 (AS7): Automatic dosing regimens. It is necessary to apply an automatic dose measurement at the WTP to continually check that it is sufficient.
Strategy 8 (AS8): Resilience capacity to assess the system's ability to handle various risk events, which can be identified by their duration and level of severity.
Strategy9 (AS9): Flow regimes change to attain standard WTPs operation protocols in a variety of flow change scenarios following transitory situations. The flow is turbulent at high velocities; however, the flow is laminar at high viscosities. The flow regime is affected by pipe diameter, velocity of the fluid, volumetric mass and viscosity.

C.3 Water Distribution Risks Response Strategies

Strategy 10 (AS10): Decrease of Leakage by upgrading the network and fixing pipe leakages. Additionally the pressure control can also minimize the leakage in the networks.
Strategy 11 (AS11): Setting up permanent water flow and pressure monitoring meters to control the demand of water.
Strategy 12 (AS12): Introduction of Network reliability analysis to identify which pipelines are at risk.
Strategy 13 (AS13): Reducing the frequency of low water flow or pressure situations.
Strategy 14 (AS14): Using new automatic control types in place of valves.

D. Risk Response Alternatives Strategies Evaluation

Strategies are suggested to mitigate the impact of risks on the WSS. To determine the relative importance index (RII) to each strategy, the authors performed an electronic questionnaire with the correlate multiple 40 experts. Each expert evaluates each risk as one of the following rates as shown in Table 13:

(EI) if the strategy is Extremely Important,
(I) if the strategy is important,
(A) if the strategy is Average Important,
(NI) if the strategy isn't Important and finally
(ENI) if the strategy isn't extremely important.

Based on the results of this questionnaire, a static analysis is done to calculate the mean value (μ), and Standard Deviation (α) by using (Likert) scale, then, the Relative Important Index (RII) [17]. The results of this survey as illustrated in Table 14.

To verify the questionnaire, coefficient of variance (CV) average is calculated and found to be **9.415**; since CV is less than 10 then the sample is very good. As regards the analysis of the electronic surveying questionnaire to get the relative importance of the alternatives as shown in Table 14.

The analysis result determined that:

- At the source stage AS5, Automatic water quality and level monitoring, has the highest importance index, then AS3, Sludge treatment, On the other hand, AS4, Installation of water meters, has the lowest importance index.
- At the treatment stage four alternative strategies have been assumed, however AS7, Automatic dosing regimens, and AS6, Emergency operating procedures, have the highest importance index which indicate their priority to apply them on the WSS specially that the treatment stage has the highest rank on the risks evaluation.
- From the five risks alternatives strategies at the distribution stage, AS13, Reducing the frequency of low water flow or pressure situations, is the most important strategy, then AS10, Decrease of Leakage.

Table 13. Risks Strategies evaluation questionnaire results

	EI	I	A	NI	ENI	Total no. of experts
	Source Risks Response Alternatives Strategies					
AS1	20	9	3	5	3	40
AS2	20	10	5	3	2	40
AS3	20	11	8	1	0	40
AS4	0	1	3	10	26	40
AS5	28	3	8	1	0	40
	Treatment Risks Response Alternatives Strategies					
AS6	25	12	2	1	0	40
AS7	25	12	3	0	0	40
AS8	10	20	3	5	2	40
AS9	1	4	15	20	0	40
	Distribution Risks Response Alternatives Strategies					
AS10	33	2	3	1	1	40
AS11	1	6	8	10	15	40
AS12	15	10	12	1	2	40
AS13	32	7	1	0	0	40
AS14	3	10	25	2	0	40

Table 14. Risks Strategies evaluation questionnaire results

	μ	α	CV	RII		Rank
	Source Risks Response Alternatives Strategies					
AS1	3.95	1.34	33.89	0.79	Medium High	8
AS2	4.08	1.19	29.08	0.82	High	7
AS3	4.25	0.87	20.46	0.85	High	6
AS4	1.48	0.75	50.89	0.30	Medium Low	14
AS5	4.45	0.90	20.32	0.89	High	5
	Treatment Risks Response Alternatives Strategies					
AS6	4.53	0.72	15.82	0.79	High	4
AS7	4.55	0.64	14.03	0.82	High	3
AS8	3.78	1.12	29.69	0.85	Medium High	10
AS9	2.65	0.77	29.04	0.30	Medium	12
	Distribution Risks Response Alternatives Strategies					
AS10	4.63	0.93	20.00	0.93	High	2
AS11	2.20	1.18	53.68	0.44	Medium	13
AS12	3.88	1.11	28.74	0.78	Medium High	9
AS13	4.78	0.48	10.05	0.96	High	1
AS14	3.35	0.70	20.89	0.67	Medium High	11

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V. CONCLUSIONS

- The study area covers a water supply system, Mostorud, in Cairo government in Egypt along Ismailia canal; this WSS is subjected to risks that affect the sustainability, reliability and resilience of the WSS.

- In this study, the risk events for Mostorud WSS had been identified and categorized at the three stages of WSS: water source, water treatment plants, and distribution networks.

- The findings of the model analysis using the risk management technique show that the treatment phase is the most significant phase in the water supply system, AHP analysis was effective in assigning the weights of the criterion and risks; however GRM method was effective in determining a score of each risk based on its frequency and impact.

- Finally, the study proposed alternatives strategies based on the view of the experts, as well as an evaluation for the alternatives strategies. This framework increased the accuracy of determining the best alternative strategy to achieve sustainability, reliability and resilience in the WSSs in Egypt.

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