International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:6, No:11, 2012

# Vulnerability of Groundwater Resources Selected for Emergency Water Supply

Frantisek Bozek, Alena Bumbova, and Eduard Bakos

***Abstract*—**Paper is dealing with vulnerability concerning elements of hydrological structures and elements of technological equipments which are acceptable for groundwater resources. The vulnerability assessment stems from the application of the register of hazards and a potential threat to individual water source elements within each type of hazard**.** The proposed procedure is pattern for assessing the risks of disturbance, damage, or destruction of water source by the identified natural or technological hazards and consequently for classification of these risks in relation to emergency water supply.

Using of this procedure was verified on selected groundwater resource in particular region, which seems to be as potentially useful for crisis planning system.

***Keywords*—**Hazard, Hydrogeological Structure, Elements, Index, Sensitivity, Water Source, Vulnerability

## I. Introduction

WITH regard to the fact that a human being without water survives for only three to six days, the water supply is of even higher significance especially under crisis situations, in which the supply of water to population from water supply systems is either limited or totally broken. Such cuts may be either local or global, depending on the extent of crisis. The supply of water to population may efficiently be solved by operating the alternative sources, which are the structures of ground waters [1].

At present we cannot rely upon the assumptions that the risks of crises, accompanied with partial or total failure of public system of supplying population with drinking water, are low. Therefore it is efficient to have a list of sources of ground waters incorporated into the crisis plans. Such sources may be classified on the basis of risk analysis and utilized in case of crises. Inseparable part of risk analysis is the assessment of vulnerability of each element of hydrogeological structure and technological equipment of water source in relation to each identified natural and anthropogenic hazard [2].

## II. The Analysis of Current State

The large extent disturbance of drinking water supply is a crisis situation, which may almost be excluded, if it does not occur in the consequence of another emergency event [3].

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

A. Bumbova is with Civil Protection Department, University of Defence, 65 Kounicova, 662 10 Brno, Czech Republic.

E. Bakos is with Civil Protection Department, University of Defence, 65 Kounicova, 662 10 Brno, Czech Republic.

The drinking water supply may be disturbed anywhere in the Czech Republic, if it is caused by an ordinary breakdown of water supply system. Such a cut off in supply is managed by a particular water supply and sewage system entity, which organizes an emergency supply of population with drinking water in the affected areas according to a particular model plan for emergency water supply [3]. However, if an emergency event causes the large extent cut off in drinking water supply, it will be solved, besides other measures being taken, by the emergency drinking water supply [3]. Such an emergency supply may be supported only by legislation, i.e. by declaring the state of crisis. In the past the crisis situation connected with the large extent disturbance of drinking water supply was managed as a part of complex emergency supply of affected population during the floods in the Czech Republic in 1997 and 2002. The technical support to the emergency water supply in the Czech Republic is provided by regional and municipal authorities through the Emergency water supply service. Depending on the type of disturbance of drinking water supply it is possible to use mainly the following [4]:

a) non-damaged water supply systems or their parts;
b) non-damaged isolated water intake structures, mainly wells;
c) water tanks;
d) mobile water treatment plants and technological devices needed to achieve required quality of water in case of water treatment plants failure or when using emergency water sources;
e) bottled water; this option is only supplementary

The emergency supply of drinking water starts within 5 hours after the state of crisis is declared [3]. The requirements for water quality in the conditions of emergency supply may be different from the requirements for the quality of drinking water for one month as a maximum [5]. It is possible to use the U.S. EPA document in order to orientate quickly, whether the concentration of individual contaminants in supplied water is acceptable. The U.S. EPA document states health advisories for 1-day and 10-day exposure of a child weighing 10 kg to the range of 210 contaminants, including inorganic anions and cations, organic substances and significant radionuclides [6].

For emergency supply it is the matter of priority to assess the capability of water supply system to supply water. It is also recommended to use the ground water sources, mainly the vertical water intake structures, established and equipped for the intake of ground waters of deeper circulation, and if need be, also the horizontal and combined water intake structures [7].

