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Risk assessment of water supply system safety based on WHOs water safety plan: case study Semnan, Iran

Vahid Razmju[a], Khalilollah Moeinian[a], Ayat Rahmani[b,*]

[a]*Department Environmental Health, Semnan University of Medical Sciences, Semnan, Iran, Tel. +98 2332239087, email: artinrazmjuu@gmail.com (V. Razmju), Tel. +98 2332239180, email: khalilollah@yahoo.com (K. Moeinian)*
[b]*Research Center for Health Sciences and Technologies, Semnan University of Medical Sciences, Semnan, Iran, Tel. +98 2122239186, email: Ayat_rahmani@yahoo.com (A. Rahmani)*

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ABSTRACT

This study investigated to assess and identify the vulnerable points in Semnan water supply system based on Water Safety Plans (WSP) in 2018. The water safety plan quality assurance tool (WSP QA tool) software was used as a tool to measure the weaknesses and the progress of the water safety plan. At the first step, WSP checklists were prepared and completed up by experts' staff and data analysis using WSP QA tool. In the next step, system hazards were listed and ranked according to WHO matrix by team member's expert's view and the risk analyses were arranged. The results show that the highest compliance with the implementation of the water safety plan related to the step system description is achieved with (100%) and the lowest match for the step improvement plan with (0%). It can be said that old infrastructure, old pipes, and consequently pressure drop in point of use were identified as the most important hazardous events. Considering that Semnan water supply is groundwater, by further focusing on other areas such as basin, transmission and distribution lines and point of consumption, as well as full implementation of the water safety program in this system, more favorable results and coordination rates are achieved.

Keywords: Water safety plan (WSP); Semnan city; Risk assessment

1. Introduction

It is the right of all humans to have adequate, safe, available and affordable water [1]. According to the Millennium Development Goals (MDGs), approximately 663 million people do not have access to improved drinking water supplies and there are 1.8 billion people that the fecal contamination is transmitted to their water resources[2]; and, In order to reduce this difference [3], it is essential to pay special attention to preventive management of the water supply system [4,5]. Studies show that diarrhea is responsible for 10% of global mortality in children under the age of 5 [6]. In goals of SDG (Sustainable Development Goals), it has stated that access to safe drinking water should be possible for all communities by 2030 [7]. In the 20th century, with the advent of science and technology, the entry of chemicals into drinking water became one of the most important causes of the outbreak of the disease [8]. The Centers for Disease Control and Prevention (CDC) reported that the incidence of 34 water-borne diseases between 1993 and 2006 in the United States is related to chemical compounds such as nitrate, nitrite, fluoride, and lead [9]. The framework of health-based targets, water safety plans and independent monitoring according to GDWQ (Guidelines for Drinking Water Quality) is required to ensure water safety that Guidelines has provided for supporting this framework [10,11]. Following the framework and structures that were expressed in the stallion in 2001, the WSP was presented in 2004 by WHO (World Health Organization) guidelines

*Corresponding author.

[12]. Following the framework and structures that were announced in Stockholm in 2001, the WSP was presented in 2004 by WHO (World Health Organization) [11]. The water safety plan has been implemented in many parts of the world, as summarized in (Table 1).

The WSP guidelines were used to assess the risk of the water supply system of Semnan city and, at the first, potential hazards in the system were identified. The purpose of this study is to assess and identify the vulnerable points with high risk in Semnan water supply system based on WSP in 2017. Detection and anticipation of weak points in the management of Semnan drinking water supply system will guide us to identify those areas that need improvements. By control of these points, safe drinking water can be delivered to consumers.

2. Materials and methods

2.1. Study sites

Semnan is one of the cities of Iran and the capital of Semnan province and Semnan County, and its climate is dry and temperate. The city is located at longitude 5323′ and latitude 3534′ and its average altitude above sea level is 1130 m. Groundwater is the water supply systems in Semnan city. In the study just, groundwater was considered in this study. The study area and its location are shown in (Fig. 1). Component of Semnan water supply system (catchment to consumer) is represented in this (Fig. 1).

