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The Analysis of Hazard and Sensitivity of Potential Resource of Emergency Water Supply

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***Abstract*—**The paper deals with the analysis of hazards and sensitivity of potential resource of emergency water supply of population in a selected region of the Czech Republic. The procedure of identification and analysis of hazards and sensitivity is carried out on the basis of a unique methodology of classifying the drinking water resources earmarked for emergency supply of population. The hazard identification is based on a general register of hazards for individual parts of hydrological structure and the elements of technological equipment. It is followed by a semi-quantitative point indexation for the activation of each identified hazard, i.e. fires of anthropogenic origin, flood and the increased radioactive background accompanied by the leak of radon. Point indexation of sensitivity has been carried out at the same time. The analysis is the basis for a risk assessment of potential resource of emergency supply of population and the subsequent classification of such resource within the system of crisis planning.

***Keywords*—**Hazard identification, sensitivity, semi-quantitative assessment, emergency water supply, crisis situation, ground water.

I. Introduction

THE importance of water was already realized by previous generations. Water was called "the pre-substance of the world", "the source of life", "the crucial raw material", and "the elementary condition for life". Water is part of all substantial biological, physical and chemical processes in nature and affects the nutrient cycle and climatic conditions on the Earth. Thanks to its specific physical-chemical properties it occurs in three states of matter and belongs to universal dissolving agent. The amount of water is constant on the Earth, but its forms and distribution on individual continents change.

The human society develops and faces global environmental problems. The quality and quantity of water decrease and water is considered to be scarce resource, i.e. limited and exhaustible resource. The protection of water resources requires the implementation of administrative, economic, private and other tools and principles of environmental policy [1].

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Significance and necessity of drinking water increases during emergencies and crisis situations when it is necessary to supply water to population in required quantity and quality for drinking purposes, preparation of food and elementary hygiene. One of the options of effective solution is the operation of alternative resources, such as unused ground water structures [2]. Risk analysis and assessment are the necessary prerequisites for including the ground water resources into crisis plans. The mentioned procedure represents one of the significant criteria of classifying the resources within the system of emergency supply of population with drinking water.

II. The Analysis of Current State

There are different approaches to emergency water supply in different countries. Many countries have transferred the responsibility for emergency water supply to their citizens. The households are tasked to be prepared for managing crisis situations and provide water of appropriate quality and quantity for drinking and hygienic purposes to themselves. Bottled water is usually used for drinking, and rain water, or water of lower qualitative parameters, is used for hygiene. The public administration deals mainly with the supplying of detention camps and centers in case an urban area is affected and there is a need of accommodating many displaced people [3], [4].

The system of emergency water supply is controlled by the Ministry of Agriculture in the Czech Republic [5]-[7]. The system of emergency water supply is activated when the state of crisis is declared and there is lack of drinking water. The emergency water supply is provided by regional and municipal authorities through the Emergency Water Supply Service. The Emergency Water Supply Service has the following tasks [6]:

a. emergency water supply in crisis situations;
b. provide safety and clearance work on water facilities serving as water supply;
c. take measures to prevent the leakage of contaminants into ground waters, surface waters and soil;
d. eliminate threats and accidental leakages of contaminants into ground and surface waters and soil;
e. find new water resources and establish the intake structures for emergency water supply.

The system of emergency supply prefers the exploitation of ground resources to surface waters due to their lower vulnerability and usually also higher quality [8]. It is necessary to assess chemical, biological and physical hazards

[9], as well as the probability of contamination in the hygienic research aimed at the quality of ground water. Other criteria important for the selection of resources include availability, accessibility and richness of the resource [10], [11]. The following aspects are considered when determining the water resource to be earmarked for emergency supply in the Slovak Republic [12]:

- Emergency water supply costs minimization, mainly with regard to the location and the distance of water resource from the area to be supplied;
- Richness of water resource;
- Water quality with regard to the need of further treatment;
- Energy consumption during the production of drinking water;
- Water resources protection possibilities.