The accumulation of surface waters in water reservoirs and watercourses cannot be recommended for emergency supply due to its high vulnerability. The sources of surface waters should be used only exceptionally and only in justified cases. It is not suitable to use all hydrogeological structures for the needs of crisis management, either, because they have different hydrogeological conditions, hydrological regime, water quality, accessibility and yield. Besides that, they are threatened by a number of hazards with various vulnerability of individual elements of technological sources [2].

The identification procedures and construction of universal processed registry of threatened elements including identification of particular hydrogeological structure and technological elements of water source, which can be disturbed, damaged, or destruct was described in our previous article [1].

The risk quantification requires the frequency of activation of each identified source and also the vulnerabilities of parts of hydrogeological structure and individual technological elements of ground water source. Generally the vulnerability of water source may be defined as a property, characterized by its susceptibility to damage or destruction due to its low resistance to hazard depending on the character of load and the time of exposure [8]. The vulnerability assessment of ground water sources is a very complex and demanding task. The semiquantitative index method is used for such an assessment [9]. The above mentioned method has been modified by our group for the needs of assessing the vulnerabilities of the threatened elements of the source of ground water [2].

The point vulnerability index has been built together with its verbal definition for each threatened element of hydrogeological structure and technological equipment of water source in relation to the intensity of hazard impact [2].The procedure of implementing the proposed vulnerability index for the selected source of ground water suitable for emergency supply is described in the text below. The necessary prerequisite of implementing the proposed procedure was the former elaboration of the register of hazards and the identification of threatened elements of the assessed source, which are specific for each water source and each hazard [10].

## III. Applied Methods

The method of "Fault Tree Analysis" has been used for building the general register of vulnerabilities [2], based on a systematic retrospective analysis of events while employing the chain of causes, which could lead to the selected top-event, in combination with the „What if" method" [11, 12].

The elements of hydrogeological structure and technological equipment of water sources, potentially affected by the activation of a particular source of hazard, have been identified at three joint meetings of seven experts and through their brainstorming with two iterations [13].

The vulnerability index determined in points for each identified pair of hazard/vulnerability of the assessed water source has used the former definitions of point indexes of vulnerability of individual elements of hydrogeological structure and technological equipment of water sources [2]. The point indexation of vulnerability of individual water source elements for each identified hazard has also been made through brainstorming, similarly to the identification of threatened water source elements.

## IV. Outcomes and Discussion

The identified threatened elements of emergency ground water sources may be divided into a hydrological structure and technological equipment for the intake, treatment and distribution of ground water [2].

The following elements may be threatened in the hydrogeological structure of water source:

f) Hydrogeological Conditions (HGC);
g) Hydrological Regime (HR);
h) Ground Water Quality (GWQ).

The following threatened elements have been identified in the technological equipment of water source:

a) Hydrogeological Conditions (HGC);
b) Water Intake Structures (WIS);
c) Water Treatment Plant (WTP);
d) Distribution system (DS);
e) House Connections and Water Distribution System (HCWDS).

Only the hazards to intake structures and water treatment plant have been monitored within the above mentioned subsystems, because they are located mostly at the places of exploited hydrogeological structure. The distribution system and terminal connections, including house connection and water distribution systems are usually located quite far from the exploited hydrogeological structure and are not closely connected with the source itself.

When assessing the $R_{j,i}$ risk of contamination, damage, or destruction of i-element of water source resulting from the activation of j-source of hazard it is necessary to start from the register of potential hazards to the individual elements of hydrological structure and technological equipment of the assessed source. The $R_{j,i}(\tau)$ risk in the given time $\tau$ is calculated according to the equation (1), where $P_j(\tau)$ represents the value of point index related to the probability of activation of j-source of hazard in time $\tau$, and $V_{j,i}(\tau)$ is the value of point index of vulnerability of i-element of water source to j-hazard in the same time $\tau$.

$$R_{j,i}(\tau) = P_j(\tau) \times V_{j,i}(\tau) \qquad (1)$$

It results from the equation (1) that besides knowing the frequency of activation of j-source of hazard, expressed on an index scale [1] it is also necessary to know the quantification of vulnerability $V_{j,i}$ in the form of index assessment of each i-element of water source in relation to each identified j-hazard at the time $\tau$. Therefore it was necessary to assign the point value of vulnerability index to each hazard/vulnerability pair of the assessed water source.