2.2. Application of the water safety plan quality assurance tool (WSP QA tool)

The WSP guidelines were used to assess the water safety plan quality assurance of Semnan city and, at the first, potential hazards in the system were identified. The water safety plan quality assurance tool (WSP QA tool) software was used as a tool to measure the weaknesses and the progress of the water safety plan. This software has provided by the World Health Organization (WHO) and the International Water Association (IWA) based on Excel in 2010 to assess the implementation of the water safety plan. Also, this software is able to determine the points that need to be upgraded [3].

The software consists of 12 tables in which each table contains the questions and some tips about how to answer the questions. In this software, the scoring is carried out in a 5-score system (zero to four); each step can include a range from “Not started” to “completely done”.

Table 1
WSP initiatives around the world

Country	Summary	Reference
Iran	Risk assessment of water supply system safety based on WHOs water safety plan: case study – Ardabil, Iran. With regard to the low level of overall implementation in WSP steps and lack of enough attention to water supply system in some phases, current control approach has no sufficient efficiency to provide safe drinking water.	[13]
Asia-Pacific	Measuring the Impacts of Water Safety Plans in the Asia-Pacific Region. This study provided an opportunity to test the impact assessment methodology itself, and a series of recommendations are made to improve the approach (indicators, study design, data collection methods) for evaluating WSPs.	[14]
Uganda	Case study of Water Safety Plan development in Uganda according to WHO guidelines	[15]
South Africa	Annex C of South African National Drinking Water Standard (SANS 241) sets out a guideline recommending implementation of WSP approach	[16]
India	Case study of Water Safety Plan development in Guntur, India according to WHO guidelines	[15]
Japan	Japan’s trial introduction of HACCP into water quality management. Investigation into a practical procedure in introducing the HACCP into water quality management in Japan	[17]
Caribbean	Water Plus’s Partnership between PAHO, CDC and EPA to implement WSPs in Latin American and Caribbean countries	[17]
Europe	TECHNEAU, an integrated project funded by the European commission, challenges the ability of traditional system and technology solutions for drinking water supply to cope with present and future global threats and opportunities. Work Area 4 is focusing on risk management	[18]
Taiwan	Integrated water management plans towards sustainability: the Taiwan experience. Water Safety Plan was developed as the ‘Green Blue-Print’ for the development of strategies and guidelines of national sustainable water environment	[19]

