original article

Implementation of hazard analysis and critical control points in the drinking water supply system

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ABSTRACT

Aims: This study was aimed to design comprehensive risk management based on hazard analysis and critical control points (HACCP) in the Isfahan drinking water system.
Materials and Methods: Data obtained from field inspections and through related organizations of Isfahan, Iran. The most important risks and risky events of water quality in all sources of raw water in the study area including the Zayanderoud river, the water treatment plant, and the distribution system were identified and analyzed. Practical measures for the protection, control, and limitation of the risks in different phases, from water supply to consumption point, were presented in the form of seven principles of the HACCP system.
Results: It was found that there was a potential of hazards during the treatment process of water because of seasonal changes and discharge of various pollutants. Water contamination could occur in eight identified critical control points (CCP). River water could be contaminated by rural communities on the banks of the river, by natural and sudden accidents, by subversive accidents, by incomplete operation, by lack of proportionate of the current treatment process, and by the high extent of antiquity of the Isfahan water distribution system.
Conclusions: In order to provide safe drinking water, it is necessary to implement a modern risk management system such as the HACCP approach. The increasing trend of the Zayandehroud river pollution needs urgent attention. Therefore, the role of the government in developing and mandating the HACCP system in water industries is essential.

Key words: Drinking water, hazard analysis and critical control points (HACCP), hazard analysis, Iran, risk management

INTRODUCTION

Supplying safe drinking water is considered to be one of the basic needs of the community, and it is possible through a preventive and comprehensive approach in the drinking water safety program. The Hazard Analysis and Critical Control Point (HACCP) is an internationally accepted process control system, which includes determining hazards in each step of the under-process product. In addition, in this approach, hazards will be eliminated by implementation of control measures during production, from the supply point to the consumption point. In recent years, some water suppliers in different countries have paid attention to drinking water safety based on the HACCP system.[1]

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The drinking water supply system of Melbourne, Australia, applied the HACCP approach in 1999.[2,3] This system was also implemented for Zurich water supply in 1999.[4] More recently, the HACCP was applied in New Zealand[5], Belgium,[6] Finland[7],Germany[8], Italy[9], South Africa[10], Sweden[11], and England.[12]

The HACCP guideline was prepared by the relevant Technical Commission and was confirmed by the Eighth National Committee of Microbiology Standard in March, 1996.[13] This guideline was also published as an official standard of Iran according to the Clause 1, Article 3 amendment to the rules and regulations of Iran's Industrial Research and Standard ratified in February, 1993.[1] However, there is no study on the implementation of the HACCP approach for drinking water supply in Iran. Therefore, the purpose of this study was to design a safety program for the drinking water of Isfahan, Iran, based on the HACCP, and provide practical measures and strategies for monitoring, controlling, and limiting the risks related to water safety in different stages, from the water supply to the consumption point.

MATERIALS AND METHODS

Isfahan is the second largest city of Iran, which supplies most of its drinking water from the surface water of Zayandehroud River. In this cross-sectional study, initially the five preliminary steps including, assembling of the HACCP team, describing the product (water), identifying the intended uses of water, constructing the flow diagram of the drinking water production process, and on-site confirmation of the flow diagram, were performed. Then the seven principles of the HACCP system were implemented as follows:[14]

Principle 1: Hazards analysis

The most important hazardous events affecting water safety in all of the three sections of the raw water in the Zayandehroud River, Baba Sheikh Ali water treatment plant, and Isfahan's drinking water distribution system were predicted, identified, and subjected to risk assessment. Most of the data were collected through field inspections performed in the Zayandehroud River catchment, the lake of the Zayandehroud dam, along the river from the dam to Baba Sheikh Ali water treatment plant intake, and the site of the treatment plant, with the aim of obtaining general information on the most important resources of the pollutants. Moreover, the water quality index (WQI) of the last six years (2005 – 2010) was analyzed. This data was obtained from the Isfahan Department of Environmental Protection in fourteen stations [Figures 1 and 2].[15] Data related to the most common qualitative parameters of Isfahan's drinking water for the last five years (2006 – 2010) were also collected. This data was obtained from the Isfahan Province Health Center and subjected to risk assessment. The HACCP program on the water supplying system was used for hazard analysis.[2-12]