Ground water resources earmarked for emergency supply of population are classified into the following three categories in the Czech Republic [6]:

a) resources of extra significance, i.e. the ground water intake structures with increased resistance capable of supplying necessary amount of drinking water;
b) selected resources capable of resisting the minor disturbance of water supply system;
c) other intake facilities, not included into the resources of the above mentioned categories, exploited for mass supply of population from public water pipelines.

The presented classification is insufficient, because it does not respect all the above mentioned requirements for the resources of emergency water supply. It does not stem from the general procedure of risk management and does not respect hazards which may damage or destroy the resource of emergency water supply.

The minimal amount of drinking water for emergency water supply ranges from 10 to 20 liters per person per day [12], [5], [13].

III. Applied Methods

The "Fault Tree Analysis" method in combination with the "What if" method [14], [15] have been applied when developing the general register of hazards [16] and the threatened hydrogeological elements and technological equipment [17] of ground water resource in relation to natural and anthropogenic threats. The general registers have then become the basis for developing the register for a particular resource. There have been seven experts and one laic participating in the assessment.

The Delphi method [18] with two iterations [19] in the group of seven experts and one laic has been applied for assessing the impact (yes-no) of each hazard identified in the general register on individual hydrogeological elements and technical facilities of water resource.

Brainstorming [19] has been used for assessing the levels of identified hazards and the sensitivity of individual resource elements in dependence on the frequency of hazard source activation [16], or the level of damage caused to individual elements [17]. 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. The general point index values of hazards and sensitivity have been used in dependence on the hazard source activation frequency, or the level of damage caused to the individual elements of ground water resource.

A. Assessment of the Levels of Hazards and Sensitivity of the Ground Water Resource Elements

The point indexation of the activation of each identified hazard source for the assessed ground water resource has been carried out in real numbers within the interval of (0; 5⟩ and used the data presented in Table I [16]. The semi-quantitative assessment of the sensitivity of individual elements of hydrogeological structure and technological equipment of water resource has been carried out similarly in the interval of (0; 4⟩. The data presented in Table II have been used for the above mentioned purpose. The index point values have been assigned to each ground water resource element on the basis of the assumed level of its damage in relation to each identified hazard [17].

TABLE I
THE MEANING OF INDEX POINT VALUES AS A FUNCTION OF HAZARD SOURCE ACTIVATION FREQUENCY

Interval of the index point values	Hazard activation frequency [year^{-1}]	Verbal assessment of hazard activation probability
(0; 1⟩	(0; 10^{-3}⟩	Very low
(1; 2⟩	(10^{-3} ; 10^{-2}⟩	Low
(2; 3⟩	(10^{-2} ; 10^{-1}⟩	Middle
(3; 4⟩	(10^{-1} ; 1,0⟩	High
(4; 5⟩	(1,∞)	Very high

The assigned index point values for the identified hazard/sensitivity pairs of elements of hydrogeological structure and technological equipment of the assessed ground water resource are clearly shown in Table III.

IV. Outcomes and Discussion

Security research project on the "Methodology of Assessing the Emergency Water Supply on the Basis of Risk Analysis" deals with a new classification of the resources of emergency water supply following the principles of risk management [20]. The proposed methodology is then tested on the selected resources listed in the water pipeline development plan of an assessed South Moravia region in the Czech Republic.

TABLE II
THE MEANING OF SENSITIVITY INDEX POINT VALUES AS A FUNCTION OF DAMAGE CAUSED TO INDIVIDUAL ELEMENTS OF GROUND WATER RESOURCE

