RESEARCH ARTICLE

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Risk Assessment of Water Supply System Safety Based on Water Safety Plan (WSP) Implementation in Hamadan, Iran

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Background & Aims of the Study: There are several methods for determining the water supply system safety, including the WSP program that recommended by the World Health Organization (WHO). So, the aim of this study was assessment the water supply system of Hamadan city based on the Water Safety Plan (WSP) guideline introduced by the world health organization in 2018.

Materials & Methods: This investigation employed the WSP-QA Tool and the WSP manual of the WHO and the AWI in 2017. For this purpose, software checklists were prepared and, after confirmation of content and face validity, completed based on Hamadan water and wastewater company records and interview with company's experts. Data was analyzed using WSP-QA Tool and then system hazards were identified and risk assessment and prioritized hazards were performed by use of semi-quantitative risk matrix approach presented by the WHO guideline.

Results: The results showed that from the total score of 440 complete implementations of WSP and according to the 384 score related investigation different phases of this study, the 220 score was achieved that 50 % was coordinated with WSP. The Results of risk assessment showed that discharge wastewater from a village and agriculture in the catchment, blocked filter and algae in treatment, old pipe and excavation and installation facilities in the distribution and pressure drop and constructing wells at home in point of use are the most important hazards in water supply system of Hamadan.

Conclusions: Overall, The results showed that the implementation WSP in Hamadan city is in a moderate situation.

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Background

One of the prerequisites for maintaining the health of the community is the use of safe drinking water (1). So, water is very important for human activity (2). In recent decades, industrialization, mechanization of agricultural activities and population growth, etc., is among the factors that pollute drinking water (3). Various diseases such as diarrhea, cholera, dysentery, typhoid, etc. can create by polluted drinking water (4). Overall, contaminated water due to the degradation of water quality and can threaten the human health and disturb the balance of the ecosystem (2,5). Water suppliers are responsible for providing safe water to the community use. Various tools are available to ensure the safety of water supply systems, including the hazard analysis critical control (HACCP), qualitative microbial risk assessment

(QMRA), and water safety plan (WSP) (6). The water safety plan is the most effective way to ensure the safety of a drinking water supply system and control hazards (7,8). WSP include three components: System assessment, operational monitoring and management, and communication.

This program should pay particular attention to the water supply system because of human health and ecosystems (9). Various studies have shown that water supply systems that have implemented a safety program have made significant advances in reducing the incidence of diarrhea, increasing consumer satisfaction and better financial management (10-12). One of the important points in implementing the water safety plan are evaluating the implementation of this program. For this purpose, the World Health Organization (WHO) and the International Water Association (IWA) presented the software quality assurance tool (QA-TOOL) in 2010 (13). This tool consists of four distinct sections (14).

To ensure the safety of drinking water to consumers, risk assessment has been recognized as a useful tool. One of the capabilities WSP is identifying hazards, hazardous events and determines their risk level (15). For risk assessment and priority hazards, WHO presented a Semi-quantitative risk matrix approach that use a 5*5 matrix table (16). WSP is implemented in most countries. Also in Iran, WSP were implemented in many of its cities since 2013, but despite the introduction of WSP-QA TOOL by WHO, not much use is made to ensure the WSP performance. Also, the important hazards in water supply system not detected by water suppliers especially in Hamadan.

Aims of the study: The purpose of this study is to investigate Water Safety Plan in Hamadan to determine their strengths and weaknesses by use of the WSP- QA TOOL and also identifying important hazards in four components of the Hamadan water supply system and risk assessment accordance with the WHO guidelines.

Materials & Methods

Study area

Hamadan province is one of the 31 provinces of Iran that located from the west zone. Its center is Hamadan city. The province of Hamadan covers an area of 19,546 km^2. The city is 1,850 meters above sea level. According to the national census held in 2016 the population of the province was 1,738,234 people. Its latitudes and longitudes are 34°.58′ and 35°.48′ N; 48°.34′ and 49°.36′ E respectively (17). Location of Hamadan city is shown in Figure 1. Sources of supply water in Hamadan based on seasons change are different, in warm season (spring and summer) the main source of supply water is Ekbatan Dam that its water stemming from Khako River. In cold seasons (fall and winter) main source of supply water is 115 wells which are drilled in the upper plains. In addition to, the sources of supply water are surface water (70 %) and ground water (30 %).

