



Risk Assessment of Drinking Water Using WSP for Azraq Spring-Jordan

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Abstract

Water Safety Plan (WSP) is considered as a collaborative approach dedicated to the risks of water impurity in a drinking water operating system, started at the catchment and finished at the end user, to protect people's health. The aim of this study is to accomplish a WSP for the drinking water operation system of Azraq Spring. It is located in Fuhais in the northwestern part of Balqa, about 20 km west of Amman. The catchment area is 23.71 km² and it has a perimeter of 20.42 km. Semi-quantitative approach is used for risk assessment. Possible hazardous events and related hazards were recognized in each portion of the water operation system. WSP decreases the risk of public health, guarantees the water quality with standards requirements, increases the trust of users, and advances management of water resources due to involvement planning. New control measures are suggested by the WSP team within this study.

Subject Areas

Hydrology

Keywords

E. coli, Risk Assessment, Water Safety Plan

1. Introduction

Accomplishing good water quality requires monitoring of the environment and human health. WSP procedure is considered as a collaborative approach dedicated to exploring the risks of water impurity in a drinking water operating system, started at the catchment and finished at the end user, to protect people's health and significantly decrease water pollution in the whole drinking water operating system (DWOS). Azraq Spring is considered the main source of

drinking water for Fuhais city, but it is difficult to get all the quantity of groundwater abstraction from Azraq in past years due to the increase in *E. coli* and nitrate. The aim of this study is to achieve the WSP for the drinking water operation system (DWOS) of Azraq Spring, and assessment of the groundwater pollution that may result from agricultural activities and Fuhais wastewater treatment plants using WSP [1].

2. Study Area

Azraq Spring is located in Fuhais in the northwestern part of Balqa, about 20 km west of Amman at N-32°1.232 and E-35°45.754 as shown in **Figure 1**. Azraq catchment area is equal 23.71 km² and it has perimeter equal 20.42 km. The long-term average discharge of Azraq Spring is around 1.4 MCM annually [2].

3. Methods

Figure 2 shows the flowchart of Water Safety Plan (WSP) that will be followed to achieve the objectives of the research.

3.1. Formation of a Multidisciplinary Team That Involved

This step included nomination of team member; operation manager, researchers, and environment and health protection Authority as shown in **Table 1**.

3.1.1. Description of Drinking Water Operation System

Azraq Spring is originated from A7/B2 aquifer which is the most exploited aquifer in Jordan. It is a highly fractured-rock aquifer, consisting of sedimentary rocks (primarily carbonates and chert) from the late Cretaceous epoch. The fractures and other discontinuities such as joints, fissures and faults that occur in the rocks are allowing it to hold huge amounts of groundwater so it can be considered as a highly productive aquifer. Average discharge of Azraq Spring is around

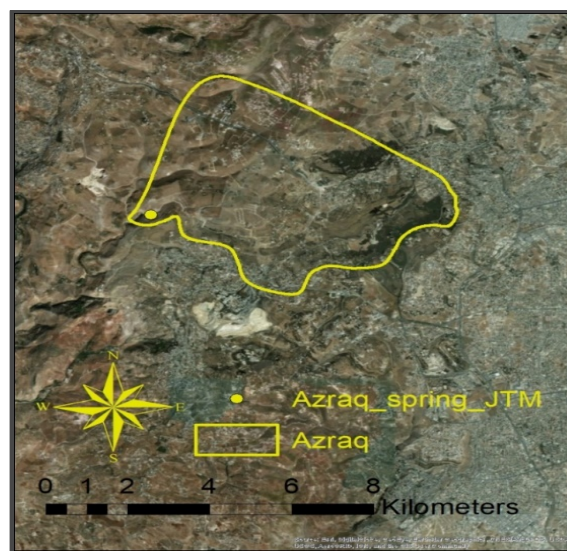


Figure 1. Study area.