Brainstorming helped to index the vulnerability while employing the data presented in Table I concerning the former verbal assessment, which defined the values of indexes in points in relation to the level of disturbance, damage, or destruction of the considered elements of water source [2].

It is also necessary to accept general and natural conditions in the broad surrounding of the assessed water source with focus not only on its protective zone, but also the infiltration area. Historical data have been used as well.

The general data include mainly the geographic specification, the former exploitation of territory, the characteristics of area settlement and possibly the property rights. As far as the natural conditions are concerned, mainly the following aspects have been specified and assessed: the character of the territory and its relation to the larger vicinity, terrain morphology, orographic data, climatic, geological, hydrogeological and hydrological conditions, geochemical data on the area and, last but not least, the protection of nature and landscape. The former emergency events and the range of damage to the assessed elements of water source have also been taken into consideration.

The potential hazards identified for the monitored water source are the hazards from the group of natural disasters caused by atmospheric and geologic changes and also by other impacts. Technological hazards include the hazards caused by common activities in husbandry and forestry. Ecological burdens near the source and its infiltration area have not been discovered [10].

In view of the fact that adjudicated well is not equipped by mobile water treatment plant, because is assumed, that in case of crisis situation will be used mobile water treatment plant, vulnerability of mentioned technological element was not assessment

### *A. Storms and Electric Effects*

Technical equipment of the source of emergency water supply is vulnerable to storms and electric effects. The strike of lightning may cause either the fall-out of electric current in the armature chamber and water treatment plant or the damage or even destruction of electronic equipment.

A short-term cut-off of water intake in case of fall-out of electric current may temporarily put the water intake structure out of operation. Damage or destruction of electro-installation will cause a long-term cut off of water intake from water intake installation and will not make the water supplies within the emergency water supply possible. The sensitivity of the system in relation to the assessed hazard is reduced by installing the protection against lightning. A short- term cut-off of water intake from the water intake structure will result in the temporary outage of the source of emergency water supply. Its functionality will not be disturbed and may be put into operation again when the supplies of electric current are operational. The long-term cut-off of water intake from the water intake structure would lead to the disturbance of the network of emergency water supply facilities and the necessity to supply population from another source.

With regard to the above mentioned facts the water intake structure (WIS) vulnerability index is 2.

### *B. Hailstorms and Torrential Rains*

Water intake structure and hydrological regime of water are vulnerable to hailstorms and torrential rains. The building of armature chamber and WTP may be flooded, which could lead to the long-term inactivation or may show unsuitable water quality supply. The WIS vulnerability to hailstorms and torrential rains has been assessed by index 2.

Infiltration of a large amount of surface water in the infiltration area of the assessed drill hole may lead to an extreme increase of ground water level and consequently to the changed gradient of piezometric level of ground water with impact on the velocity and direction of ground water flow.

Neither changing of level nor direction of groundwater flowing can seriously affected function of potential resource for emergency water supply and that is the reason for assessing of vulnerability index 1 for this treatment and hydrogeological regime.

### *C. Extreme and Long-lasting Precipitation*

Both hydrological structure and technical equipment of the source of emergency water supply are vulnerable to extreme and long-lasting precipitation. Because consequences for threatened elements are the same as in case of hazards caused by hailstorms and torrential rains, the vulnerability has been equally assessed by vulnerability index 1.

### *D. Floods*

Floods can be originated by creek which is distant approximately 30 m from drill hole. Floods may lead to influence hydrogeological regime and to flood WIS. Technological equipment of WIS can be damaged or destroyed. The facilities may be wet from floods and their statics may be affected by that. The entrance to the drill hole will be limited or discredited by water or alluvial ground which overlaps WIS. Hydrogeological regime will be not fundamentally affect in the locality. If the flood occur in infiltration area of drill hole, it could be possible to wait minimal increasing of groundwater level. For the above mentioned reasons the vulnerability index of WIS in relation to the flood has the value 3 and for hydrogeological regime 1.

### *E. Soil Erosion*

Only the technical equipment of the source of emergency water supply is vulnerable to soil erosion. Around the water intake zone is not protected against soil erosion from the surrounding farmland. Therefore the vulnerability index has been assessed as value 3.

