RISK ASSESSMENT AND MANAGEMENT IN DOMESTIC WATER SUPPLY SYSTEM IN PLEIKU CITY – GIA LAI PROVINCE

Nguyen Tuan Anh, Nguyen Ninh Hai, Nguyen Minh Ky
Nong Lam Universityof Ho Chi Minh City;
ngtuananh@hcmuaf.edu.vn, ngninhhai@hcmuaf.edu.vn, nmky@hcmuaf.edu.vn

Abstract - Water is essential for maintaining life, ensuring a safe and continuous supply of water, therefore, it should be given the priority for concerns. Developing countries often face a number of problems with domestic water supply systems such as treatment plants with old technologies, degraded equipment leading to inefficient treatment, and a network of degraded piping, which could cause re-pollution of treated water during transport. Pleiku city, which is located in the Central Highlands of Vietnam, has built two treatment plants and a network of water supply pipelines in the core area. An analysis of the current state of the water supply system including water supply, treatment plant and pipeline system helps identify existing problems in the system. Through mixed methods, hazards or hazardous events are identified as a basis for risk assessment by using semi – quantitative method to assess raw risk and residual risk for each hazard. Priority risks are identified to focus on proposing the possible solutions that will improve the performance and management of domestic water supply systems.

Key words - water supply; water supply risks; risk management

1. Introduction

Water plays in an integral part of our life because it helps to sustain a healthy life. Therefore, a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking-water can result in tangible benefits to health. Every effort should be made to achieve drinking-water that is as safe as practicable [1]. In contrast, lack of access to safe and adequate water supplies has caused the problems related to public health and poverty. For instances, diarrhea is attributed to poor water supply, sanitation and hygiene account for 1.73 million deaths each year [2].

In some parts of Vietnam, the quality of water sometimes does not meet the requirements of National standards QCVN 01:2009/BYT for drinking water and QCVN 02:2009/BYT for domestic water when water comes to consumers [3]. The causes are identified as poor pipelines, the high rate of leakage, polluting water sources and inadequate water quantity for meeting the demands of locals.

The same problem of unclean supply water has happened in many places in the world, especially in developing countries where the water supply system is old and under-standard, or the sources of water supply is polluted. All incidents above have arisen the question "what should we do to prevent them?". In that context, the water safety plan (WSP) was first introduced by WHO in Guidelines for Drinking-water Quality [4].

The aim of a WSP is to ensure that a drinking water supply consistently produces safe drinking water that is acceptable to consumers. The most cost-effective and protective means of consistently assuring a supply of acceptable drinking-water is the application of some forms of risk management based on sound science and supported by appropriate monitoring. It is important that risk management is inclusive and, therefore, needs to cover the whole system from catchment to consumer [5]. Therefore, the risk management of domestic water supply system in Pleiku City is essential for supplying safe water.

2. Methodology

2.1. The research area

This research focuses on the domestic water supply system in Pleiku City, including water source, Bien Ho Lake, water plants, Bien Ho Plant and Saigon – Pleiku Plant, and distribution system. The pipeline system is about 200 km, and some 20000 households are connected to this system [6].

2.2. Research framework

The research framework is outlined to implement steps to assess and manage risks. Firstly, analyzing the components of the domestic water supply system, including water source, the plants and the distribution system in Pleiku City helps to fully understand the current status and identify its existing problems. From that, hazards and hazardous events are identified to assess raw risks for each. Each hazard will be assessed for likelihood and severity of consequences, and then multiple two components to be risk scores. Existing control measures are also documented to take into account reducing or minimizing risk scores, and experts and senior people are consulted to do this. Finally, the residual risk will be reassessed to give the priority for the basis of proposing possible control measures. These measures could enhance the existing ones or introduce new solutions, which help improve the effectiveness of operation of the domestic water supply system.

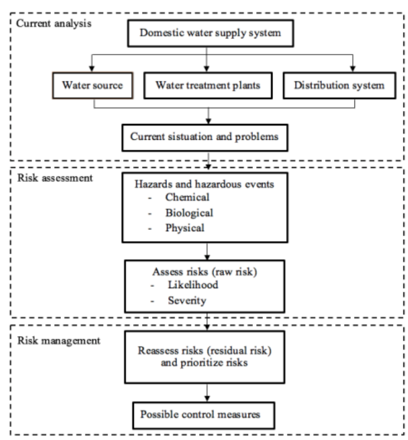

Figure 1. *The research framework of water supply system risk assessment and management*