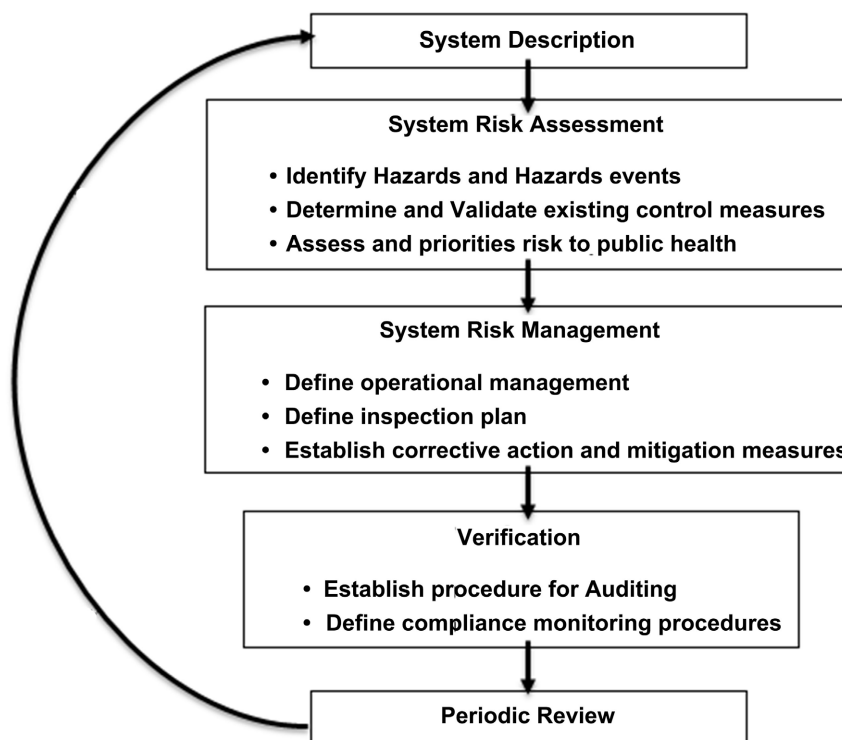


Figure 2. WSP flowchart.

Table 1. Water safety plan team members and their roles for each one.

Name	Position	Describe water system	Identify hazard and assess risks	Control measures	Operational control procedures	Verify effectiveness of WSP	Prepare management procedures	Develop support Program	Validation
Dr. Hassan Khrisat	Head of water resources and environment division	R	R	R	R	R	R	R	R
Lama Saleh	Head of water safety Division	R	R	R	R	I	R	A	R
Khaled Hadidi	Engineer of water safety Division	I	I	I	I	I	I	I	I
Feda'a Massaede	Engineer of water safety Division	I	I	I	I	I	I	I	I
Samah Salhi	Engineer of water safety Division	I	I	I	I	I	I	I	I
Amjad Fityani	Geology of water protection Division	I	I	I	I	I	I	I	I
Omar Rahamneh	Engineer of Shuraia Treatment plant	I	I	I	I	I	I	I	I

R: Responsible; I: Involved; A: Aware.

1.4 MCM/Annual. Azraq is used for water supply of Fuhais and Mahis. According to increasing number of microbial contaminations that associated with *E. coli*, the water of Azraq Spring starting treated through Shuraia treatment plant

since 2007 [3]. Shuraia Treatment plant is non-conventional membrane plant that started of strainers and then three main consecutive treatment processes; Filtration by Micro-filtration, Disinfection by ultraviolet (UV), and post chlorination by residual chlorine. Each of these treatment processes provides a barrier to microbial contamination to provide greatest assurance for safe drinking water. About 90 m³ of chlorinated water returns back to Azraq tank (550 m³) which pumps water to Fuhais pumping station (PS), as shown in **Figure 3**. Azraq Spring was sampled regularly on a monthly basis by WAJ Lab.

3.1.2. Determination of Hazards, Hazardous Events, and Risk Assessment

What-If/Checklist analysis was applied to determine hazardous events and to assess the risk. It included brainstorming of results of the What-If/Checklist [4]. Typical hazards were analyzed, such as chemical, physical and microbial contamination, water deficiency events as shown in **Table 2**.

Semi-quantitative risk matrix was used as recommended by World Health Organization (WHO) guidelines as shown in **Table 3**, to approximating the likelihood of occurrence for each hazard and calculating the severity of consequences when hazard occurred.

Classification of likelihood and the severity of consequences are shown in **Table 4**, which agrees with national drinking water quality standards and health regulations. The management actions for each risk category that resulted from the risk matrix are shown in **Table 5**.