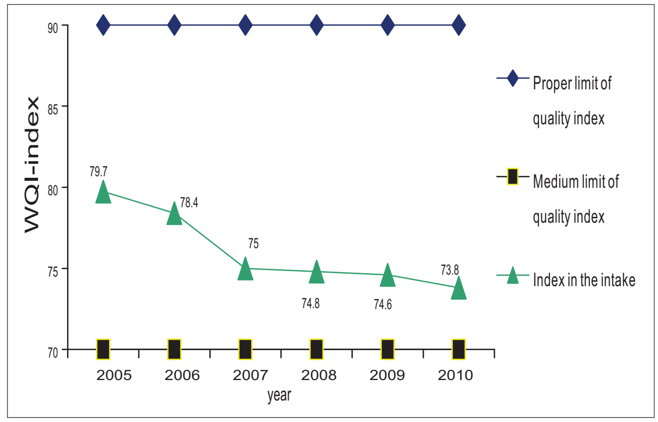

Figure 1: The process of change in the quality of Zayandehroud River water, where the water is removed from the Baba Sheikh Ali water Treatment Plant, based on the water quality index annual mean

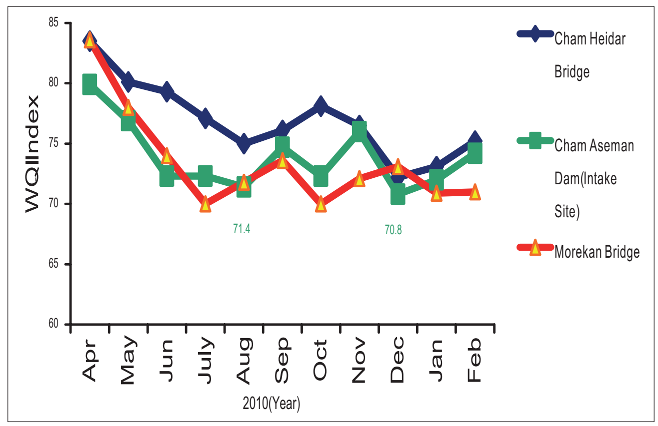

Figure 2: Quality changes in the water based on monthly quality index in three measurement stations in the upstream of the Baba Sheikh Ali Water Treatment Plant intake, in 2010

Principle 2: Identification of critical control points

The critical control point (CCP) is a step of the process where the occurrence of the water safety threatening hazard must be prevented or decreased to an acceptable level.[1] In this respect, the decision questions were applied to determine the CCP [Table 1].

Principle 3: Establishing critical limits

Critical limits are the criteria and standards specifying the distinction between safe and unsafe water.[1] In this study, the national and international standards related to the physical, chemical, and biological hazards of raw water, water under treatment, and drinking water, were used for critical limits. Information in the related literatures and the HACCP program in other countries with conditions similar to this study,[2-12] were also used to establish the critical limits in each CCP [Table 1].