2.3. Research methods

2.3.1. Data collection

a. Mixed method

Table 1. *Risk assessment matrix*

	Severity of consequences					
		Insignificant or no detectable impact: 1	**Minor** impact on compliance: 2	**Moderate** aesthetic impact: 3	**Major** Regulatory impact: 4	**Catastrophic** public health impact: 5
Likelihood	Almost certain (once per day) 5	5	10	15	20	25
	Likely(once per week) 4	4	8	12	16	20
	Moderately likely (once per month) 3	3	6	9	12	15
	Unlikely (once per year) 2	2	4	6	8	10
	Rare (once every 5 years) 1	1	2	3	4	5

Empirical approach: Primary data is collected by observation and interview with residents about (current, incidents…) and experts at the expected site (2 experts of risk water supply and 2 leaders in the plants), while secondary data is taken from documents and local authorities to assess the current situation.

b. Data collection design

Primary data is collected by observation (water sources, human activities, distribution systems, the use of customers, etc.), and questionnaires and interviewing local residents (about water source, distribution system), workers and leaders in two water supply companies.

The next step is to interview workers and leaders in water treatment plants to inquire about incidents in the plants and the related risks, and plans for preventing and handling those incidents. It is necessary to consult leaders to assess and manage these risks, reducing the uncertainty of assessing the risks. Secondary data from documents, reports of local authorities and water treatment plants (population, land use, planning, incidents, internal audits, monitoring data) is reviewed to determine the related problems. In addition, literature review will help to identify possible risks as well as support assessment of those risks.

2.3.2. Data analysis

The approach of risk assessment is to consider the likelihood of a hazardous event that will occur and the severity of its consequences. It depends on the scales of water supply systems to select the approach to risk assessment including qualitative, semi-quantitative, quantitative approaches. For instance, the small water supply system should employ expert judgment or decisions of a WSP team for assessment [7].

Based on the collected data, the depth analysis of the current status is completed to fully understand the status of water supply risks, and this helps identify hazards that could cause the water supply system to contaminate, or interrupt through site visits as well as desk studies. After that, the risks associated with each hazard may be described by identifying the likelihood of occurrence and evaluating the severity of consequences if the hazard has occurred. This assessment method applies Semi-quantitative risk matrix approach [8]. Existing measures should be documented to consider whether the existing controls are effective, and potential controls need to be done. The reduction in risk level achieved by each control measure will be an indication of its effectiveness.

Risk score = rating of likelihood x rating of severity.

Table 2. *Risk score and rating*

Risk score	<6	6-9	10-15	>15
Risk rating	Low	Medium	High	Very high

Source: (WHO,2009) [7]; [4]

Table 3. *Risk categories and resulting priority for taking action*

Low	**Not a priority:** Actions may be taken as part of routine operation. Both the risk and the measures in place to control should be described in documentation in order to maintain the controls implemented and to manage them well, and they should be considered in the future, especially when changes in the catchment take place, or as part of the WSP review process.
Moderate	**Medium priority:** Currently there is no impact on drinking-water safety, but attention is required in operation and/or possible improvements in the medium and long term to continue minimizing risks.
High	**Priority:** Actions need to be taken to minimize the risk. Possible options (short-, medium- and long-term options) should be documented (as part of the improvement plan) and implemented based on priorities and available resources.
Very high	**Clearly a priority:** Serious negative impacts on drinking-water safety and even interruption of the supply cannot be excluded. Check short-term options to mitigate acute consequences.

3. Results and discussion

3.1. Water risk assessment

3.1.1. Hazard identification and risk assessment

Hazards are identified in three main components of the domestic water supply system including water source, water treatment plants and distribution system [4]. The next step is that the classification of hazards is based on sources, characteristics and possible incidents including Microbial, Physical, Chemical. Hazards are identified based on the in-depth analysis of the status quo through interviews, observations and literature review. Existing control measures are then considered to reassess residual risks. This aims to give the priority to the risks to control risks, which are done by strengthening existing measure and proposing new control measures.