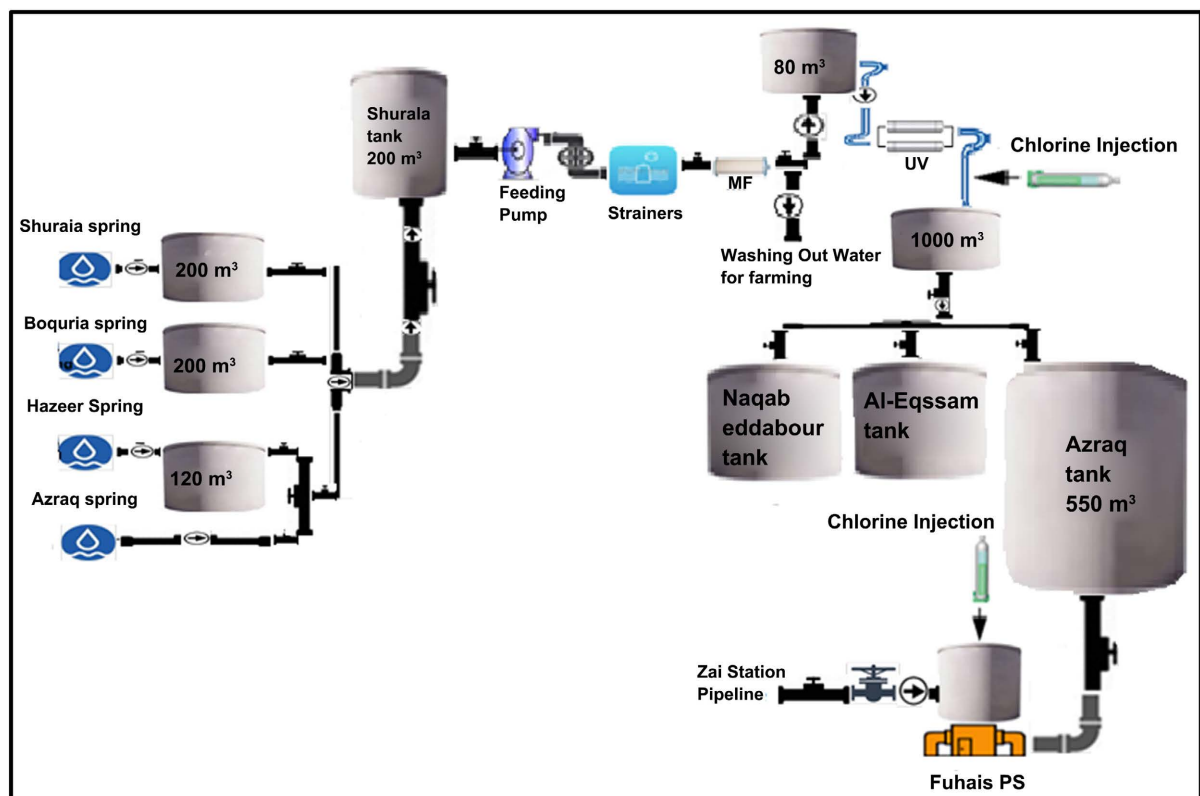


Figure 3. Diagram of Azraq drinking water supply system.

Table 2. Hazardous events and hazard type for each step in DWSS.

Process step	Hazardous event	Hazard type
Catchment	High turbidity in Azraq Spring and probability for Pollution due to the flow of rainwater in the valleys that lead to the spring during the winter	Microbial chemical physical
	contamination of Azraq Spring due to the leakage and flood of sewage lines and drains due to the overload of the connections which causes by the population increase in the area and the connection of rain water to the sewage network, causing infiltration of wastewater to the karst aquifer	Microbial chemical physical
	Pollution of Azraq Spring due to active and non-active cesspits present in the catchment area causing infiltration of wastewater to the karst aquifer which influence the spring water	Microbial chemical physical
	Pollution of Azraq Spring due to the presence of flat and fractures in the lift line leading to the wastewater treatment plant (WWTP), Mahesh and Fuhais	Microbial, chemical physical
	Pollution of Azraq Spring due to flooding in the lift station as a result of overload due to the connection of rain water to the sewage network	Microbial chemical physical
	Pollution of Azraq Spring due to the infiltration of fertilizers, pesticides from agricultural activities in the area to the shallow water basin	Microbial chemical physical
	Pollution of Azraq Spring because of animal waste from barns and sheep grazing areas to the shallow water basin	Microbial chemical physical
Treatment	Pollution of Azraq Spring due to spilling of industrial Wastewater from fuel station and car washing	Microbial chemical physical
	Contamination in the outlet from the MF unit due to the failure of the filter membranes	Physical Microbial
	The probability of exceeding the reference limits of the Jordanian standard of water produced due to decrease the intensity of radiation and the dose of disinfectant and low efficiency of purification of raw water from the ultraviolet sterilization unit because bulbs are not cleaned or lamps come near the shelf life	Microbial
Distribution	Shortage of production quantities of the station to disable the work of air valves, which leads to high pressure of the unit and stop automatically due to the failure of the air-feeding system of the air valves in the MF filter unit	physical
	Increase in turbidity due to withdrawal of soil to the network due to fractures in it	physical
	Pollution of water due to the flood of sewage manhole that result from the clogging of sewage networks	Microbial chemical physical
	Pollution of water due to accumulation of soil and sediments at the end of the lines, especially in low areas	Microbial physical
	High water turbidity due to the entry of soil to the network through broken pipes, due to maintenance of damaged networks, which include repair or replacement of main lines	physical




Table 3. The semi-quantitative risk matrix [5].

RISK MATRIX 5 × 5		Severity				
		Negligible (1)	Slight (2)	Sensible (3)	considerable (4)	Terrible (5)
Likelihood	Frequent (5)	5	10	15	20	25
	Most probable (4)	4	8	12	16	20
	Probable (3)	3	6	9	12	15
	Improbable (2)	2	4	6	8	10
	Infrequent (1)	1	2	3	4	5

Table 4. Severity of consequences and likelihood classification.