Sensitivity point index interval and its verbal assessment	Impact of hazard on the resource of ground water				
	Hydrogeological structure of resource			Technological equipment of resource	
	Hydrogeological conditions	Hydrological regime	Water quality	Water intake structures	Water treatment plant
(0; 1⟩ Negligible	Local damage to an aquifer or the protective function of resource covering layer with a limited possibility of contamination leaking into the layer; the function of water resource is not significantly affected.	Local change in the direction of the current and the level of ground water; the function of water resource is not significantly limited.	Water in the local parts of resource structure rarely does not meet the requirements for the quality of drinking water. It meets the requirements for the quality of emergency water supply without treatment, though.	Isolated intake structures are damaged, exploitation of water is not significantly disturbed.	The change of parameters of isolated technological units, or minor damage to a building of water treatment plant; water supply is not significantly limited.
(1; 2⟩ Marginal	Local damage to an aquifer or the protective function of resource covering layer with a possibility of contamination leaking into the layer; the function of water resource is partially affected.	Change in the direction of the current and the level of ground water at multiple locations; the function of water resource is partially limited.	Water in the local parts of resource structure is contaminated by certain pollutants, but after a simple treatment it meets the requirements for the quality of emergency water supply	Some intake structures are damaged, or not functioning; exploitation of water is partially limited.	The change of parameters of some technological units or their breakdown, building of water treatment plant is partially damaged and water supply is partially limited.
(2; 3⟩ Critical	Extraordinary damage to an aquifer or the protective function of resource covering layer with a significant possibility of contamination leaking into the layer; the function of water resource is significantly limited.	Extraordinary change in the direction of the current and the level of ground water; the function of water resource is significantly limited.	Water in the major part of resource structure is significantly contaminated by a number of pollutants and only after a complicated treatment it meets the requirements for the quality of emergency water supply	Most intake structures do not function or are heavily damaged; exploitation of water is significantly limited.	Technological units have breakdowns or are out of service, water treatment plant is significantly damaged and water supply is significantly limited.
(3; 4⟩ Catastrophic	Destruction of geological layers of aquifer or the resource covering layer; aquifer lost its protection against massive leakage of contamination; the water resource is permanently out of operation	Permanent change in the direction of the current and the level of ground water; the function of water resource is permanently impossible.	Water in the whole resource structure is contaminated and it is impossible to treat it by commonly available technologies to reach the quality suitable for emergency supply.	All intake structures are destroyed, or irreparably damaged; exploitation of water is impossible.	Destruction of technology or water treatment plant; water supply is impossible.

TABLE III
SEMI QUANTITATIVE ASSESSMENT OF HAZARD/SENSITIVITY PAIRS OF INDIVIDUAL ELEMENTS OF JEŽKOVICE RV 12 GROUND WATER RESOURCE

Potential Hazards	Frequency point index	Sensitivity point index of threatened elements				
		HG	HR	WQ	WIS	WTP
Fires of Natural Origin	1.40				1.60	
Flood	1.90		1.82		1.82	
The Increased Radioactive Background Accompanied by the Leak of Radon	5				1.82	

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

The resources mentioned in that plan are not classified according to the methodical instructions [6]. Risk analysis and assessment are carried out for all drilled wells, which are then methodically classified into particular groups of resources earmarked for emergency water supply.

The paper presents the analysis of hazards and sensitivity of Ježkovice RV 12 drilled well listed in the water pipeline development plan. Based on the analysis it is then possible to assess the risk level of the resource of emergency water supply and classify it according to a new classification.

A. The Characteristics of Ježkovice RV 12 Drilled Well

Ježkovice RV12 drilled well is located in the land register of Račice. It is registered as another land and owned by a village called Ježkovice. The area border is a water resource protective zone of the first category. It is located in Rakovecké valley, southwest of Dvora Pastviny on the right bank of the Rakovec creek, below its confluence with the right bank tributary called Malý Rakovec.

The partial hydrological catchment area of RV 12 drilled well includes the part of Rakovec catchment area over the assessed drilled well, against the current in East-North-East – West-South-West direction. The highest point of catchment area is not Rakovec headwater, but Malina hill (571m above sea-level), west of Ruprechtov.

The lands in the above mentioned catchment area have solely the function of forest. The large part of the drilled well catchment area belongs to the natural park called “Rakovecké valley.” The most precious parts of the natural park are natural reservations called “Rakovec”, “Rakovecké hillsides” and the “Valley of snowflakes.” There are not any villages in the catchment area at present. There are only residues of two medieval settlements called Bystřec and Sokolí. There are not any roads in the catchment area. Geographic and hydrological situation in the area is shown in Fig. 1. Hydrological situation in the area is shown in Fig. 2. Ježkovice RV12 drilled well and its surroundings are shown in Fig. 3.