Table 1: A summary of HACCP plane applied in Isfahan drinking water system

Step / process/ number of CCP	Hazard analysis	Control measures	Critical limits	Corrective actions
Intake point CCP_1	Severe downfall of the quality of the water coming into the intake, (microbial, chemical, and physical)	pH TOC EC	4.5-11.5 < 10 mg/l < 3000 μS/cm	- Preventing unauthorized people from entering intake - Reduction of water input to the treatment plant - Changing the depth of intake - Making downstream processes proportionate in pollutants removal regarding their types and nature
Coagulation and Flocculation CCP_2	Non-removal of organic pollutants during coagulation (THMs precursors, algae, toxins, and pesticides), heavy metals (microbial and chemical)	Output TOC EC Alkalinity Heavy metals Planktons Alga masses	< 2mg/l 750-2000 μS/cm Removal percentage of TOC is adjusted based on alkalinity According to national standard, < 2000 cell/ml not seen on the pools wall and upper hand units of treatment	- TOC removal during advanced coagulation (adjusting pH in coagulation process to the range of 5-6 for the effective coagulation of NOM using additional coagulant or adding acid) - Decreasing the dose of middle-injection chlorine gas (sedimentation unit entry) to 0.5 mg/l in order to prevent THMs production - Considering proper processes in water treatment plant including the processes based on absorption (PAC-GAC) as stand by processes used when necessary at coagulation or filtration entry like the use of powdered activated carbon - Reduction of the filtration rate if necessary - Performing optimum coagulation process or using treatment shock (use of 2-3 mg / l of a high dose of chlorine intermittently at night) in middle disinfection process in algae mass removal
Sedimentation and middle disinfection with chlorine & ozone CCP_3 Filtration CCP_4	The output containing high TOC (physical and chemical) High turbidity with/out coagulum containing heavy metals residue and large numbers of bacteria in the output water of filtration (microbial, chemical and physical)	Turbidity TOC Color Smell Input turbidity Turbidity (break point of every filter) Turbidity of all filters Flushing speed Pressure drop in each filter P/A microbial test Aluminum	< 3 NTU < 2 mg/l < 20 TCU < 5 TON < 15 NTU < 0.5 NTU < 1 NTU < 3 m/s under specified limits for backwash < 100/100 ml < 0.2 mg/l	- Perform jar test and increasing dose of coagulant (advanced coagulation) (decreasing pH by adding acid or coagulant) - Increasing dose of injecting ozone at entry and exit of sedimentation unit to oxidize TOC residue - Using activated carbon slurry at entry of filtration if necessary - Adjusting the cycle of backwashing (washing rate, duration) - Driving filters out of the circle and solving the probable problem (removal of clay balls manually) - Replacing the out-of-service media, resolving the air binding, resolving media constriction - Reduction of filtration rate through decreasing the input flow (adding filter to the circle) when the entry turbidity is high - Control of pressure drop and turbidity break point and backwashing when necessary
Final disinfection CCP_5	Not adjusting final chlorine residue in proportion to the environment and water qualitative changes and microbial contamination of the output stream (microbial)	Heavy metals pH Floc Iron pH Turbidity Free chlorine residue C.T (chlorine) P/A(heat-resistant Coliform) Numbers of particles	according to national standard 7-8.5 not seen < 0.3 mg/l 7-8.5 < 1 NTU 1-2 mg/l 30-60mg.min/l zero in100 ml < 30 /ml	- Driving filter out of the circle, surface washing and applying it again (avoid opening backwash tap during filter performance for removing the stuck solids in filter bed) - Increasing the dose of final disinfectant (chlorine gas) - Consideration of replacement for chlorine injection devices - Increasing the usable dose (C.T adjustment) until the desirable residue remains through identifying chlorine inflection point - Adjusting optimum PH of the input water of final disinfection - Re-chlorination of the reservoirs exit in treatment plant if necessary - Closing output taps of treatment plant until ensured about water biological quality

(Continued...)

Table 1: Contd...