Risk assessment is to identify likelihood and severity for each hazard. Information needs to be gathered from related people to assess whether or not a risk is significant [9]. One of the main challenges identified during the risk assessment is to properly define likelihood and consequences with sufficient detail to avoid subject assessment [7]. Therefore, the selection of people having expertise in each component of domestic water supply system helps improve the confidence of risk assessment.

a. Water source

In general, water sources are influenced by natural and human factors. Major natural factors include climate, topography, wildlife and vegetation, and human factors include point sources (e.g. wastewater discharges) and non-point sources (e.g. surface runoff) [4]. Some of point source pollution derive from sewage treatment plants, industrial plant effluents, and animal farms. These sources usually lack control in developing countries because of insufficient infrastructure, regulation or ineffective enforcement [10]. In addition, nonpoint sources of pollution associated with surface runoff include sediments, nutrients, pesticides, pathogens, metals, oils, and many chemical contaminants entering water bodies from unknown locations. It is quite difficult to control nonpoint sources of pollution due to its diffused characteristics and pinpointing the origin of pollutions [11]. Analyzing the current status of the water supply system from source to users helps identify the existing problems in the water supply system. In the water source, activities that may affect the quality of raw water are mainly farming and livestock, particularly in the vicinity of the water intake point of the Bien Ho water plant. Some of the local people have cultivated directly under the lake, which could cause pollution through runoff with bypass pollutants, residues of pesticides and fertilizers. These hazards have been assessed to a medium level of risk and prioritized for control measures by enhancing propaganda local people not to cultivate the buffer zone.

Table 4. *Risk assessment in water source*

Hazardous event (or possible sources of hazards)	Hazards	Likelihood	Severity	Raw risk	Risk rating	Existing control measures	residual risk	Reassessment of risk
Water source								
Soils, sand in vacant lands around the lake can be swept into the lake through runoff	P	4	2	8	Medium	Buffer zone around the lake, but is cut in some areas such as water intake point of Bien Ho Plant.	4	Low
Receiving waste from livestock through runoff or groundwater	M	3	3	9	Medium		6	Medium
Receiving waste from cultivation activities	C	3	3	9	Medium		6	Medium
Waste from boat, canoeing for tourists or fishing	M,C	2	2	4	Low	No control measures	4	Low

b. Water plants

The treatment processes should be taken into account to create the next barriers to contamination of the drinking water (Pretreatment, Coagulation, flocculation, sedimentation, filtration, disinfection process, Storage). Chemical coagulation is the most important step in determining the removal efficiency of coagulation/ flocculation/ clarification processes. It also directly affects the removal efficiency of granular media filtration units and has indirect impacts on the efficiency of the disinfection process [4]. The important issue in identifying hazards in water treatment plant is to check chemicals in treatment processes about use and storage, and disinfection process is an essential element to achieve the necessary level of microbial risk reduction [7]. If water treatment plans are well-equipped and appropriate to remove the pollutants from water source effectively, treatment-related risks can be minimized to acceptable level. Therefore, it is necessary to assess whether the treatment processes can eliminate or minimize the organisms and substances present in the water source that vary considerably in some different conditions. In contrast, the treatment processes that are insufficient can be obviously a risk [12].

In order for the plants to operate, energy needs to be supplied constantly, which requires more than one source of power in case of an incident of the main supply [13]. Therefore, the risk of power failure should be identified to assess risk and to have a preventive plan when the incident occurs. Meanwhile, the pumps ensure continuous water supply to the treatment process for the system to operate, and other types of pumps such as chemical pumps, circulating water pumps, waste pumps, waste water should also be considered. When the pumps have error, ineffective operation will affect the processing efficiency of the process [13].

Secondly, management of chemicals including storage and use is very important for the process. Specifically, in the process of coagulation and flocculation if the quality of chemicals is guaranteed and used at a reasonable dose, the effective treatment will be achieved, otherwise it will affect the quality of water after treatment.

In this regard, the plants have managed well, have proper warehousing and storage procedures, and managed the preparation and dosing of pumps into very good treatment stages [14]. Finally, the operating equipment helps to operate the equipment and the processing stage effectively. The problems of operation may cause failures to processing, which can cause serious consequences if not controlled. Water quality parameters are usually checked online continuously to ensure the performance of each stage. Specifically, the Saigon - Pleiku factory uses a SCADA system, a self - contained online control system, which makes managing the system very efficient.

Bien Ho water plant uses traditional technology, but has also upgraded control systems to make the plant more efficient.