Likelihood	Description	rate
Frequent	Is expected to occur in most circumstances (more than one time per a year), has been observed regularly in the field, confirmed by water quality	5
Most probable	Will probably occur in most circumstances (at least one time per a year), has been observed occasionally in the field, confirmed by water quality	4
Probable	Might occur at some times (once per two years), has been observed occasionally in the field, no significant water quality data trend that confirm the risk	3
Improbable	Could occur at some time (once per 5 years), has not been observed in the field, no water quality data trends that confirm the risk	2
Infrequent	May occur only in exceptional circumstances (didn't happened during 5 years), has not been observed in the field, water quality data do not indicate any risk	1
Severity	Description	rate
Negligible	Negligible impact on water quality, service delivery or normal operation	1
Slight	Minor water quality influence for slight fraction of users, certain practicable description to process, corrective action required for service delivery, rise in complaints not significant	2
Sensible	Minor water quality influence for huge fraction of users, clear growth in objections, public displeasure, slight gap of monitoring requirement, regulator interest, significant but manageable modification to normal operation, increased operational cost, increase monitoring	3
considerable	Major water quality impact for small percentage of customers, large numbers of complaints, and significant breach of regulatory requirement, regulator interest and investigation, system is significantly compromised with abnormal operation, extra high level of monitoring required	4
Terrible	Major water quality impact for large percentage of users, disease in public related with the water system, litigation by customers, major regulatory breach, major investigation by regulator with prosecution likely, complete failure of system	5

Table 5. Management action for each risk category resulted from applying risk matrix.

	Risk category			Management action
	Low risk	0 - 5	L	Addressed by routine procedures
	Medium risk	6 - 14	M	Management attention needed
	High risk	15 - 25	H	Requires urgent management attention

3.1.3. Determination of Control Measures, Validation and Risk Re-Assessment

Control measures are phases in the drinking-water operation that directly effect on water quality to ensure the water regularly correspond water quality limitations as shown in **Table 6**. Risks were re-assessed for each hazardous event and hazard according to a new value of severity.

3.1.4. Development of an Upgrade Plan with New Control Measures to Reduce Risk Rating

Evaluating whether the control measures are effective or not, if improvement are required, establish corrective action for deviations and incidents that may occur

Table 6. Determination of control measures, validation.

Process step	Hazard events	Hazard type	Existing control measures
Catchment	High turbidity in Azraq Spring and probability for Pollution due to the flow of rainwater in the valleys that lead to the spring during the winter	Microbial chemical physical	Stop the station
	Contamination of Azraq Spring due to the leakage and flood of sewage lines and drains due to the overload of the connections which causes by the population increase in the area and the connection of rain water to the sewage network, causing infiltration of wastewater to the karst aquifer	Microbial chemical physical	<ul style="list-style-type: none"> • The presence of a Sharia treatment plant • Maintain the integrity of the facilities for the manholes • Preventive maintenance programs by the Balqa Water Department • Activation of laws, regulations, instructions: including the application of penalties
	Pollution of Azraq Spring due to active and non-active cesspits present in the catchment area causing infiltration of wastewater to the karst aquifer which influence the spring water	Microbial chemical physical	<ul style="list-style-type: none"> • The existence of the Code of Practice for the construction of cesspits, in addition to the drilling of cesspits during the process of connecting with the sewage network from the Ministry of Public Works
	Pollution of Azraq Spring due to the presence of flat and fractures in the lift line leading to the wastewater treatment plant (WWTP), Mahesh and Fuhais	Microbial, chemical physical	<ul style="list-style-type: none"> • The presence of a Sharia treatment plant
	Pollution of Azraq Spring due to flooding in the lift station as a result of overload due to the connection of rain water to the sewage network	Microbial chemical physical	<ul style="list-style-type: none"> • Activation of laws, regulations, instructions: including the application of penalties
	Pollution of Azraq Spring due to the infiltration of fertilizers, pesticides from agricultural activities in the area to the shallow water basin	Microbial chemical physical	<ul style="list-style-type: none"> • The Water Resources Protection guideline for 2011. • Operating licenses issued by the Ministry of Agriculture and the conditions required to obtain these licenses, in addition to the approval of the Ministry of Environment to obtain these licenses
	Pollution of Azraq Spring because of animal waste from barns and sheep grazing areas to the shallow water basin	Microbial chemical physical	<ul style="list-style-type: none"> • The Water Resources Protection guideline for 2011. • Operating licenses issued by the Ministry of Agriculture and the conditions required to obtain these licenses, in addition to the approval of the Ministry of Environment to obtain these licenses
Treatment	Pollution of Azraq Spring due to spilling of industrial Wastewater from fuel station and car washing	Microbial chemical physical	<ul style="list-style-type: none"> • The presence of a Sharia treatment plant
	Contamination in the outlet from the MF unit due to the failure of the filter membranes	physical Microbial	<ul style="list-style-type: none"> • Keep 2 of the Mf unit stand by. The presence of UV purification unit after the MF unit • The extra barrier of the final chlorination of productive water is considered one of the safety barriers against bacterial contamination
	The probability of exceeding the reference limits of the Jordanian standard of water produced due to decrease the intensity of radiation and the dose of disinfectant and low efficiency of purification of raw water from the ultraviolet sterilization unit because bulbs are not cleaned or lamps come near the shelf life	Microbial	<ul style="list-style-type: none"> • The extra barrier of the final chlorination of productive water is considered one of the safety barriers against bacterial contamination