Step / process/ number of CCP	Hazard analysis	Control measures	Critical limits	Corrective actions
Distribution system (reservoirs and distribution network) CCP_6	Microbial recontamination, microbial re-growth (microbial)	pH Free chlorine residue (reservoirs) P/A test Water pressure in network Grab sample turbidity Annual turbidity mean) Free chlorine residue (network) HPC public complaints	< 8 0.5-0.8 ppm zero in 100 ml 30-100 psi < 5 NTU < 1 NTU 0.2-0.8 ppm < 500 CFU/ml no objection about taste, color, smell, and turbidity	- Checking the reservoirs for pollutants entry & flushing - Re-chlorination of reservoirs exit & being ensured of microbial water safety through doing consecutive tests until the removal of contamination - Identifying and resolving the pipes' infraction or any other deficiency in water distribution system - Flushing distribution network lines in its sightless points & numerous complaints about the water quality (taste, color, smell, & turbidity) - Ringing the sightless point of the network - Examining the consumers' complaints about the water quality including the taste, color, smell, & turbidity, etc., visiting the place and resolving the problem.
Distribution system (reservoirs and distribution network) CCP_7 Distribution system (reservoirs and distribution network) CCP_8	Downfall in the amount of disinfectant on reservoirs exit or various points of distribution system (microbial) Major spill of toxins and other hazardous pollutants due to terrorism actions, etc. (microbial and chemical)	Grab sample turbidity Free chlorine residue in network pH Free chlorine residue on reservoirs exit pH Continuous turbidity TOC EC Entry and exit of individuals	< 5 NTU > 0.2 ppm 7-8.5 0.5-0.8 ppm 6.5-9 < 5 NTU not exiting from normal limit < 2000 μS/cm non-entry of irresponsible people to the place of reservoirs site	- Flushing and cleaning the reservoirs and distribution network lines - Identifying and resolving the pipes' infraction or any other deficiency in water distribution system - Changing the related pipeline if it is antiquated and has the potential for high chlorine consumption - Ringing the sightless point of the network - Possibility of automatic closure of reservoirs exit when the index parameters exit out of the critical limit such as TOC, pH, EC, etc. - Inspecting the cause(s) of qualitative changes of water immediately and carrying out other supplementary qualitative analyses until reaching desired results - Discharging the polluted water and preventing it to enter into the distribution system - Informing the water consumers

Principle 4: Establishing monitoring methods

Control of the critical limits in the CCPs is a dynamic and proper system to measure and present specific quantitative and qualitative parameters as soon as possible, to react quickly, and take the corrective actions required for returning to the normal and desirable mode.[1] In this study, the monitoring methods were determined considering the two kinds of continuous and intermittent monitoring systems [Table 1].

Principle 5: Establishing corrective actions

Actions need to be taken by the staff of the operation section in the water treatment and distribution system at the time of any deviation from an established critical limit. More extensive actions might be involved in particular sections of the drinking water supply. In addition, in the treatment and distribution system the advice of other organizations was used to set up appropriate corrective actions [Table 1].

Principle 6: Establishing auditing and verification methods

This principle considers the necessary control actions for the HACCP system performance. Auditing was conducted from the beginning of the production chain to the farthest point of the distribution network, through supplementary tests, internal auditing (by water suppliers), and external auditing (by the supervisors of water quality).[1]

Principle 7: Documentation

Data of monitoring of various parameters and all actions performed in the critical control points were recorded accurately and completely. Documents were maintained for a specific period of time to be used for validation (based on the sixth principle).[1]