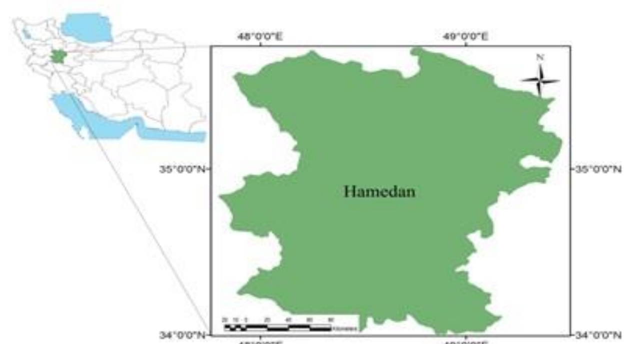

Figure 1) Location of Hamadan city

Methods

This is an analytica-discriptive study that was conducted in two sections as follows in the Hamadan supply system in 2018.

First section: assessing the Hamadan WSP program

For assessing and survey WSP program, we used the WHO QA tool (16). This tool is the MS Excel-based tool and has four sections including menu, description of the tool, assessment of data entry, and assessment of results. The assessment of data entry section is divided into two parts: qualitative and quantitative questions being presented in 12 tables. Each table includes a series of questions where each question includes some guidance on how to answer. For data collection, software checklists consisting of 85 questions or 110¬ question items were prepared and completed by the members of the WSP team based on implemented activities in WSP. System, scoring is based on the manner of implementation of every stage ranging from 0 to 4, in which every stage can range from "not started" to "done completely." Furthermore, in addition to the mentioned scores, some questions could be marked "not applicable." After entry data and completion of the evaluation process, the results were presented in form of tables and graphs. To measure the validity of the translation of the software questions, the translation-back translation technique was employed (8). For reliability and validity of the checklist, face validity and content validity methods are usually used along with an expert panel (8).

Second section: Risk assessment

In this study, the WHO guidelines were used to identify hazards and risk assessment of the Hamadan water supply system. For this reason, experts from the water and wastewater company of Hamadan who had enough information about the WSP program and the risks present in different stages of the water supply system were used. After identifying the hazards by the help of WSP team and also field visits of different sections of the Hamadan water supply system, Semi-quantitative risk matrix approach was used for ranking the hazards. In this method, we used a 5*5 matrix table (Table 1) (16). One part of this table includes the severity and the other part is the likelihood or frequently hazardous event. The aim of the prioritization matrix is classification hazardous events and identifies important risks for proper planning to manage them. After determining the important risk, corrective actions were also proposed.

Table 1) Semi-quantitative risk matrix approach

	Severity or consequence				
Likelihood or frequently	Insignificant or no impact – Rating: 1	Minor compliance impact – Rating: 2	Moderate aesthetic impact – Rating: 3	Major regulatory impact – Rating : 4	Catastrophic public health impact – Rating: 5
Almost certain/ Once a day – Rating: 5	5	10	15	20	25
Likely / Once a week – Rating: 4	4	8	12	16	20
Moderate / Once a month – Rating: 3	3	6	9	12	15
Unlikely / Once a year – Rating: 2	2	4	6	8	10
Rare / Once every 5 years – Rating: 1	1	2	3	4	5
Risk Score	<6	6-9	10-15	>15	
Risk rating	Low	Medium	High	Very High	

Results

In Table 2 overall score of implementing different step of WSP was shown.

Table 2) The result of a general assessment of WSP steps using the WSP AQ tool for Hamadan water supply system in 2018

Overall progress with WSPs			Score (Implemented %)
Step	No. of questions	Total possible points	
WSP team	5	20	17 (85.00%)
System description	2	8	6 (75.00%)
Hazard identification and risk assessment	7	100	86 (86.00%)
Control measures and validation	5	68	12 (17.65%)
Improvement plan	3	48	15 (31.25%)
Operational monitoring	4	64	40 (62.50%)
Verification	8	32	9 (28.13%)
Management procedures	3	36	28 (77.78%)
Supporting programmers	2	8	7/8 (87.50%)
Review of the WSP	5	56	-*
Total	44	440	220 (50.00%)

Table 3) Acquired score by main component of water supply system Hamadan in 2018

System components			Score (Implemented %)
Component	No. of questions	Total possible points	
Catchment	23	88	41 (47.00%)
Treatment	23	88	46 (52.00%)
Distribution	23	88	44 (50.00%)
Point of use	23	88	42 (48.00%)
Total	92	352	173 (49.15%)

According Results of Table 2, from the total score of 440 complete implementations of WSP and according the 384 score related investigation different phases in this study, the 220 score was achieved that 50% was coordinated with WSP.

