Risk Assessment of Selected Source for Emergency Water Supply Case Study II

Frantisek Bozek, Alexandr Bozek, Eduard Bakos, Jiri Dvorak, Alena Bumbova, and Lenka Jesonkova

***Abstract*—**The case study deals with the semi-quantitative risk assessment of water resource earmarked for the emergency supply of population with drinking water. The risk analysis has been based on previously identified hazards/sensitivities of the elements of hydrogeological structure and technological equipment of ground water resource as well as on the assessment of the levels of hazard, sensitivity and criticality of individual resource elements in the form of point indexes. The following potential sources of hazard have been considered: natural disasters caused by atmospheric and geological changes, technological hazards, and environmental burdens. The risk analysis has proved that the assessed risks are acceptable and the water resource may be integrated into a crisis plan of a given region.

***Keywords*—**Crisis, emergency, frequency, ground water, hazard, point index, risk, sensitivity, water supply.

I. Introduction

ALTHOUGH supply of population with drinking water is one of the key branches of critical infrastructure, the appropriate attention has not been paid to the protection of public water pipeline network and the emergency supply of population even at the beginning of this millennium. The issue has been given more prominence after assessing mainly economic, social, health and ecological risks. The risk that especially anthropogenic, but also natural sources of hazard will cause an emergency or a crisis situation increases permanently. Such situations would result in multiple damages and also the necessity to supply drinking water in required quantity and quality.

The discontinued supply of drinking water from a distribution system would lead to the paralysis of public life, production processes exploiting drinking water, medical facilities, fire protection of urban areas, and industrial premises [1]. The situation may be successfully managed by exploiting the reserve, especially ground water resources of drinking water [2]. In order to exploit such resources efficiently it is necessary to integrate them into crisis plans and classify them on the basis of risk analysis [3], which is an important step in the decision making process.

Frantisek Bozek is with the Civil Protection Department, University of Defence, 65 Kounicova, 662 10 Brno, Czech Republic (phone: 00420973443170, e-mail: frantisek.bozek@unob.cz).

Alexandr Bozek is with the Institute of Materials Science and Engineering, Faculty of Mechanical Engineering, Brno University of Technology, 2 Technicka, 616 69 Brno, Czech Republic (phone:00420602828688, e-mail: A.bzk@unob.cz).

Eduard Bakos, is with the Civil Protection Department, University of Defence, 65 Kounicova, 662 10 Brno, Czech Republic (phone: 00420973443155, e-mail: edusrd.bakos@unob.cz).

Jiri Dvorak is with the Language Training Centre, University of Defence, 44 Kounicova, 662 10 Brno, Czech Republic (phone: 00420724041061 e-mail: dvorakji@post.cz).

Alena Bumbova is with the Civil Protection Department, University of Defence, 65 Kounicova, 662 10 Brno, Czech Republic (phone: 00420777837168, e-mail: alena.bumbova@unob.cz).

Lenka Jesonkova is with the Civil Protection Department, University of Defence, Brno, Kounicova 65, 662 10, Czech Republic (phone: 00420973442097, e-mail: Lenka.Jesonkova@unob.cz).

II. The Analysis of Current State

Emergencies and crisis situations often include the area of supplying the population with drinking water. The solution of such emergencies is often specific in dependence on the character of primary event. Fast and effective decision making is thus considerably individual and has to reflect the knowledge of a particular situation and local conditions [4]. However, preventive measures, including a thorough specification of reserve water resources in crisis plans, may significantly contribute to fast and successful management of an emergency [5].

The issue of emergency water supply is pursued by state, private and non-profit making organizations. Their approaches are different though. Most countries transfer the great deal of responsibility for emergency water supply from public sphere to their citizens. It is assumed that in an emergency each household will prepare sufficient amount of water depending on the number of people and animals in the household. Some authors recommend people to treat raw water on their own in case drinking water supply is cut off [6]. They present what to do in such cases [7]. The detailed guidelines published by the US EPA on its website inform public about what to do in a crisis, when people either do not have enough bottled water, or water cannot be disinfected by boiling [8].

Public administration deals mainly with water supply in camps and centers, where it is necessary to accommodate many dislocated people [9]. Emergency supply of drinking water is in competence of state administration also in case of hospitals, medical facilities and other public institutions [10]. One report does not focus only on the practical aspects of local planning in relation to the emergency supply of drinking water, but describes also the roles and responsibilities among various levels of state administration [11]. The report also deals with technical planning elements and presents the key findings which enable the administration to respond much better to post-crisis situations with regard to the drinking water supply [12]. The emergency supply of drinking water during emergencies and crisis situations is not addressed by Community Law in the EU. The solution of this matter is the responsibility of each EU member state [13].