Table 5. *Risk assessment in water plants*

Hazardous event (or possible sources of hazards)	Hazards	Likelihood	Severity	Raw risk	Risk rating	Existing control measures	residual risk	Reassessment of risk
Water treatment plants								
Power failure or loss	P, C, M	2	5	10	High	Saigon – Pleiku plant: Dual power sources (generator)	5	Low
						Bien Ho Plant: no back-up power source	10	High
Failures of pumps	P	3	5	15	High	Back-up pumps	5	Low
The quality of chemicals	C	2	5	10	High	Chemical warehouses(Design and storage); Compliance audits and materials checklist	5	Low
Failure of Chemical pumping system	C	2	5	10	High	Alarms on high or low level of chemical dosing	5	Low
Failures of monitoring equipment	P	3	4	12	High	Daily Operational checks	8	Medium
Filtration failures (filter material, backwashing etc.)	P	2	5	10	High	Monitoring, alarms	5	Low
Less effective disinfection due to high level of turbidity	M	2	5	10	High	Monitoring, alarms	5	Low

Table 6. *Risk assessment in Distribution system*

Hazardous event (or possible sources of hazards)	Hazards	Likelihood	Severity	Raw risk	Risk rating	Existing control measures	residual risk	Reassessment of risk
Distribution system								
Chlorine content does not meet the requirements of QCVN 01: 2009 / BYT (the early of network is higher than 0.5 mg / L, or in the end of network is less than 0.3 mg / L)	C,M	3	5	15	High	Maintaining residual chlorine concentration after treatment at stable plant. Checking and monitoring the residual chlorine content on the network.	10	Medium
Contamination during new installations or construction of water pipes	P,C,M	3	4	12	High	Compliance audit	6	Medium
Contamination during replacing or installing auxiliary equipment (such as meters, valves, pumps)	P,C,M	3	4	12	Very High	Compliance audit	6	Medium
Internal corrosion of pipes	P,C,M	2	3	6	Medium	Testing water samples in the tap's user periodically; Detection and repair programs	3	Low
Contamination due to leaky water pipe, from waster entering	P,C,M	3	4	12	High	Detection and repair programs	6	Medium
Accumulation of bio-films, sediments and particles	P,C,M	1	3	3	Low	Pipe Cleaning programs; Chlorine residuals in distribution network	1	Low
Backflow from residential or industrial or commercial sources due to lack of prevention devices or failures of devices	P,C,M	2	5	10	High	Backflow device installed at users	5	Low
Ingress of polluted water into storage tanks (joint or cracks) in the booster pumping station	P,C,M	2	4	8	Medium	Detection and repair programs	4	Low

c. Distribution system

The last barriers to contamination are distribution systems before supplying for customers. Distribution systems are often considered as passive systems that are only responsible for conveying treated water from treatment plants to consumers [14]. The most common problems are cross-connections and back-siphons. Apart from these faults, pressure fluctuations, contamination during storage, poor practices during repairing and installing new distribution systems are also significant causes affecting the distribution systems [13]. For instance, outbreaks of illness have been associated with low water pressure and intermittent supply [2]. The distribution system in Pleiku City, which was installed mainly in 2001, so some of pipeline sections have degraded, possibly leaking and risking scurrying. This could result in the ingress of contaminants entering treated water in the pipeline network through the leaks. In addition, the construction of the new pipeline or replacing auxiliary equipment could pose a risk of contamination during construction process. Finally, the hazard of water supply pipes connected to the household are installed just below or very close to the sewage pipeline, which can cause the ingress of wastewater into the water supply pipe need to be addressed. This issues are identified and scored at medium risk, and prioritized to control by short and medium term measures.

3.1.2. Prioritization of the risks

Medium, high and very high level of risks will be prioritized for further consideration of enhanced or possible measures to minimize or mitigate risks to acceptable levels. The risk score of each hazard will be shown clearly in terms of both the likelihood and the severity score of the residual risk, which will help to consider mitigation measures for these two components.

3.2. Risk management

3.2.1. The approach and possible solutions

It is not feasible to address every possible risk to the surface-water source. Therefore, a stepwise approach is to deal with the highest risks and take into account what can be achieved with the resources available, and with the stakeholders who are willing to take action [15]. Hazards given the priority should be controlled by enhancing the effectiveness of existing measures and proposing possible measures to reduce the risk. This is done by expert consultations and reference to measures in related research and projects. Stakeholder analysis will help to understand the relationship, responsibilities and coordination. The measures will identify responsibilities for each stakeholder, which allow implementing those measures more effectively. The phases of implementing these measures should be divided into two phases, short-term and medium-term, due to the period of assessing risk within five years.