Continued

	Shortage of production quantities of the station to disable the work of air valves, which leads to high pressure of the unit and stop automatically due to the failure of the air-feeding system of the air valves in the MF filter unit	physical	<ul style="list-style-type: none"> • Preventive maintenance programs issued and prepared based on catalogs and standard operating books • Availability of spare parts • The existence of a backup air system
	Increase in turbidity due to withdrawal of soil to the network due to fractures in it	physical	<ul style="list-style-type: none"> • Response speed to repair broken water lines and quality complaint • Matching materials used with relevant specifications
Distribution	Pollution of water due to the flood of sewage manhole that result from the clogging of sewage networks	Microbial Chemical physical	<ul style="list-style-type: none"> • Preventive maintenance of sewage lines close to water networks • Preserving excess residual chlorine in the distribution network according to the Jordanian Standard for drinking water • Existing of qualified technician that can deal with situation
	Pollution of water due to accumulation of soil and sediments at the end of the lines, especially in low areas	Microbial physical	Increase the length of the pipe line about 5 m to give sediment and soil extra space to accumulate
	High water turbidity due to the entry of soil to the network through broken pipes, due to maintenance of damaged networks, which include repair or replacement of main lines	physical	<ul style="list-style-type: none"> • Regular maintenance of pressure dampers in the area • Increase staff efficiency

and emergency responses. All control measures are important and should be afforded ongoing attention. They should be subject to operational monitoring and control, with the means of monitoring and frequency of data collection based on the nature of the control measure and the rapidity with which change may occur.

3.1.5. Development of a Monitoring Plan

This monitoring plan establishes what will be monitored, how it will be monitored, the frequency of monitoring, who will do the monitoring, and critical limits and related corrective actions. According to Jordanian Drinking Water Standards [6], drinking water must show conformity with the health standards, and carry out the necessary laboratory tests by applying the operation monitoring program of WAJ as shown in **Table 7**.

4. Results and Discussion

4.1. Identification of Hazardous Events, Hazards and Risk Assessment

The potential hazardous events and all related potential physical, biological, chemical or radiological hazards associated with each step in the DWOS were identified. **Table 8** showed the result of risk assessment before consideration of the current control measures.

Table 7. Monitoring programs of the water authority on the quality of raw water, treatment and network.

Location	Level of protection	Repeatability of sample collection	Laboratory test
Baqouriya spring	Second	3/week = 12/month	Total Coli. + <i>E. coli</i> + Turbidity + NH ₄ + Residual Cl ₂
Sharia spring	Second	3/week = 12/month	Total Coli. + <i>E. coli</i> + Turbidity + NH ₄ + Residual Cl ₂
Hazier spring	First	3/week = 12/month	Total Coli. + <i>E. coli</i> + Turbidity + NH ₄ + Residual Cl ₂
Azraq Spring	First	3/week = 12/month	Total Coli. + <i>E. coli</i> + Turbidity + NH ₄ + Residual Cl ₂
		1/year	pH, TDS, TH, Al, Fe, Zn, Cu, Na, Cl, SO ₄ , NO ₂ , NO ₃ , Mn, Temp., Color, Odor, MBAS.
		1/year	As, Pb, CN, Cd, Cr, Ba, Se, B, Hg, Ag, Ni, Sb, F, Mo
Sharia treatment plant for each stage (Raw, Micro filtration, Product tank)	Second	3/week = 12/month	Total Coli. + <i>E. coli</i> + Turbidity + NH ₄ + Residual Cl ₂
		2/year	pH, TDS, TH, Al, Fe, Zn, Cu, Na, Cl, SO ₄ , NO ₂ , NO ₃ , Mn, Temp., Color, Odor, MBAS.
		1/year	As, Pb, CN, Cd, Cr, Ba, Se, B, Hg, Ag, Ni, Sb, F, Mo, Algae, Nematode, Giardia, Ameba
Buhaira Tank	First	1/month	Total Coli. + <i>E. coli</i> + Turbidity + NH ₄ + Residual Cl ₂
		1/year	pH, TDS, TH, Al, Fe, Zn, Cu, Na, Cl, SO ₄ , NO ₂ , NO ₃ , Mn, Temp., Color, Odor, MBAS,
Al-Eqsam tank	First	1/month	Total Coli. + <i>E. coli</i> + Turbidity + NH ₄ + Residual Cl ₂
Yarqa Tank	First	1/month	Total Coli. + <i>E. coli</i> + Turbidity + NH ₄ + Residual Cl ₂
Naqib Dabour Tank	First	1/month	Total Coli. + <i>E. coli</i> + Turbidity + NH ₄ + Residual Cl ₂
Sawada Tank	First	1/month	Total Coli. + <i>E. coli</i> + Turbidity + NH ₄ + Residual Cl ₂

Table 8. Risk assessment of hazards for each step in the DWSS before consideration of the current control measures.