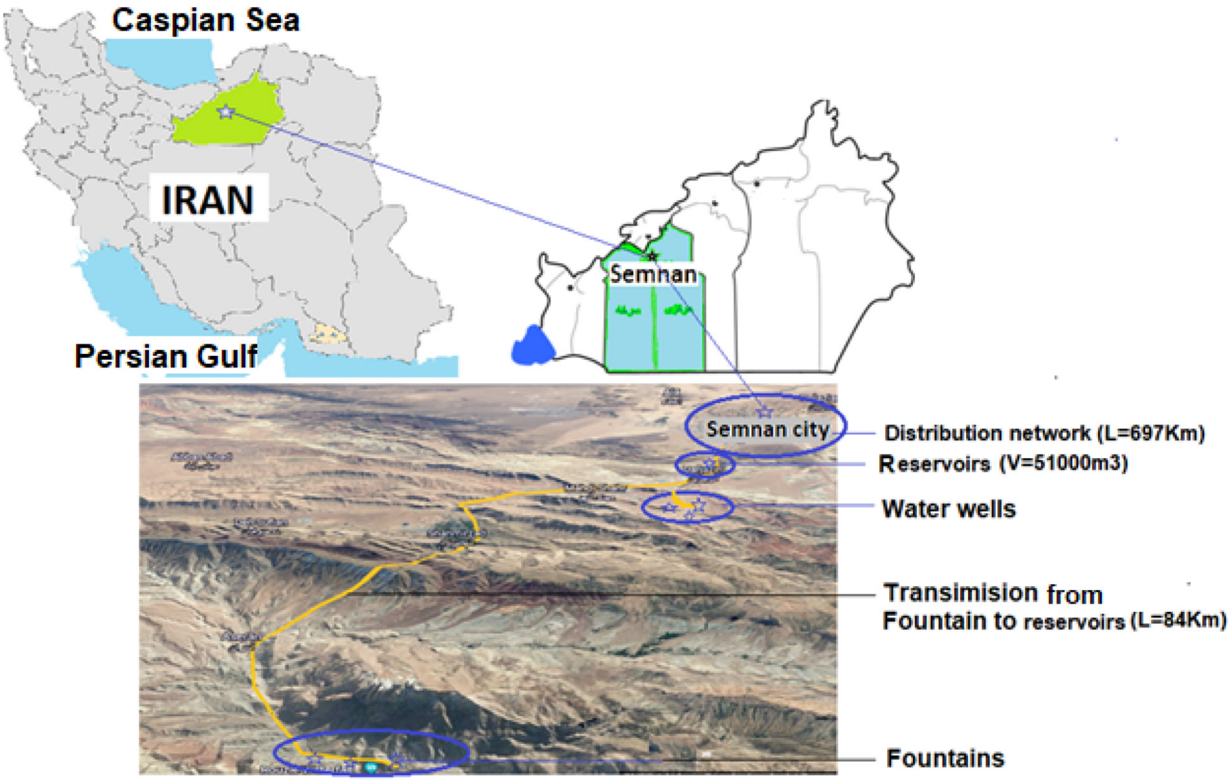

Fig. 1. Component of Semnan water supply system and location of Semnan city in Iran.

2.3. Risk assessment

Risk assessment was conducted through interview and discussion methods and the Semnan urban water and waste water experts, who had sufficient information and awareness about the system, were used to assess the risk. This group should be able to provide methods to control the risks. In order to understand the most important threats to the system, prioritization of hazards has been done to focus on the most important ones; and, in addition, the documentation on the risks was also examined. Prioritization of risks was done in two steps; and, after the first stage, the second stage was completed two weeks later. After prioritizing the risks, the 5 × 5 semi-quantitative risk matrix approach was used which, according to the requirements of the water safety plan, all potential hazards were considered [1]. The common hazards in many four main component of Semnan water supply system are listed. that identified a risk are prioritized based on risk assessment matrix in WSP. The objective of the matrix is to emphasize the risks and hazardous events that had the highest importance in the water supply system. Next risk assessment, hazard analysis tables are prepared and finally corrective actions are planned to control and reduce the identified risks. All commonly identified hazard events to each component are listed as follows:

1. Watershed and catchment 10 hazards
2. Water treatment plant 12 hazards
3. Distribution network 12 hazards
4. Point of use 9 hazards

Risk levels are classified into four groups as follows: Low (< 6), Medium (6–9), High (9–15), and Very High (>15), which are shown in (Table 2).

These levels are calculated based on the following formula (Eq. (1)):

$$Risk = Likelihood \times Severity \tag{1}$$

After assessing the risks, using the views of the experts of the Water and Wastewater Company, texts, reports, articles and people who were aware of this, the corrective strategies were proposed to prevent and eliminate hazards.

2.4. Data analysis

The internal correlation coefficient (ICC) was used for data analysis, and Cronbach's alpha using SPSS software was applied to determine the reliability of the questionnaire. This is a descriptive statistic that can be used when quantitative measurements are made on units that are organized into groups. It describes how strongly units in the same group resemble each other. Cronbach's alpha is one of the most common methods for determining the internal correlation coefficient used which is calculated using the following equation:

$$r_{\infty} = \frac{j}{(j-1)}\left[1 - \frac{\sum s_j^2}{s^2}\right] \tag{2}$$

where j is the number of questions, S_j^2, the variance obtained for each question and S^2 is the general variance of all questions.