The emergency water supply is managed by the Ministry of Agriculture in the Czech Republic. The Emergency Water Supply System is activated when the state of crisis is declared and the drinking water supply is cut off. The system is managed by regional and municipal authorities though the Emergency Water Supply Service, which has to start operating within five hours from the emergency or the crisis situation when it either has a negative impact on the water supply of population, or such an impact may be assumed [14].

The executive bodies of the Emergency Water Supply System are legal persons and natural persons with binding contracts, especially the owners and operators of water pipelines and the operators of technical facilities treating raw water [14]. There are also the persons and entities designated by Water Authority according to the Water Act [15].

There are many ways of providing the emergency supply of drinking water. If the system is supplied from several resources then the affected resource may be removed. Water may be supplied from the neighboring system if it is connected with the neighboring water pipelines. However, this option has to be technically and legally feasible in advance [4]. If the above mentioned options are not available there are other possibilities described in our previous publication [16]. It has already been stated that it is beneficial and effective to exploit hydrogeological structures, the ground waters as the resources of low vulnerability, high quality and sufficient water yield [5].

Regional and municipal authorities have to supply the following amount of water in required quality during emergency water supply [14]:

a) 5 dm^3 per person per day for the first two days;
b) 10 to 15 dm^3 per person per day for the third and other days.

Requirements for the quality of drinking water under the conditions of emergency water supply may be different from the requirements for the quality of drinking water [4].

The ground water resources are classified into the following three categories according to the current Czech system of selecting the ground water resources for emergency supply [17]:

a) Resources of extra significance, such as ground water intake structures of increased resistance supplying the required amount of drinking water;
b) Selected resources, capable of resisting a small scale damage to the water supply system;
c) Other intake structures not included into the category of resources for emergency water supply, which are used for mass supply of population from public water supply systems.

The presented classification system does not respect the principles of classifying the water resources into categories on the basis of risk analysis. The risks result from natural and anthropogenic hazards to ground waters and the health risks related to organoleptic, physical, chemical and microbiological indicators of water. During classification it is necessary to consider also traffic accessibility, availability, richness and economic criteria of operating ground water resources [3].

The paper presents in the form of a case study our previously published methodology of risks assessment of a particular ground water resource earmarked for emergency supply [3]. The hazards being considered include natural hazard sources caused by atmospheric and geological changes, anthropogenic hazard sources such as technological accidents, common human activities and environmental burdens.

III. Applied Methods and Devices

The hazard risk quantification that the selected ground water resource is threatened has been based on the index point values identified hazards/sensitivities pairs of individual elements of hydrogeological structure and technical equipment of ground water resource [18]. Brainstorming [19] has been used for indexing the levels of identified hazards and the sensitivity of water resource elements in dependence on the frequency of hazard source activation [16], or the level of damage caused to individual elements [20]. The assessment has been carried out in the group of seven experts and one laic at three joint meetings.

Brainstorming has also become the basis for forming the hazard/sensitivity pairs for individual elements of water resource and the point indexation of their levels. Indexation of the level of j-hazard $F_j(\tau) \in (0;\, 5\rangle$ has been carried out in real numbers Re^+ in dependence on the frequency of hazard source activation. In the same way the index point values have been assigned in real numbers Re^+ to sensitivity $S_{j,i}(\tau) \in (0;\, 4\rangle$ as a function of the level of damage caused to i-element of water resource due to the activation of j-source of hazard.

The quantification of risk index $R_{j,i}(\tau)$ representing the level of contamination, damage, or destruction of i-element of the assessed ground water source caused by j-hazard in given time τ has been calculated with the help of relation (1):

$$R_{j,i}(\tau) = const_i'(\tau) \times F_j(\tau) \times S_{j,i}(\tau) \qquad (1)$$

Thus risk index $R_{j,i}(\tau)$ represents the product of invariable $const'_i(\tau)$, frequency value $F_j(\tau)$ expressed in point indexes that j-source of hazard is activated and sensitivity value $S_{j,i}(\tau)$ expressed in point indexes of the i-element of hydrogeological structure or technological equipment of water resource being threatened by j-hazard in given time τ. The invariable $const'_i(\tau) \in \langle 1;\, 3\rangle \wedge const'_i(\tau) \in Re^+$ is the reflection of criticality $C_i(\tau)$ of the assessed i-element of water resource in time τ.