Process step	Hazardous event	Hazard type	L	S	R Score	R rating before considering control measure
Catchment	High turbidity in Azraq Spring and probability for Pollution due to the flow of rainwater in the valleys that lead to the spring during the winter	Microbial chemical physical	5	4	20	High
	contamination of Azraq Spring due to the leakage and flood of sewage lines and drains due to the overload of the connections which causes by the population increase in the area and the connection of rain water to the sewage network, causing infiltration of wastewater to the karst aquifer	Microbial chemical physical	4	4	16	High
	Pollution of Azraq Spring due to active and non-active cesspits present in the catchment area causing infiltration of wastewater to the karst aquifer which influence the spring water	Microbial chemical physical	3	3	9	Moderate
	Pollution of Azraq Spring due to the presence of flat and fractures in the lift line leading to the wastewater treatment plant (WWTP), Mahesh and Fuhais	Microbial chemical physical	4	4	16	High

Continued

	Pollution of Azraq Spring due to flooding in the lift station as a result of overload due to the connection of rain water to the sewage network	Microbial chemical physical	4	3	12	Moderate
	Pollution of Azraq Spring due to the infiltration of fertilizers, pesticides from agricultural activities in the area to the shallow water basin	Microbial chemical physical	2	3	6	Moderate
	Pollution of Azraq Spring because of animal waste from barns and sheep grazing areas to the shallow water basin	Microbial chemical physical	2	3	6	Moderate
	Pollution of Azraq Spring due to spilling of industrial Wastewater from fuel station and car washing	Microbial chemical physical	2	2	4	Low
	Contamination in the outlet from the MF unit due to the failure of the filter membranes	Physical Microbial	4	4	16	High
Treatment	The probability of exceeding the reference limits of the Jordanian standard of water produced due to decrease the intensity of radiation and the dose of disinfectant and low efficiency of purification of raw water from the ultraviolet sterilization unit because bulbs are not cleaned or lamps come near the shelf life	Microbial	2	4	8	Moderate
	Shortage of production quantities of the station to disable the work of air valves, which leads to high pressure of the unit and stop automatically due to the failure of the air-feeding system of the air valves in the MF filter unit	physical	3	3	9	Moderate
	Increase in turbidity due to withdrawal of soil to the network due to fractures in it	physical	2	3	6	Moderate
Distribution	Pollution of water due to the flood of sewage manhole that result from the clogging of sewage networks	Microbial Chemical physical	5	4	20	High
	Pollution of water due to accumulation of soil and sediments at the end of the lines, especially in low areas	Microbial physical	3	1	3	Low
	High water turbidity due to the entry of soil to the network through broken pipes, due to maintenance of damaged networks, which include repair or replacement of main lines	physical	3	3	9	Moderate

At the catchment, Storm water event in the drinking-water catchment causing surface water runoff which leads to infiltration of polluted surface water to the shallow aquifer causing increase in turbidity and microbial contamination of the raw water at inlet of water treatment plant. This mean there is no water inlet the plant. So, the severity of consequences is 4 (considerable). Based on the information reported by the operator of the water system, the probability of occurrence more than once a year so the likelihood is considered as Frequent (5). Thus the calculated risk is very high ($5 \times 4 = 20$). At treatment phase, inefficient filtration due to the failure of the filter membranes or before expected life time (*i.e.* before 18 - 24 months), microbial contamination resulted due to the presence of *E. coli* in the water. So the severity of consequences is major impact (4). Based on the

information reported by operator of water system, the possibility of occurrence is once a year so the likelihood is most probable (4). Thus, the calculated risk is medium ($4 \times 4 = 16$). Fifteen events of hazard were analyzed (8 at catchment, 3 at treatment and 4 in distribution phase) [7]. Risks assessing uncertainty resulted due to lack of data, poor knowledge of activities within the water operating system and their contribution of risk created. This problem was overcome by collaboration of the DWOS manager and operator through providing with information that required for WSP development, which is essential for a successful operation of WSP [8].

4.2. Identification of Control Measures and Validation, Risk Reassessment and Prioritization

Validation of control measures were by site investigation of catchment areas and validating performance monitoring procedures such as qualitative measures. If a results of control measure did not compliance with Jordanian water quality regulations the validation was considered ineffective.

As shown in **Table 9**, at the treatment plant there are seven MF units at full

Table 9. Identification of control measures and validation, risk reassessment and prioritization.