Table 2
Semi-quantitative risk matrix approach [20]

		Severity or Consequence				
		Insignificant or no impact – Rating: 1	Minor compliance impact – Rating: 2	Moderate esthetic impact – Rating: 3	Major regulatory impact – Rating: 4	Catastrophic public health impact – Rating: 5
Likelihood or frequency	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 Risk rating		< 6 Low	6–9 Medium	10–15 High	>15 Very High	

3. Results

Water resources used for drinking and sanitary purposes of the Semnan city are supplied from groundwater. These resources include three fountains of Gol, Roodbar and Ruziyeh, wells inside and around the city. The transmission water from the sources of Gol, Roodbar and Ruziyeh is entered into 4 reservoirs with a total capacity of 20,000 m^3 and then is entered into the distribution network. In addition, there are other reservoirs in this system, which, in total, the total volume of water reservoirs in Semnan city is 51000 m^3. The length of the water pipeline to transfer the water to the city is 84 km. The length of the water distribution network is 696.97 km.

The results showed that, out of 440 total scores related to complete application of the program for the phases studied, 156 scores were obtained and the coordination with WSP was observed to be 35.45%. As shown in Tables 3 and 4, the highest compliance with the implementation of the water safety plan related to the step system description is achieved with 100% and the lowest match for the step improvement plan with zero percent.

Table 4
Results of general evaluation of WSP phases using software for basin separation for water supply in Semnan in 2017

System components	No. of questions	Total possible points	Score (% implemented)
Catchment	23	88	30/88 (34.00%)
Treatment	23	88	0/88 (0.00%)
Distribution	23	88	30/88 (34.00%)
Point of use	23	88	32/88 (36.00%)
Total	92	352	92/352 (26.14%)

Table 3
Result of general assessment of WSP steps using WSP AQ tool for Semnan water supply system in 2017–2018

Table	No. of questions	Total possible points	Score (% Implemented)
Table 3 – WSP team	5	20	18/20 (90.00%)
Table 4 – System description	2	8	8/8 (100.00%)
Table 5 – Hazard identification and risk assessment	7	100	52/100 (52.00%)
Table 6 – Control measures and validation	5	68	13/68 (19.12%)
Table 7 – Improvement plan	3	48	0/48 (0.00%)
Table 8 – Operational monitoring	4	64	9/64 (14.06%)
Table 9 – Verification	8	32	22/32 (68.75%)
Table 10 – Management procedures	3	36	16/36 (44.44%)
Table 11 – Supporting programmes	2	8	6/8 (75.00%)
Table 12 – Review of the WSP	5	56	12/56 (21.43%)
Total	44	440	156/440 (35.45%)

Result of general assessment of WSP steps using WSP AQ tool for Semnan water supply system in 2017–2018 Table 3.

The correlation coefficient (ICC) by Cronbach's alpha in the post-test was $r = 0.887$; CI 95%: 0.380–0.913 (Table 5). In addition, a Pearson correlation coefficient was used to assess the accuracy of the questionnaire and its results were obtained equal with $r = 0.996$, $p < 0.001$, respectively.

To assess the of existing status, the biological and chemical parameters measured in Semnan water supply system in 2017–2018 and their compliance percent with the standards represented in (Table 6).

4. Discussion

Protecting public health and providing safe drinking water should be the main objective of public water supply systems [1]. These goals are achieved through system assessment, operational monitoring, and Guided management plans based on health and monitoring purposes [3]. As shown in (Table 6), the parameters measured during the one year that coincided with the launch of the WSP show that these parameters are consistent with the standards biologically and chemically that represent the safety of the system during the research. Setty et al. conducted a review on the five studies carried out in developed countries implementing the WSP showed the improved compliance with water quality standards and reduced unwanted effects after WSP implementation [21]. One of the major challenges in assessing the impact of the WSP can be mentioned the variety of water systems that are different forms such as urban and rural areas, large and small, and so on, which can lead to the heterogeneity of the results of the WSP. In the water supply system of Semnan, at the present, the water safety plan is not fully implemented, but the measures taken in this system partly correspond to the water safety program and thus different steps have obtained various scores. The results are presented in Tables 4 and 5.