RESULTS

According to the field inspections and examination of other reports on the determination of the main sources of contamination of the River Zayandehroud,[15] the most important threatening hazards were as follows: The function of the catchment land, especially the bank of the river (discharge of pollutants related to activities such as agriculture, livestock, gardening, etc.), discharge of household waste of most rural areas on the banks of the river, pollution from recreation centers, urban and agricultural runoff (during the rainy season, occurrence of heavy rainfall, and floods), decrease in water volume of the river (arising from unauthorized removal of water, particularly in the agricultural section, recent droughts, etc.), and the lack of hygienic disposal of waste in most rural areas and recreation centers on the bank of the river. In addition, the possibility of leakage from the waste disposal sites, existence of natural habitats of wildlife and native and migratory birds in the catchment, and discharge of petroleum materials into the river (crude oil transmission pipeline passing across the catchment and upstream of the intake point, leakage of fuels due to the use of diesel engines in agricultural water removal and washing automobiles in the river bed by tourists, etc.) may cause contamination. Moreover, air pollution due to the adjacency of the steel industry to the river and the water treatment plant, precipitation or washing out of the seasonal dust coming from the western cities or neighboring countries may contaminate the quality of water. The occurrence of eutrophication [algal bloom, plant decomposition] in area of the river behind the adjusting dam, and accidental or intentional fire of pastures and agricultural lands in the catchment may also contaminate the water. The active or abandoned mines in the river catchment and their discharge of acidic drainage into the water streams are also important sources of river contamination. Natural and artificial radioactive substances may enter the water streams due to acts of terrorism and sabotage [discharge of toxins and hazardous chemical materials in the upstream of intake]. The annual mean of the water quality index of Zayandehroud [Figure 1], in the intake, decreased from 79.7 in 2005 to 73.8 in 2010. There was a downfall if the quality of six units, which came close to the threshold of a water quality index mean of 70 (WQI = 70) during the last six years.[15] These results showed an increase in the discharge of pollutants over time, regardless of the self-purification capacity and dilution of pollutants. According to Figure 2, when examining the process of change in the water quality index of Zayandehroud in the three measurement stations, upstream of the intake point, especially at the Cham-Aseman dam station (intake site), in 2010, it showed that the best quality of the removed water was in April and the worst quality was in August and December.[15] Disregarding particular events resulting in sudden and severe changes in water quality, the most critical time for removing raw water from the intake, in normal conditions, was considered to be mid-summer (reduction of quantity of flow) and early winter (rainfall and the effect of agricultural and urban run-offs), and needed special attention to be paid to the performance of treatment units in meeting the water quality requirements.

DISCUSSION

The present study found that water contamination may occur in eight identified critical control points (CCP). There was a potential of chemical, biological, and physical hazards during the water treatment process, because of seasonal changes and discharge of various pollutants. The parameters impact the Zayandehroud river water contamination, and may lead to low-quality water at the point of consumption, and hence were subjected to risk analysis. The five introductory steps and seven HACCP principles were applied and documented.

The rapid growth in the optimization of drinking water safety programs in the world and also the experiences of developed countries, indicate the importance of modern risk management. The use of multi-barrier approaches and risk analysis in the drinking water supply, treatment, and distribution systems seems necessary, especially in large cities, whose drinking water is mostly supplied through the surface water. Protection of the water resource is the most important measure to maintain the quality of drinking water. Catchment management is often beyond the responsibility and authority of the drinking water supply organizations. Therefore, planning and implementing any safety program needs the cooperation of other organizations such as policy-making authorities, the boards supervising of the catchment, agricultural and road construction organizations, disaster headquarters, and industrial and commercial enterprises. The organizations are responsible for the protection of the river water quality, the identification of the pollutants, and the control of their discharge into the water streams of the catchment.[1] Comparing the results of the present study with the other studies, such as the HACCP program in Melbourne, Australia,[2,3] the drinking water supply in Zurich,[4] water supply in Kyoto and Osaka in Japan,[16] water treatment plants in France,[17] and the water treatment plant and distribution network in Cape Town, South Africa,[10] show an emphasis on the protection of catchments and controlling the discharge of pollutants into the water streams. Catchment management is important in order to prevent the reduction of the overall quality of the water under treatment. It is expected that the quality of the water under treatment will continue to decrease in the coming years. There is a high potential for the contamination of the Zayandehroud water, due to the discharge of various pollutants, especially pollutants arising from household and agricultural activities. These pollutants are discharged into the catchment and upstream of Isfahan's Water Treatment Plant intake, which supplies drinking water to more than 40 cities and 400 villages. The lack of attention to the self-purification capacity and dilution of the pollutant charge and the change of suspended pollutants, the solution and mineral pollutants, into organic ones, play an important role in water contamination.[15] Under these circumstances, reaching the standards of output drinking water requires the use of advanced processes for water treatment and incurring great costs.