3.2.2. Implementation of proposed solutions

Proposed solutions focus on operational management and technical issues. Operational management solutions such as training, review of operating procedures, operational monitoring must be carried out in the short-term phase. Technical solutions such as plant upgrade, investment in backup power generation system, and establishment of water protection corridors, taking time, funding are implemented in the medium-term phase. These are presented as follows:

Table 7. *Proposed solutions*

Solutions	Subjects	Contents	Frequency	Stakeholders
Short-term solutions				
Propaganda program	User, and people around the lake	Buffer zone protection; The protection of the pipeline network; Instructing the procedure of the incident report	Annual	Water company Authority, DoNRE Residents/User
Training	Staff, workers	Work instructions, operational procedures, hazards and risks	Annual	Water company External audits
Review of procedures	Operating procedures	Maintenance, Calibration, Operational construction and commissioning procedures.	Annual	
Inspection and monitoring programs	Treated water	Residual chlorine indicator; Examining water pressure in distribution system	Monthly	WC; Preventive medicine center
Medium-term solutions				
Sanitary engineering program	Local residents	Support finance incentives to invest in waste disposal/sewer	2018-2023	DoNRE, water company, Authority, Residents
Establishment of water protection corridor	Buffer zone of the Bien Ho Lake	Implementing Decree No. 43/2015/NĐ-CP and circular 24/2016/TT-BTNMT	2018-2023	
Upgrading the plant	The Bien Ho Plant	Back-up power station; SCADA operating system control	2018-2023	Water company (WC)
The pressure measure system	Distribution system	Maintaining positive pressure, provide continuously supply	2018-2023	Water company

4. Conclusions and recommendations

The risk identification in three components of water supply system is essential for improving system operation and supplying clean water for residents safely. For the risks given the priority, water companies should focus on managing and taking effective measures to control them.

A water safety plan is a holistic approach to manage risks; water companies, therefore, should consider applying and implementing it in Pleiku City. Moreover, risk assessment need to support scientific research and technical measurement, which can be conducted by stakeholders from scientists to authorities.

Stakeholders coordinator should be enhanced to manage water source better, helping water plans operate in a stable manner. In other words, it is important to minimize risks from water source, which helps supply good quality raw water to plants and prevent pollutants over these two barriers. Therefore, focusing on water source protection should be taken as soon as possible and given the top priority in proposing short-term sollutions.

REFERENCES

[1] G. Howard, J. Bartram, and others, *Domestic water quantity, service level, and health*. World Health Organization Geneva, 2003.

[2] P. Hunter, R. Chalmers, S. Hughes, and Q. Syed, *Self-reported diarrhea in a control group: a strong association with reporting of low-pressure events in tap water*. 2005.

[3] Ministry of Health, “QCVN 01: 2009/BYT. National Technological Regulation on Drinking Water Quality”, 2009.

[4] World Health Organization, Ed., *Guidelines for drinking-water quality*, 4th ed. Geneva: World Health Organization, 2011.

[5] J. Bartram, D. Deere, M. Stevens, G. Howard, P. Callan, and L. Fewtrell, “Water Safety Plans: managing drinking-water quality from catchment to consumer”, 2005.

[6] Gia Lai water company, “The technical report on treatment process in Saigon-Pleiku Plant”, 2014.

[7] L. Fewtrell and Weltgesundheitsorganisation, Eds., *Water quality: guidelines, standards and health; assessment of risk and risk management for water-related infectious disease*, Reprinted ed. London: IWA Publ, 2002.

[8] J. Bartram, World Health Organization, and International Water Association, Eds., *Water safety plan manual: step-by-step risk management for drinking-water suppliers*. Geneva: World Health Organization, 2009.

[9] WHO, Ed., *Water safety planning for small community water supplies: step-by-step risk management guidance for drinking-water supplies in small communities*. Geneva: World Health Organization, 2012.

[10] M. H. Dore, “Risk Assessment for Safe Drinking Water Supplies”, in *Global Drinking Water Management and Conservation*, Cham: Springer International Publishing, 2015, pp. 117–151.

[11] O. US EPA, “Types of Nonpoint Source”, [Online]. Available: https://www.epa.gov/nps/types-nonpoint-source. [Accessed: 11-Nov-2016].

[12] Environmental Protection Agency, “A handbook on the implementation of the regulations for water service authorities for private water supplies”, 2007.

[13] World Health Organization, Water safety in distribution systems. 2014.

[14] Gia lai water supply sewerage SJC, “Technical report”, 2016.

[15] WHO, Ed., Protecting surface water for health. Identifying, assessing and managing drinking-water quality risks in surface-water catchments. Switzerland: World Health Organization, 2016.

(The Board of Editors received the paper on 15/12/2018, its review was completed on 21/3/2019)