Considering that WSP has recently begun in Semnan, but employees have a good awareness about the threatening hazards of the system, they somehow know the threatening hazards of the system and their effects on health and water quality. This is because of the appropriate periodic training that has been implemented and the results also indicate the appropriate training of relevant personnel. However, due to the lack of the facilities and the aging of the lines in the distribution network, it cannot be expected that training alone can be sufficient in the event of accidents and risks. Also, the probability of organic compounds in fountains water resources of Semnan, which can increase the potential of THMS generation in the chlorination process, the use of methods for removing the organic compounds such as coagulation [22], flocculation [23], nanofiltration [24], ultrasonic [25], adsorption onto the activated carbon prior to chlorination can reduce the generation potential [26]. The use of disinfection methods, including ozonation, UV and SODIS, can play a role in reducing THM [27].

Due to the fact that the formation of biofilms in the reservoirs is one of the potential risks of water supply system in Semnan and the chlorine is used as a disinfectant

Table 6
Water quality results in year 2017–2018

Content	Maximum allowed (WHO)	Mean	Number	Compliance percentages
Free chlorine (mg/l)	0.8	0.48	60	100.00
Total coliform (CFU/100 ml)	0	0	60	100.00
Turbidity (NTU)	5	0.77	11	100.00
SO_4^- (mg/l)	400	148.18	11	100.00
NO_2^- (mg/kg)	3	0.0256	11	100.00
NO_3^- (mg/kg)	50	9.22	11	100.00
Fe (mg/l)	1	0.0375	11	100.00
Cl^- (mg/l)	400	166.63	11	100.00
E.C (µs/cm)	1000	881.5	11	100.00
Cd (ppb)	3	3	2	100.00
As (ppb)	10	5	2	100.00
Hg (ppb)	1	1	2	100.00
Pb (ppb)	10	5	2	100.00
Se (ppb)	10	5	2	100.00
Sb (ppb)	20	2	2	100.00

Table 5
Interclass correlation coefficient

	Interclass correlation[b]	95% confidence interval		F Test with true value 0			
		Lower bound	Upper bound	Value	df1	df2	Sig
Single measures	0.095[a]	0.034	0.359	8.853	6	444	0.000
Average measures	0.887[c]	0.725	0.977	8.853	6	444	0.000

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C interclass correlation coefficients using a consistency definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 7
Matrix risk assessment and control measures of the WSP in Semnan water supply system

Type of risk	Location	Hazardous events	Risk assessment			Corrective action
			Like lihood	Severity	Risk	
Physical, chemical, biologically	Catchment (source)	Rapid change in the quality of water supply due to seasonal changes, floods, heavy rainfall in the catchment area and catchment (severe drop in water entering the catchment)	2	5	10	Improvement of transmission lines, Reducing the flow of input into the treatment plant, stopping the extraction from the water source during periods of high pollution, Deviation of local flood currents by installing online devices in the direction of directing water off-route, intake control in terms of entering different and non-responsible individuals, matching downstream processes in removing pollutants according to their nature and nature, Miscellaneous and non-responsive, proportionate processes for the removal of pollutants according to their type and nature
Physical	Catchment (source)	Lack of quality online monitoring system	3	5	15	Provide adequate credit for installing equipment, equipping complete portable laboratory devices until the installation of online devices
Physical	Catchment (source)	Personnel disability, equipment and facilities in specialized operations	2	5	10	The use of trained specialist people and the establishment of training classes to increase the level of technical and specialized expertise, coordination between the relevant units at the time of the incident, follow up and submit requests for the purchase of equipment required
Physical, chemical, biologically	Catchment (source)	Corrosion or incomplete wall inside the well	2	5	10	Check existing wells regularly, schedule schedules for monitoring and regular upgrades
Physical, chemical, biologically	Distribution/ transmission system	Infrastructure of worn outs	3	5	15	Providing credit for replacing and repairing worn networks in the event of a high degree of recognition and exhaustion
Physical	Distribution	Pressure fluctuations	3	4	12	Monitoring and recording the amount of pressure/maintaining sufficient pressure on the network
Physical	Distribution/ transmission system	Lack of proper number of water drainage valves	3	4	12	Determining the status of the valves and recording as a comprehensive plan, determining the exact location of the drain valve according to the test results of the blind and the end points of the network
Physical	Distribution system	Entry of contamination due to negative pressure/pressure fluctuations	3	4	12	Monitoring and recording the amount of pressure/maintaining sufficient pressure on the network
Physical	Distribution system	Lack of proper number of water drainage valves	3	4	12	Identify the status of the valves and register as a comprehensive map
Physical, chemical, biologically	Distribution/ transmission system	Infiltration of contaminated water into the distribution network during explosion, fracture, leakage or repair of water supply lines	3	4	12	The rapid detection and removal of points in the system where frequent leaks, fractures and ... have been reported, rapid washing and disinfection of new main tubes, developed health instructions and training for all employees