Regarding the results of the present study and the descriptive study of the Zayandehroud catchment, most of the pollutant sources in the upstream of the Baba Sheikh Ali Water Treatment Plant intake, entered a microbial charge into the water stream, which could have been the most important threat to the quality of the water under treatment. In this respect, most of the established critical control points in this study were allotted to the microbial hazards control. The next priority was allotted to the chemical and physical hazards control, assuming that the treatment units were well-operated and controlled and the treatment plant output conformed to the standards and desirable qualitative requirements. The water coming into the distribution system from the moment of entry until it reached the consumer would have a downward quality trend due to the extent and antiquity of Isfahan's water distribution system.[15] Therefore, water quality maintenance through continuous monitoring and controlling parameters related to physical, chemical, and especially microbial quality through a distribution system is essential, but not only the major lines.[15] Control of microbial hazards during treatment processes and in the distribution system may lead to the increase of the liability coefficient specially in terms of microbial quality, through consideration of critical control points in the units, including coagulation (CCP_2), middle disinfection (CCP_3), filtration (CCP_4), final disinfection (CCP_5), and the distribution system ($CCP_6 – CCP_8$). Extensive controls in these points are needed to assure water safety.[18-20] Some projects, in which drinking water quality was assessed before and after the implementation of the HACCP program, showed a promotion in water quality, particularly the microbial quality, after the program.[18-19] The principles and procedures of the previous studies were in consistent with each other, although there was no thorough consistency due to the difference in the amount and kind of pollutants contaminating the water source.[2,6,10,12] For example, there was a major difference in the water under treatment supplied from various sources, such as, the river, lake, or ground water. In addition, the existence or lack of protected catchments, various treatment processes, stream process diagram, and various chemical materials also played a major role in the inconsistency of the water safety protocol.[2,10] The monitoring equipment and assessment, standards, and qualitative requirements for raw water, specifications of the water distribution system, and finally the viewpoints of the HACCP team had a great impact on the implementation of the HACCP system.[6,10] This inconsistency existed in all the projects related to water safety programs, however, it did not interfere with the nature of the studies. It was evident that in case of any change in the current conditions of the water supply, treatment, and distribution system, the procedures would be evaluated and corrected again. It seemed that the present processes of the Isfahan's Water Treatment Plant have met drinking water quality requirements according to the Iranian standard in normal conditions, regardless of any accidents that have caused a severe downfall in the quality of the water under treatment in recent years. On the other hand, the study of the most significantly measured physical, chemical, and biological parameters of the treatment plant and distribution system is an urgent need. Organizations supplying drinking water and also the organizations supervising the quality of drinking water play an important role in this regard. However, the results of the present study and similar studies on the determination of sources contaminating the Zayandehroud River have shown a potential of various hazards due to periodic changes in water quality during the treatment process.[15] The water quality is strongly related to seasonal changes, discharge of various pollutants, especially by rural communities and recreation centers along the banks of the Zayandehroud River. In addition, natural and sudden accidents, intentional and malicious events, lack of proper management of the current procedures and proportionate treatment processes, the high scope and antiquity of Isfahan's water distribution system are also responsible for the water quality.

In conclusion, the water supply system in most of the Iranian cites need to implement prerequisite programs so that they can be ready for the implementation of HACCP. A written standard operation and sanitation protocol needs to be carefully developed and implemented in the water supplying chain. The problems in the application of the HACCP in the Iranian Water Industries have been a low level of water sanitation and management training, lack of motivation, lack of financial support, and failure of the government. Therefore, in order to access the desirable and high-quality drinking water, the role of the government in developing HACCP is essential. Finally it is necessary that the regulatory authority clarifies the goals of the strategy of water safety and mandates the implementation of HACCP in water supply as a long-term project.

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