The values of $const'_i(\tau)$ for each i-element of the assessed ground water resource have been also determined with the help of brainstorming [19]. During the assigning process the importance of each element was respected for fulfilling its function as a water resource for emergency water supply, as well as the possibility of their substitution or repair as in case of water intake structures and water treatment plant being substituted by a mobile water treatment facility.

The values of invariable $const'_i(\tau)$ are reported in Table I. They have been acquired as a median from the values suggested by the individual members of brainstorming team.

TABLE I
THE INVARIABLE OF CRITICALITY FOR PARTICULAR ELEMENTS OF THE ASSESSED WATER RESOURCE

Element of water resource	HGC	HR	WQ	WIS	WTP
The value of invariable $const'_i(\tau)$	2.85	2.77	2.55	1.80	1.43

HGC = hydrogeological conditions, HR = hydrological regime, WQ = water quality, WIS = water intake structures, WTP = water treatment plant

The calculated value of $R_{j,i}(\tau)$ has been shown in a risk matrix and the risk acceptability for each *i*-element of ground water resource has been determined in relation to each *j*-hazard source.

IV. FINDINGS AND DISCUSSION

The outcomes of our previous study [18] have been used for the calculation of risk $R_{j,i}(\tau)$ for individual *i*-elements of the assessed water resource in relation to *j*-hazard source. They are clearly shown in Table II.

Then the risk matrix has been built with its elements in intervals $R_{i,j}(\tau) \in \langle 1; 60\rangle \wedge R_{i,j}(\tau) \in \mathrm{Re}^+$. The intervals have been calculated according to the relationship (1). The risk matrix is presented in Table III.

Furthermore it has been necessary to define individual intervals of risk point indexes for assessing the acceptability of risk. The outcomes have been acquired through brainstorming and are in a well arranged way shown in Table IV. A median has been applied for assessing the obtained outcomes.

TABLE II
POINT INDEXES OF HAZARD SOURCE ACTIVATION FREQUENCY AND SENSITIVITY POINT INDEXES OF THREATENED ELEMENTS OF OBSERVED WATER RESOURCE

Potential hazards	Frequency point index $F_j(\tau)$	Sensitivity point index $S_{j,i}(\tau)$				
		HGC	HR	WQ	WIS	WTP
1 Natural hazards (natural disasters)						
1.1 Natural disasters caused by atmospheric changes						
Hailstorms and torrential rain	3.40	-	-	-	0.90	-
Drought	3.15	-	1.82	-	-	-
1.2 Natural disasters caused by geological changes						
Soil erosion	2.33	1.55	-	-	1.40	-
2 Technological hazards						
2.1 Accidents						
Accidents of farm machines	2.83	-	-	1.98	-	2.45
2.2 Common activities						
Agricultural production	4.80	-	-	1.30	-	-

HGC = hydrogeological conditions, HR = hydrological regime, WQ = water quality, WIS = water intake structures, WTP = water treatment plant

TABLE III
MATRIX OF RISK FOR THE GROUND WATER RESOURCE EARMARKED FOR THE EMERGENCY SUPPLY OF POPULATION BY DRINKING WATER

Frequency Point Index $F_j(\tau)$	Sensitivity point index $S_{j,i}(\tau)$			
	(0; 1〉 - negligible	(1; 2〉- marginal	(2; 3〉 - critical	(3; 4〉 - catastrophic
(0; 1〉 - very low	(0; 3〉	(0; 6〉	(0; 9〉	(0; 12〉
(1; 2〉 - low	(0; 6〉	(1; 12〉	(2; 18〉	(3; 24〉
(2; 3〉 - middle	(0; 9〉	(2; 18〉	(4; 27〉	(6; 36〉
(3; 4〉 - high	(0; 12〉	(3; 24〉	(6; 36〉	(9; 48〉
(4; 5〉 - very high	(0; 15〉	(4; 30〉	(8; 45〉	(12; 60〉

Based on the known values of invariable $const'_i(\tau)$, values of frequency point indexes $F_j(\tau)$ and sensitivity point indexes $S_{j,i}(\tau)$ the calculation of risk point indexes $R_{j,i}(\tau)$ has been made for each *i*-element of the assessed ground water resource in relation to each *j*-source of hazard. The acquired outcomes are clearly shown in Table V.