Table 7 *(Continued)*

Type of risk	Location	Hazardous events	Risk assessment			Corrective action
			Like lihood	Severity	Risk	
Physical	Distribution/ transmission system	Inability of manpower, equipment and facilities in specialized operations	4	4	16	Use of repair manuals for main lines, formation of specialized meetings for updating specialized information, holding periodic training courses
Physical	Transmission system	No installation of qualitative online equipment	3	5	15	Providing adequate credit for equipment installation, continuous monitoring of the distribution network
Physical, chemical, biologically	Distribution/ transmission system	Improper water quality after disaster recovery	3	5	15	The immediate investigation of the causes or causes of water quality changes and other qualitative supplementary analyzes to reach the desired results, to investigate complaints from consumers about the quality of water, such as taste, smell, color, turbidity, etc. Refer to and fix the problem.
Biologically	Reservoir	The formation of microbial biofilms in storage tanks and THM formation	2	5	10	Continuous visits to reservoirs, scheduling of washing containers to prevent biofilms, conduct bacteriological and chemical tests continuously and in accordance with standard
Physical	Reservoir	Inefficiency diesel generator	2	5	10	Regular monitoring of equipment and storage of consumables
Physical	Reservoir	Lack of equipment quality online	2	5	10	Provide adequate credit for equipment installation
Physical	Reservoir	Damage mechanical equipment	3	4	12	Periodic visits to the facility, the use of petroleum-based materials in the tank repairs, especially lions and Peripherals materials in the tank repairs, especially lions and Peripherals
Physical	Reservoir	Damaged electrical equipment	3	4	12	Elimination of defects by the expert, the expert at recruiting and defect fixes
Chemical, Biologically	Point of use	Contamination of domestic storage tanks	3	4	12	Provide a package for consumers on how to use household purifying devices, filter replacement time and possible contamination in this regard.
Physical	Point of use	Lack of consumer satisfaction of the water quality and the use of alternative sources	3	4	12	Immediate investigation of the cause or causes of water quality changes and other qualitative complementary analyzes to reach the desired results, Investigating consumer complaints about water quality such as taste, smell, color, turbidity, etc. Addressing and solving problems, providing educational package for consumers in order to protect their water safety in the field of health, proposing sound and safe methods. To replace the water supply section

in the system, the assessments regarding the presence of Trihalomethanes (THMs) should be considered, and its measurement tests should be done [28]. The results of the investigation of heavy metals in the water supply system of Semnan also indicate that these metals in drinking water are at the standard levels [29]. Ye et al. conducted a study on two rural water supply systems in Beijing, China and found that the coordination percentage of water quality criteria with standards has increased in both systems after the WSP implementation [30]. The hazards of the water supply system, along with the proposed corrective actions, can be seen in (Table 7).