### *F. Hailstorms and Torrential Rains*

Water intake structure and hydrological regime of water are vulnerable to hailstorms and torrential rains. The building of armature chamber and WTP may be flooded, which could lead to the long-term inactivation or may show unsuitable water quality supply. The WIS vulnerability to hailstorms and torrential rains has been assessed by index 2.

Infiltration of a large amount of surface water in the infiltration area of the assessed drill hole may lead to an extreme increase of ground water level and consequently to the changed gradient of piezometric level of ground water with impact on the velocity and direction of ground water flow.

Neither changing of level nor direction of groundwater flowing can seriously affected function of potential resource for emergency water supply and that is the reason for assessing of vulnerability index 1 for this treatment and hydrogeological regime.

*G. Extreme and Long-lasting Precipitation*

Both hydrological structure and technical equipment of the source of emergency water supply are vulnerable to extreme and long-lasting precipitation. Because consequences for threatened elements are the same as in case of hazards caused by hailstorms and torrential rains, the vulnerability has been equally assessed by vulnerability index 1.

*H. Floods*

Floods can be originated by creek which is distant approximately 30 m from drill hole. Floods may lead to influence hydrogeological regime and to flood WIS. Technological equipment of WIS can be damaged or destroyed. The facilities may be wet from floods and their statics may be affected by that. The entrance to the drill hole will be limited or discredited by water or alluvial ground which overlaps WIS. Hydrogeological regime will be not fundamentally affect in the locality. If the flood occur in infiltration area of drill hole, it could be possible to wait minimal increasing of groundwater level. For the above mentioned reasons the vulnerability index of WIS in relation to the flood has the value 3 and for hydrogeological regime 1.

*I. Soil Erosion*

Only the technical equipment of the source of emergency water supply is vulnerable to soil erosion. Around the water intake zone is not protected against soil erosion from the surrounding farmland. Therefore the vulnerability index has been assessed as value 3.

*J. Soil movements*

Deformation of equipment of previous realised hydrogeological drill was proved in the past in this locality due to landslides. A proof for that is evident change in this terrain showed morhopologically lateral ridge in the field which is located - hill east from investigated drill hole. This type of threat can damage or destroy facility and technological equipment, especially drill pump. Currently it can also assume significant disruption of the hydrogeological regime including hydrogeological conditions. Vulnerability of hydrogeological regime of investigated drill caused by landslides has been assessed by vulnerability index 4, hydrogeological regime by vulnerability index 3 and WIS also 3.

*K. Increased Radioactive Background*

The increased radioactive background may have a negative impact on water quality. The infiltration territory of the source is known as the area with increased radioactive background. The outcomes of chemical analyses show that the content of radon meets the valid legal standards. The vulnerability assessment considered the fact that the accompanying effect of increased radioactive background is the gas leakage from the Earth´s interior. Such a hazard could have a significant impact on water quality for a long period of time.

Meeting the water quality standards for a short-term emergency supply would require the implementation of adjustments aimed at reducing the concentrations of radionuclides below the limit values. However, the process of reducing the concentration of radionuclides from the monitored source is technologically complicated and expensive.

The vulnerability of ground water quality to the hazard of increased radioactive background has been assessed by vulnerability index 3.

*L. Husbandry and Forestry*

WIS is vulnerable to husbandry and forestry. Due to favourable geological conditions in the infiltration area of the assessed drill it can be assumed that the leakage of fuels and other operation fluids and the substances protecting, nourishing and stimulating the growth of plants, cannot have an impact on the quality of water. Careless handling of agricultural vehicles may result in the damaged fence of the facility. It will not have a significant impact on the technological equipment of the source. If the vehicles hit the brick buildings, either statics may be disturbed, or the buildings may be destroyed. Minor static disturbance of buildings will not affect water intake from the WIS and its further treatment. Serious damage of WIS will put the source of emergency water supply out of service. The destruction of the WTP building will not limit the operation of the source of emergency water supply, because it may be replaced by a mobile water treatment plant.

The vulnerability of WIS to the hazard of husbandry and forestry has been assessed by vulnerability index 2.