Process phase	Hazard event	Hazard kind	Without control measure				In-place control measure					
			L	S	R	Rating	Existing control measure	V	L	S	R	Rating
Catchment	High turbidity in Azraq Spring and probability for Pollution due to the flow of rainwater in the valleys that lead to the spring during the winter	Microbial chemical physical	5	4	20	High	stop the station	E*	5	2	10	Moderate
	contamination of Azraq Spring due to the leakage and flood of sewage lines and drains due to the overload of the connections which causes by the population increase in the area and the connection of rain water to the sewage network, causing infiltration of wastewater to the karst aquifer	Microbial chemical physical	4	4	16	High	<ul style="list-style-type: none"> The presence of a Sharia treatment plant Maintain the integrity of the facilities for the manholes. Preventive maintenance programs by the Balqa Water Department. Activation of laws, regulations, instructions: including the application of penalties 	E*	3	3	12	Moderate
	Pollution of Azraq Spring due to active and non-active cesspits present in the catchment area causing infiltration of wastewater to the karst aquifer which influence the spring water	Microbial chemical physical	3	3	9	Moderate	<ul style="list-style-type: none"> The existence of the Code of Practice for the construction of cesspits, in addition to the drilling of cesspits during the process of connecting with the sewage network from the Ministry of Public Works. 	NE+	3	3	9	Moderate
	Pollution of Azraq Spring due to the presence of flat and fractures in the lift line leading to the wastewater treatment plant (WWTP), Mahesh and Fuhais	Microbial chemical physical	4	4	16	High	<ul style="list-style-type: none"> The presence of a Sharia treatment plant 	E*	4	2	8	Moderate

Continued

	Pollution of Azraq Spring due to flooding in the lift station as a result of overload due to the connection of rain water to the sewage network	Microbial chemical physical	4	3	12	Moderate	Activation of laws, regulations, instructions: including the application of penalties	NE+	4	3	12	Moderate
	Pollution of Azraq Spring due to the infiltration of fertilizers, pesticides from agricultural activities in the area to the shallow water basin	Microbial chemical physical	2	3	6	Moderate	<ul style="list-style-type: none"> The Water Resources Protection guideline for 2011. Operating licenses issued by the Ministry of Agriculture and the conditions required to obtain these licenses, in addition to the approval of the Ministry of Environment to obtain these licenses 	NE+	2	3	6	Moderate
	Pollution of Azraq Spring because of animal waste from barns and sheep grazing areas to the shallow water basin	Microbial chemical physical	2	3	6	Moderate	<ul style="list-style-type: none"> The Water Resources Protection guideline for 2011. Operating licenses issued by the Ministry of Agriculture and the conditions required to obtain these licenses, in addition to the approval of the Ministry of Environment to obtain these licenses 	NE+	2	3	6	Moderate
	Pollution of Azraq Spring due to spilling of industrial wastewater from fuel station and car washing	Microbial chemical physical	2	2	4	Low	<ul style="list-style-type: none"> The presence of a Sharia treatment plant 	E*	2	1	2	Low
	Contamination in the outlet from the MF unit due to the failure of the filter membranes	Physical (Turbidity) Microbial (<i>E. coli</i>)	4	4	16	High	<ul style="list-style-type: none"> keep 2 of the Mf unit stand by. The presence of UV purification unit after the MF unit The extra barrier of the final chlorination of productive water is considered one of the safety barriers against bacterial contamination 	E*	1	4	4	Low
Treatment	The probability of exceeding the reference limits of the Jordanian standard of water produced due to decrease the intensity of radiation and the dose of disinfectant and low efficiency of purification of raw water from the ultraviolet sterilization unit because bulbs are not cleaned or lamps come near the shelf life	Microbial	2	4	8	Moderate	<ul style="list-style-type: none"> The extra barrier of the final chlorination of productive water is considered one of the safety barriers against bacterial contamination 	E*	1	4	4	Low
	Shortage of production quantities of the station to disable the work of air valves, which leads to high pressure of the unit and stop automatically due to the failure of the air -feeding system of the air valves in the MF filter unit	physical	3	3	9	Moderate	<ul style="list-style-type: none"> Preventive maintenance programs issued and prepared based on catalogs and standard operating books. Availability of spare parts. The existence of a backup air system 	E*	2	2	4	Low

Continued

	Increase in turbidity due to withdrawal of soil to the network due to fractures in it	physical	2	3	6	Moderate	<ul style="list-style-type: none"> Response speed to repair broken water lines by operations department Matching materials used (pipe materials used, joints and joints) with relevant specifications Speed response to quality complaints related to color change or the presence of turbidity 	E*	2	2	4	Low
Distribution	Pollution of water due to the flood of sewage manhole that result from the clogging of sewage networks	Microbial Chemical physical	5	4	20	High	<ul style="list-style-type: none"> Preventive maintenance of sewage lines close to water network lines. Preserving excess residual chlorine in the distribution network according to the Jordanian Standard for drinking water. Existing of qualified technician that can deal with situation 	E*	3	2	6	Low
	Pollution of water due to accumulation of soil and sediments at the end of the lines, especially in low areas	Microbial physical	3	1	3	Low	<ul style="list-style-type: none"> increase the length of the pipe line about 5 m to give sediment and soil extra space to accumulate 	E*	2	1	2	Low
	High water turbidity due to the entry of soil to the network through broken pipes, due to maintenance of damaged networks, which include repair or replacement of main lines	physical	3	3	9	Moderate	<ul style="list-style-type: none"> Regular maintenance of pressure dampers in the area. Increase staff efficiency 	E*	2	3	6	Low

*E: Effective; +NE: Not Effective.

capacity 22,000 m³/h but the amount of water entering the station is about 14,000 m³/h which was 2/3 of the full capacity of the treatment plant. Currently the operator uses 5 of 7 of the MF unit and if one of the MF is damaged or need maintenance the operator used one of the MF unit that is stand by. The validation of this control measure displayed that they are effective. So that, likelihood for this hazardous event reduced from most probable to infrequent, so on the risk becomes low. But when the control measures are not effective the likelihood could not be reduced.