TABLE IV
CHARACTERISTICS OF RISK FOR INDIVIDUAL INTERVALS OF RISK POINT INDEXES

Interval of risk point indexes $R_{j,i}(\tau)$	Characteristics of risk
(0; 5⟩	*Negligible*. Water resources may be immediately exploited without implementation of countermeasures.
(5; 18⟩	*Acceptable*. Water resource can be immediately exploited with implementation of countermeasures, if need be, on the basis of a statement and decision made by top-management of resource operator.
(18; 30⟩	*Tolerable*. The exploitation of water resource is heavily limited. If water resource is to be used for the emergency supply of population, it is necessary to implement countermeasures in order to reduce the risk on acceptable level. The costs of reducing the risk have to be adequate for the value of protected resource element and the social benefit. In this case it is recommended to apply the Cost-Benefit Analysis method, possibly a Multi-Criterial Assessment, which will enable to assess the effectiveness of particular countermeasures being taken.
(30; 60⟩	Unacceptable. It is not recommended to exploit the water resource for emergency supply.

TABLE V
RISK POINT INDEXES FOR INDIVIDUAL THREATENED ELEMENTS OF OBSERVED WATER RESOURCE

Potential hazards	Risk point indexes $R_{j,i}(\tau)$				
	HGC	HR	WQ	WIS	WTP
1 Natural hazards (natural disasters)					
1.1 Natural disasters caused by atmospheric changes					
Hailstorms and torrential rain	-	-	-	5.51	-
Drought	-	15.88	-	-	-
1.2 Natural disasters caused by geological changes					
Soil erosion	10.29	-	-	5.87	-
2 Technological hazards					
2.1 Accidents					
Accidents of farm machines	-	-	14.29	-	9.91
2.2 Common activities					
Agricultural production	-	-	15.91	-	-

HGC = hydrogeological conditions, HR = hydrological regime, WQ = water quality, WIS = water intake structures, WTP = water treatment plant

By comparing the data from Table V with the risk point index values intervals presented in Table IV it may be found out that all identified risks resulting from the studied risk area of the natural and anthropogenic hazards threatening the assessed ground water resource are acceptable.

The risk point index $R_{i,j}(\tau)$ has the highest values for natural disasters caused by droughts, the frequency of which has been permanently on the increase in the observed region. Extremely hot, long-term periods of minimal precipitation may have an impact on the hydrological regime of the drilled well. Under such conditions the accumulation of ground water is reduced, which results in the decrease of ground water level and the richness of the resource. Long-term droughts may negatively influence also water quality by increasing its overall mineralization.

During droughts wind denudation is intensified on the fields with thin or dry vegetation near the drilled well. Thus the protective function of the cover layer of hydrogeological aquifer is reduced. The fluctuating level of ground water may in the long-term lead to faster deterioration of the drilled well equipment.

The point index value of risk related to the contamination of ground water by the accident of farm machines, agrochemicals and the spill of POL and operating fluids from the farm machines is near the tolerable level as well. The accident of farm machines may be caused by human factor, breakdown of technical equipment, bad weather conditions and terrain. The breakdowns are usually accompanied by the spill of operating fluids and transported media, which are usually contaminants in the same way as synthetic fertilizers and pesticides used for increasing the crop yields. However, it has to be mentioned that such a leakage of contaminants into the hydrogeological aquifer of explored ground resource is prevented by a cover layer of loess having a good sorption capability.

It should be added that the risk analysis considered also the previous exploitation of the infiltration area and vicinity of the assessed ground water resource, which could signal the occurrence and character of environmental burden and thus the expected contaminants in water. The area surrounding the resource has been exploited solely as agricultural area and infiltration area for forest production. Therefore no significant environmental burden could be expected in the area of interest except for the increased content of agrochemicals near the resource. No increased contamination of water has been detected due to the character of rock bed, which has been proved by a detailed water analysis.

Therefore it may be stated that the observed ground water resource is suitable for emergency supply while considering the natural disasters, technological hazards in the form of accidents and common anthropogenic activities and environmental burdens in the infiltration area and vicinity of the resource. It will be necessary to assess also availability, accessibility, richness of the ground water resource and the costs of making it operational before it is classified into a particular category and included into a regional crisis plan.

V. Conclusion

The semi-quantitative risk analysis and risk assessment were carried out for the ground water resource which was selected as a backup source for the emergency water supply of population during emergency and crisis situations. All identified pairs of hazard/sensitivity of the individual elements of hydrogeological structures and technological equipment of water resource meet the requirements of the acceptable risk. Thus, the risk analysis has proved that the water resource is sufficiently resistant to identified natural disasters and explored anthropogenic hazard sources such as technological accidents and common human activities in the infiltration area and vicinity of resource. It is expected that the submitted case study happens the instruction and simultaneously basis for risk assessment, as one of the main prerequisite of which should stem the classification of the ground water resources within the system of crisis planning.

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