In Table 3, WSP program implementation is shown according the system components. Based on results of this Table, treatment component is a highest coordinate with WSP (52%) and the catchment is low coordination (47%). But differences between score four components are low and in total the score implementation of components is 49.15 percentages. In Aghaei et al. (14) study, so the treatment and distribution component are in high attendance.

The identification hazard and risk assessment phase include three key parameters such as stakeholder identification, risk identification and risk assessment (16). The result shows that stakeholder, hazard identification and risk assessment above the 80% coordinate with the WSP program (Figure 2).

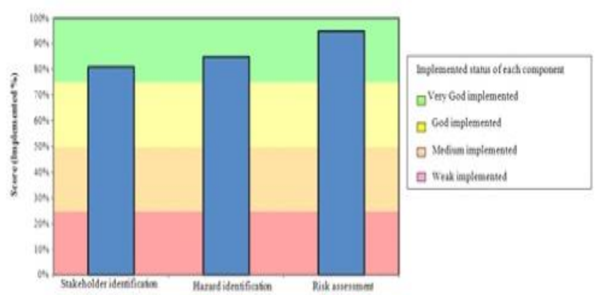

Figure 2) Implementation different section of hazard identification with WSP in Hamadan in 2018

In Figure 3 (A-D), results of coordinated implementation of WSP phases of main component of the system: catchment, treatment plant, distribution system and point of use (A-D) are shown.

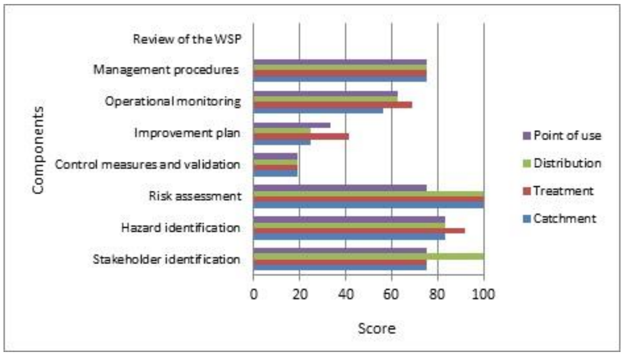

Figure 3) Results of coordinated implementation of WSP phases in Main component of system

In Table 4, the result of important risks in different components of the Hamadan WSP program is shown.

Table 4) Prioritization and risk assessment of most important hazardous event in Hamadan water supply system in 2018

Process step	Hazardous event	Hazard type	Likelihood	Severity	Score	Risk rating	Corrective actions
Catchment	Discharge wastewater from village	Microbial	5	4	20	Very High	- Construction treatment plant - Increasing Villagers awareness about the risks of Drainage into water
	Pesticide and nitrogen fertilizer use in agricultural activities	Chemical	3	5	15	High	- Collection and management of agricultural Runoffs - Train Farmers to use green fertilizer
	Wastewater from mining	Chemical	5	4	20	Very High	- Collection and management of - Construction treatment plant - Applying fines in the event of drainage into the water
Treatment	Algae bloom	Chemical	2	3	6	Medium	- Reducing water stays - Continuous cleaning of water reservoirs - Appropriate chlorination
	Block filter	Microbial and Chemical	3	4	12	High	- Create an appropriate water back wash - Change the filters on time
Distribution	Fracture of pipe due to the excavation and installation of facilities	Chemical and physical	3	4	12	High	- Installing the panel in The Length of the distribution network Preparing GIS map for Pipe Line - Coordination with relevant departments to create facilities
	Old pipe	Chemical	3	3	9	Medium	- Replacing worn pipes - Continuous inspection
	Neighboring the sewage line with distribution pipe	Microbial	2	5	10	High	- Moving the water transmission path - Install leak warning system
Point of use	Pressure drop	physical	4	3	12	High	- Use of special pumps with high power - Consumer education to optimize consumption culture
	Construction of wells in home	Chemical	4	4	16	Very High	- Prevent the construction Wells - Information on the dangers of using such wells

Discussion

The results showed that supporting programmers (87.50 %) and Control measures and validation

(17.65 %) phases were the highest and the lowest coordinated with WSP program, respectively (Table 2). Eslami et al. (2018), in their study showed the 52.95 % coordinating with WSP program (8). They indicated that, system description phase is the highest score. Also Aghaei et al. (2017), in their study showed that the system description phase has a high score, whereas in this study supporting programmers has the highest score (14).