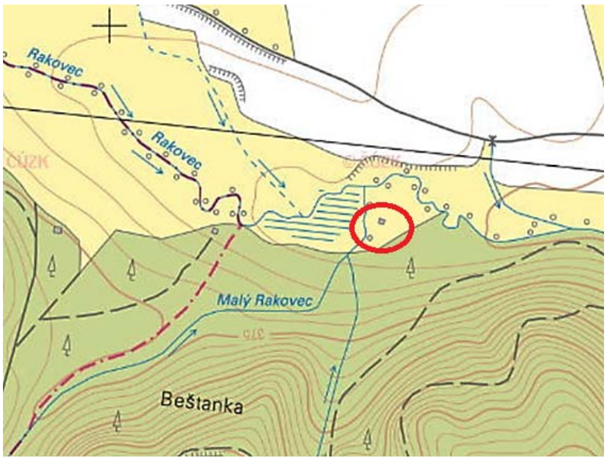

Fig. 1 Geographic Map of the Area

Note: Red circle shows the site of drilled well

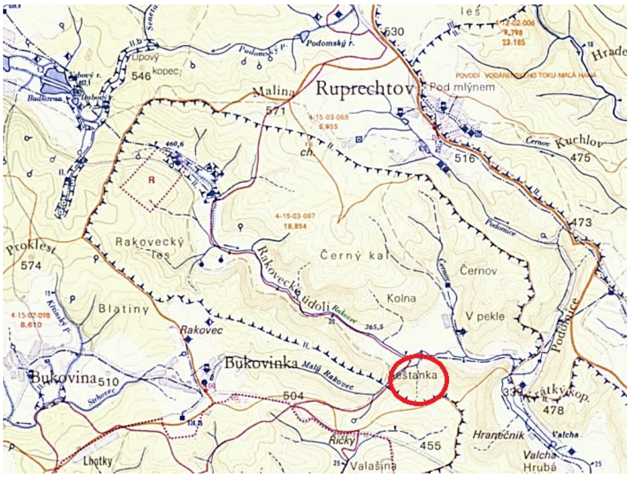

Fig. 2 Hydrological Map of the Area

Note: Red circle shows the site of drilled well

Fig. 3 Ježkovice RV12 drilled well and its surroundings

B. Identification of Hazards and Sensitivity of Ground Water Resource Elements

Hazard identification has been carried out on the basis of developed general register of hazards, the territory reconnaissance and the research of relevant data. The following natural hazard sources have been identified for Ježkovice RV 12 drilled well: fires of natural origin, floods and the increased radioactive background accompanied by the leak of radon. Hydrological regime and the quality of ground water are the threatened elements of RV 12 drilled well hydrogeological structure. Water intake structure is the only threatened element in the technological equipment of water resource.

1. Fires of Natural Origin

Fires of natural origin may be caused by storms and other electric phenomena the most often. There is forest and the growth of trees and bushes around the fenced waterworks facility, which may catch fire and endanger the facility armature chamber. The synergic effect of fire of natural origin near the drilled well is the increased susceptibility of deforested landscape to erosion, or the landslides.

Hydrogeological structure is not sensitive to the fires of natural origin either at all, or only minimally. Fires cannot affect hydrogeological conditions, hydrological regime and the quality of ground water. Only in case of a large deforestation they may disturb the landscape hydrological balance in the long term.

Technological equipment is only minimally sensitive to the fires of natural origin. Only grass may catch fire within the fenced area. However, fire can spread from the trees and bushes growing in the surrounding area of the fenced waterworks facility due to wind and the fall of tree in fire. The armature chamber will probably not be destroyed by fire. However, wiring may have blackout, be damaged or destroyed by fire. Short term interruption of water pumping from the water intake structure due to damaged wiring will lead to a temporary shutdown of the resource emergency water supply, which will not disturb its function. It will start operating again when the electricity supply is renewed. In case the wiring is seriously damaged or destroyed the water could be exploited with the help of mobile diesel power generators and then transported either through the water pipeline into Ježkovice water reservoir or in truck tanks. The long-term shutdown of water pumping from the water intake structure would lead to the disturbance of network of emergency water supply facilities and the necessity to supply population from another source. The problem might be the worse accessibility of drilled well only on field roads, which might make the employment of heavy machinery impossible in case of unfavorable meteorological and climatic conditions.