Assessment of likelihood must be objective. So, WSP members used historical data of monitoring programs from data bank of Laboratories and Quality Affair/Water Authority of Jordan and the facts provided by the DWOS manager and operator.

Upgrade of WSP must be done after assessment of a risk. So new control measures were identified to reduce risks for each hazard event considered that had medium to high risk rate. Stopping work of air valves lead to high pressure

of the unit and which stop automatically due to the failure of the air -feeding system of the air valves in the MF filter unit and so on reducing quantities of water production of the station. So that existence of a backup air system and availability of spare parts could be considered as a new proposed effective control measures.

4.3. Upgrading Plan of a Monitoring and WSP's Effectiveness Verification

Monitoring plan was developed after determination of new control measures, including; what should be done, how it should be done, when it should be done, where it should be done and who is responsible. Furthermore, stringent limits and related reformist actions were recognized. Stringent limit for each water quality characteristics were fixed value lower than limits of Jordanian standards [9]. An override of stringent limits needs serious reformist actions, to get safe water to users. WSP members should discussed reformist actions for each hazard event with local health authority to take a decision about application of an alternative emergency plan for water operating system.

Table 10 showed an example regards the monitoring of increase in turbidity of the water produced from the MF unit due to damage and rupture of the filter membranes. The water utility engineer and the operator should monitor the pressure differential readings of the filters (ΔP) and the measurement of the flow of the individual filters in addition to the turbidity measurement of the MF filters.

Table 10. Example of stringent limits and related reformist actions (monitoring plan of WSP).

Process phase problem	What should be done	When it should be done	Who is responsible	How it should be done	Stringent limit	Reformist actions
Increase in turbidity of water protected from MF unit due to damage and nature of filter membrane	<ul style="list-style-type: none"> Pressure reading for filters (ΔP) Resistance The turbidity measurement of MF filter 	Instantaneous measurement	<ul style="list-style-type: none"> Measuring devise in the station Operator in the station 	Instantaneous devise and Instantaneous reading on the control panel	$\Delta P > 4.0$ Kpa/MIn $\Omega > 8.0$ Turbidity = 1.0	<ul style="list-style-type: none"> Replace the filter according the operation maintenance manual Request with new filters Monitor the turbidity of each candidate individual based on the reading of combined filters Control the R-Cl₂ to be at least 1.5 mg/l of water produced
High water turbidity due to the entry of soil to the network through broken pipes, due to maintenance of damaged networks, which include repair or replacement of main pipe	Status of complaints received from the united complaints center	All the time	Balqa water Administration	Respond to compliant status	Contamination status	Depending on the procedure for dealing with quality complaints

Table 11. Example of what, where, when, how, and who will be verified in verification plan.

What	Where	When	How	Who
Chemical parameter (Comp, NO ₂ , ABS, Al, Fe, Zn, Cu, Mn, Color)	Final product	Every 6 month	Waj Lab	Monitoring section/Maj lab
Chemical parameter (As, Pb, Cn, Cd, Cr, Ba, SeB, Hg, Ag, Ni, Sb, F, Mo)	Final product	Annually	Waj Lab	Monitoring section/Maj lab
Pesticide, Herbicide)	Final product	Annually	Waj Lab	Monitoring section/Maj lab
Turbidity, R-Cl ₂ , NH ₄	Raw water and final product	3 times/week	Waj Lab	Monitoring section/Maj lab
Total Coliform, <i>E. coli</i>	Raw water and final product	3 times/week	Waj Lab	Monitoring section/Maj lab
Total Coliform, <i>E. coli</i>	Network	4 times/week	Waj Lab	Monitoring section/Maj lab

A verification plan was established after generating the monitoring plan. It included what will be verified, where it will be verified, when it will be verified, how it will be verified, and who will do the verification as shown in **Table 11**.

Table 11 showed example related with verification of biological water quality characteristics in distribution system, in order to accomplished water safety requirements for users. Biological water quality parameter (microbial pathogens, such as *E. coli*) must be monitored monthly. Monitoring process includes collecting water samples from drinking water treatment plant and from water distribution network randomly and analyzing it in WAJ laboratory.

5. Conclusion

WSP is an important tool for water operational and management assessment for Fuhais town. So it was discussed and shared with the water administration manager. To improve water quality, serious topics related to DWOS were determined and control measures were proposed. By implementing WSP, many advantages were realized in Azraq DWOS. It minimizes risks related to public health, confirms compliance of the water quality parameters with Jordan regulation requirements, improves the confidence of consumers about drinking water quality to use, and develops intervention planning for good resource management. Some of the new control measures proposed in WSP are already adopted by the water administration manager.

Conflicts of Interest

The author declares no conflicts of interest.

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