In all study that done on the WSP program in different city of Iran (Ardabil, Zanjan, Birjand), results demonstrate that the review of the WSP has the lowest score which can indicate a lack of attention to this phase (8,14,18). The formation of the WSP team and them role is very important. The WSP team includes the leading group, development group, the operating group, and expert. Each of these groups has its own unique responsibilities. For example review of the WSP, control measures and validation are the main role of the operational group (19). In this study, in spite of the high coordinate some phases such as WSP team (85%), system description (75%) and hazard identification and risk assessment (86%), the Control measures and validation (17.6 %) and verification (28.13 %) have in low coordination that this result can demonstrate that the teams are inadequate combined because based on study Ye and et al. (2015) (20) one of the important role of the leading group in the WSP team is planned and organizes the coordination of WSP activities, that seems this goal has not been well achieved in the Hamadan WSP team. On the other hand, the development team has done its job well. In Iran, WSP has been implemented several years. In most cities, has implemented well into the third phase. The WSP team in Hamadan consists of experts from various departments, such as urban and rural water and wastewater, environmental, medical science and etc., Due to the government being and the lack of coordination between them, regular meetings are not normally held. Another problem of the WSP in Hamadan is a lack of basic information because of not record information. So, due to the not fully implementation WSP in Hamadan, the review of the WSP has done yet.

According the Figure 3, in three components (catchment, treatment plant and distribution system) the risk assessment phase is in high score, whereas control measurement and validation is the lowest score. In point of use, hazard identification and, control measurement and validation are in the high and low score, respectively. Eslami et al. (2018) in their study that conducted on the WSP program in Sarayan (Birjand city), demonstrated that stakeholder phase in four components is the high score and management procedures are in lowe score (8). In this study, in spite of the high score in some phases such as stakeholder identification, hazard identification and risk assessment, control measurement and validation and, improvement plan phases are in low scores. Concurrently with identifying the hazards and evaluating the risks, the WSP team should document existing and potential control measures. In this regard, the team should consider whether the existing controls are effective. Depending on the type of control, this could be done by site inspection, manufacturer's specification, or monitoring data. Validation is the process of obtaining evidence on the performance of control measures (16). Management procedure is a serious action that to be taken during normal and incident condition (Ye et al. 2015). Procedure management should be written by expert staff and their experienced and it needs to update (16). In a WSP of Hamadan, fortunately, different aspects of WSP are well documented and management procedures are written, it's also necessary to work on the implementation plan in the system.

According to the progress made in the development of the south Korean WSP program in 2013, one of the objectives of this development is to increase the safety of drinking water due to the identify and assess the risks and incidents of the water supply System (21). The berlin WSP program workshop in 2014 also introduces this program as an effective method for risk management in the 21 century, which even in the long run, complies with the EU drinking water Guidelines, the WSP is a systematic approach and is a useful management tool for ensuring the continuous delivery of safe drinking water to the consumer (22). Accordingly, risk assessment the Hamadan water supply system was carried out according to the guidelines provided by the World Health Organization.

According the season changes in Hamadan, the source of water supply is different. In summer, Ekbatan Dam is the main source of water supply. The water of this dam is provided by the Khako River. In the upper reaches of this dam, there are villages that use water of the Khako River for agricultural activities. Therefore, the use of agricultural pesticides and the entry of agricultural drainage to the river and finally the Ekbatan dam is one of the sources of water pollution. Another source of water pollution in Hamadan water supply is the entry of human sewage into the river. Also, in this study, according to results of Table 4, the discharge wastewater from the village and pesticide from agriculture activities are high Risks in catchment component (score=25). Agaei et al. (2017) in their study demonstrated that discharge wastewater from rural around the source water supply in Ardabil is a high risk (14). Pourakbar et al. (2015) in their study stated that, one of the main source pollution that threatens the safety water is discharged wastewater into the river (18). Enter the wastewater and sewage into the source water can cause microbiological problems. One of the concerns to consumer, regulators and water suppliers is the microbiological quality of drinking water (23). It is documented that transport microbial pathogens in drinking water can cause subsequent illness (24). Upon the opinion expert in the wastewater organization in Hamadan and based on result of risk assessment (Table 4), the leaching nitrogen fertilizer used in agriculture is a high risk item (score =15) can be cause problems nitrate in surface and groundwater. Ye et al. (2015) in study on two water utilities showed that agricultural fertilization surrounding water source is a concern in catchment (20). The main sources nitrate in drinking water is nitrogen-fixing bacteria in soil, animal manure, and nitrogenous fertilizer and nitrogen compounds emitted by industry (25). The united state environmental protection agency (26), in a study on concentration nitrate in wells, private and public water system in 38 and 50 states, respectively, demonstrated that nitrate in 1.2% public water system and 2.4 % of private wells were exceeded from standard level. The poisoning of nitrate at first, related to its ability to convert nitrite (27). It can effect on the hemoglobin's ability to bind with oxygen because of oxidize it to meth hemoglobin. More concern related to metabolism of dietary nitrate is potential to formation N-nitrous compound that can cause cancer (28). According to study that conducted in Germany (29), it is demonstrated that the first barrier to presentation of entering contamination into the water system, is protection of water sources. Various methods exist for removing nitrate in water includes Reverse osmosis (30), biological treatment (31) and electro dialysis (32). According to experience indicated that the best technique for removing nitrate in ground water is ion exchange, whereas in surface water, biological denitrification is the perfect method (33). Other high risk items that indicated in catchment of water supply system in Hamadan is discharge wastewater from granite stone mining (score =20). The particulate matter from this mining can pollute the water and decreases the quality water and cause the block filter in a treatment plant.