2. Flood

The Rakovec creek runs approx. 30 m north of the assessed drilled well. Malý Rakovec, its right tributary, runs along the west edge of the area. During spring thawing of snow and torrential rains the above mentioned streams may leave their banks and flood the terrain on many sites of partial hydrological catchment area of the drilled well. The RV 12 drilled well is not located in the inundation area of 100-year water according to the hydrological map. It results from the above mentioned that n-year floods of higher occurrence cannot reach the drilled well and its surrounding area. Flash floods in the catchment area of Malý Rakovec may have more serious impact, because Malý Rakovec runs in the immediate vicinity of the assessed location. Their occurrence is difficult to be predicted, though. Synergic effect of floods may be the erosion of hillsides and subsequent hillside instabilities.

Hydrogeological structure is minimally sensitive to floods. Water reaches the drilled well only rarely during floods. Besides that there is a compact vegetation cover on the whole territory of partial catchment area. Mainly grass has a significant protective function against mechanical erosion. Therefore mechanical erosion of cover layers and acquifers near the drilled well is not a problem. The vegetation cover in the drilled well partial catchment area leads to the retardation of infiltration of surface water into hydrogeological acquifer. Thus the impact on the hydrological regime is gradual, without sudden changes of surface levels and the direction of ground water flow. As the protective cover layer is thick the quality of ground water cannot be significantly affected either. The quality of surface water is not threatened in the area of stricter regime of nature protection even during floods.

Technological equipment is sensitive to floods minimally as it is located in walled and protected facility. Besides that, the overflow of surface water during floods does not reach the drilled well.

3. The Increased Radioactive Background Accompanied by the Leak of Radon

The Drahanská highland is the area of increased radioactive background. The reason is the origin of sedimentary rocks in the Drahanská highland from the area of Českomoravská highland. The rocks contain potassium and many crude ores of radioactive materials, which are still mined at present. While the radioactive background is almost constant in the area and its intensity decreases in time only due to gradual decomposition of radioactive isotopes, the leakages of radon into atmosphere fluctuate in dependence on atmospheric pressure. The synergic effect of increased radioactive background accompanied by the leak of radon in the area is the deterioration of working conditions in non-ventilated waterworks facilities where water is treated.

Quality of ground water is sensitive to the increased radioactive background accompanied by the leak of radon in the hydrogeological structure. Hydrogeological conditions and hydrological regime are not sensitive to such threat. The occurrence of radon in water does not represent risk in case of oral exposure. The respiration exposure to radon in water being volatile in non-ventilated environment represents not negligible carcinogenic risk.

Technological equipment is not sensitive to the increased radioactive background accompanied by the leak of radon.

V. Conclusion

The first step of risk analysis has been carried out for Ježkovice RV 12 potential resource of emergency water supply. Registers have been developed and semi-quantitative assessment of hazards and sensitivity made. The following hazards have been identified for the drilled well in relation to the threatened elements of hydrogeological structure and individual technological elements: fires of natural origin, floods, and the increased radioactive background accompanied by the leak of radon. Then each hazard activation frequency has been assessed. The set of potential sensitivities of particular asset in relation to individual hazards has been determined. The semi-quantitative point indexation of sensitivity of each element of hydrogeological structure and technological equipment of water resource to each identified hazard has been carried out. When the sensitivities of water resource elements were indexed the sensitivities to each hazard had to be considered.

Risk assessment will be carried out on the basis of risk analysis. The resource of emergency water supply will be classified according to the level of risk and according to a newly developed methodology reflecting the needs of crisis management. The presented procedure of hazard/sensitivity analysis will be used as an example for assessing other resources of emergency water supply.

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