This table shows the 4 high-risk for basin area, 8 high-risk and 1 very high-risk for water supply lines, 5 high-risk for storage tanks and 2 high-risk for consumption. Among all hazards, 19 are classified as high risk and 1 risk as a very high risk. According to the results, the most important hazards in the basin area are the shortage of facilities and equipment that these deficiencies can affect the quality and health of the water due to the occurrence of events occurring in the transmission lines. Totally, it was obvious that these results distinguished the areas and points which need to be improved and also determined the insufficiency of current approach (according to endpoint testing). Another main defect of the current approach in Semnan drinking water management was concentration on "Verification" and "System Description" and abandoning other stages in authorities. This research appeared that management of major components of the water supply system was not considered appropriate that may affect the quality of delivered water to consumers. Therefore, the investigated system is not completely safe and it requests to be upgraded and improved. However, high scores that were assumed to some phases of similar verification, system description, and operation monitoring, rise the system flexibility to change recent quality management to WSP. In a study by Corinna Summerill et al. studied the role of organizational culture and leadership in implementing the WSP to improve the risk assessment; they introduced the continuous improvement of culture, accountability, competitiveness, the presence of active leaders, empowerment of workforce and appreciation in creating an effective organizational culture [31].

There is pressure drop and insufficient remaining chlorine problems which this pressure drop in point of use of water produced consumer displeasure. In research in Iceland, worn out distribution pipes are renewed in some zones that often-had high bacteria count in water samples, about limitation also observed in water due to inadequate external and internal auditing [32] exemplar the developed in Iceland frame for water supply system safety [33], development of a national frame that includes legal requirements for protection and surveillance of drinking water quality and its safety was recommended for Semnan water supply system.

In Fig. 2, the output results of the software are divided into basin areas, distribution network, and consumption point, and in Table 5, the overall assessment of the steps is noted in all three mentioned basins. Considering that there is no treatment process and its units in the water supply system of Semnan, it can be expected that, by further focusing on other areas such as basin, transmission and distribution lines and point of consumption, as well as full implementation of the water safety program in this system, more favorable results and coordination rates are achieved. Among all the different parts of the water supply system in Semnan, the point of consumption with coordination and the implementation rate of 36% had the most consistency with the water safety program; this could indicate more attention to the results and final points of the water system in Semnan. Unlike conventional drinking water quality tests, which are based on the test at the end point, WSP is a way to prevent the penetration of contaminants into the water system and its risk [31].

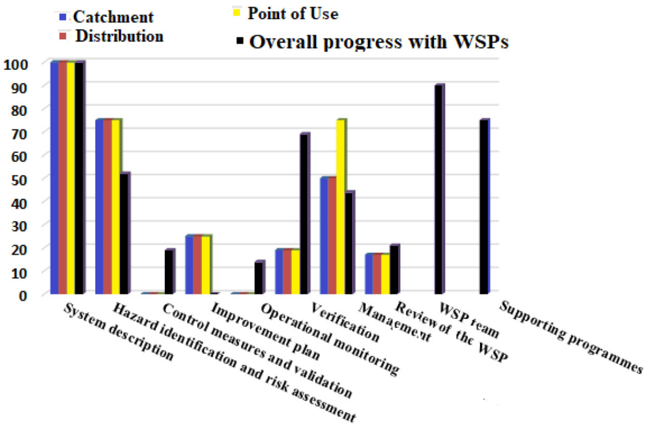

Fig. 2. WSP output results of the software are divided into basin areas, distribution network, and consumption point.

5. Conclusion

As a result, it can be expected that this limitation will be diminished by fully implementing the water safety program in this system. The results of water quality showed that there were no microbial and biological defects in the water supply system of Semnan during the research period, but due to the lack of complete implementation of WSP, there was no guarantee towards the non-occurrence of the problem. Moreover, there was no program to deal with the risks at the time of their occurrence and if contamination enters the water supply system, it can only be detected by the point of use tests. The employees of the water supply system are aware of the hazards of the system, but due to the lack of facilities, this awareness alone cannot prevent accidents and injuries. By completing the WSP in the Semnan water supply system, allocating sufficient funds to supply the necessary systems and equipment, as well as assessing all possible contaminating chemical factors, it can be expected that the risks of the system are controlled and if detected, the future risks are prevented.

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