According the staff opinion and result risk assessment in treatment component, one of the most important risks is block filter (score =12)

(Table 4). Another source water supply in Hamadan is well. To transport water wells, storage tanks and sedimentation pond are provided, that is pumped in distributed network after chlorination. One of the specific hazards that are determined in Treatment plant such as storage pond is algae bloom (14,20). Also, in this study, according to the results of (Table 4) Algae bloom are identified as a medium risk (score =6) in this system because the water is stable. According to the studies, there are more risks for filtration and chlorination in treatment plan, so, it is necessary to pay special attention to these units. There are a several methods to eliminate algae include sand spray, micro filter and coal application (9). In the treatment process, online control of filter flow may be necessary to avoid different flows in parallel operating filters and too high filter velocities. Additionally, the online measurement of turbidity, dissolved oxygen and pH-value in the filter effluent may be advisable dependent from the application. If surface water is treated, additional particle counting in the filter effluent will be an advisable monitoring action. Also, results showed that three hazards identified as high risk in distribution system include: Fracture of pipe due to excavation and installation of facilities (score=12, high risk), old pipe (score=9, medium risk) and neighboring the sewage line with distribution pipe (score =10, high risk). The likelihood rating the neighboring sewage line with distribution pipe is 2 (Unlikely/Once a year) but in case of danger, it can create a serious threat to human health. Old pipe known One of the medium risk in the Hamadan water supply system (score =9). US EPA (2002) argued that corrosion of pipes is one of the main concerns of the distribution system (34). In a study that conducted in Iceland, indicated that one of the reasons for increasing the number of bacteria in drinking water is old pipes (35). So, for solving this problem, prioritize the area with high exposure to risks and huge money investments are needed.

In Hamadan, in some parts of the city, because of the presence of residential houses on the upstream, often face the problem of dropping pressure, that in this study identified as high risk (score =12) (Table 4), therefore residents of these areas have drilled wells in their own yard, which is used without any treatment that according results of Table 4 is in very high risk level (score =16). So, in this case supposed that use power pumps bring water to the upstream areas, informing people about the health risks of using wells drilled by them. In addition, for hazard control, appropriate measures must be defined. These measures called corrective action and control measures. Corrective action happens when the results indicate the loss of excitation controls, but control measures are activities that used to prevent the occurrence of hazards (36). In Table 4 for each hazard, corrective action is proposed. Control points are essential to ensure corrective action. Control points can include warning and alarm instruments. In water supply system, treatment plants are very important. Experience has shown that some treatment plants already have control procedure, but, the existing procedures are not well applied.

Conclusion

The risk assessment of the water supply system in Hamedan showed that there are very serious risks in this system that could endanger the health of citizens if control strategies are not provided. The most important of these hazards in the source of supply and at the point of use are the entry of human waste and wells drilled in residential houses to provide drinking water, respectively. Water from these wells is used without any purification, due to the presence of sewage wells in these homes, the probability of microbial contamination is high. The results showed that implementation WSP program in Hamadan city is in a moderate situation. Management procedure is defined, but control measures and validation and improvement plan not fully implemented. So, it needs the corrective actions control points must be defined for preventing and controlling hazards in different component of the Hamadan water supply system.

Footnotes

Conflict of Interest:

The authors declared no conflict of interest.

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