TABLE I
THE MEANING OF THE VULNERABILITY POINT INDEXES OF THE ASSESSED ELEMENTS OF WATER SOURCES FOR EMERGENCY SUPPLY

| Vulnerability index and its verbal assessment | Consequences of hazard impact on the source of ground water | | | | |
|---|---|---|---|---|---|
| | Hydrogeological structure of source | | | Technological equipment of source | |
| | Hydrogeological conditions | Hydrological regime | Water quality | Water intake structures | Water treatment plant |
| 1 Negligible | Local damage to a collector or the protective function of source covering layer with a limited possibility of contamination leaking into the layer; the function of water source is not significantly affected. | Local change in the direction of the current or the level of ground water; the function of water source is not significantly limited. | Water in the local parts of source structure rarely meets 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. |
| 2 Marginal | Local damage to a collector or the protective function of source covering layer with a possibility of contamination leaking into the layer; the function of water source is partially affected. | Change in the direction of the current or the level of ground water at multiple locations; the function of water source is partially limited. | Water in the local parts of source 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. |
| 3 Critical | Extraordinary damage to a collector or the protective function of source covering layer with a significant possibility of contamination leaking into the layer; the function of water source is significantly limited. | Extraordinary change in the direction of the current and the levels of ground water; the function of water source is significantly limited. | Water in the major part of source 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. |
| 4 Catastrophic | Destruction of geological layers of collector or the source covering layer; collector lost its protection against massive leakage of contamination; the function of water source is permanently out of operation | Permanent change in the direction of the current and the level of ground water; the function of water source is permanently impossible. | Water in the whole source 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 II
REGISTER OF POTENTIAL HAZARDS AND VALUES OF VULNERABILITY INDEXES FOR THE THREATENED ELEMENTS OF THE ASSESSED GROUND WATER SOURCE

| Register of hazards | Value of vulnerability indexes | | | | |
|---|---|---|---|---|---|
| | HGC | HR | GWQ | WIS | WTP |
| Storms and other electric effects | - | - | - | 2 | - |
| Hailstorms and torrential rains | - | 1 | - | 2 | - |
| Extreme and persistent rainfall | - | 1 | - | 2 | - |
| Floods | - | 1 | - | 3 | - |
| Soil erosion | - | - | - | 3 | - |
| Slope movements | 4 | 3 | - | 3 | - |
| Increased radioactive background | - | - | 3 | - | - |
| Agricultural and forestry production | - | - | - | 2 | - |

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

## V. CONCLUSION

The practical applicability of the proposed procedure of semi-quantitative assessment of vulnerability of the threatened elements of hydrogeological structure and technological equipment of the source of ground water has been verified. The outcomes in the form of the register of hazards, together with the point values of vulnerability indexes for the threatened elements of the assessed water source potentially exploitable for the emergency supply of population with drinking water, are presented in the Table II.

## ACKNOWLEDGMENT

The outcomes presented in this contribution are part of the security research project on “The Methodology of Assessing the Sources of Emergency Water Supply on the Basis of Risk Analysis”. The project No is VG20102013066 and the project is financed by the Ministry of Interior of the Czech Republic.

## REFERENCES

[1] Bozek, F., Dvorak, J., Caslavsky, M. Sources for Emergency Water Supply I. Hazard Identification. In Demiralp, M., Bojkovic, Z., Repanovici A. (Eds.). Mathematical Methods and Techniques in Engineering & Environmental Science. Proceedings of the 4th WSEAS International Conference on Natural Hazards (NAHA´11). Catania: WSEAS Press, 2011, pp. 85-90. ISBN 978-1-61804-046-6.

[2] Bakos, E., Bozek, A., Caslavsky, M., Bozek, F. Emergency Water Supply II. Vulnerability of Particular Selected Water Resource. In Niola, V., Ng, K. (Eds.). Recent Researches in Chemistry, Biology, Environment & Culture. Proceedings of the 9th WSEAS International Conference on Environment, Ecosystems and Development (EED´11). Montreux: WSEAS Press, 2011, pp. 17-21. ISBN 978-1-61804-060-2.

[3] Ministry of Agriculture of the Czech Republic (MoA CR). *Typified Plan Disruption of Drinking Water Supplying in Major Extent.* Prague: MoA CR, 2004.

[4] Ministry of Agriculture of the Czech Republic (MoA CR). MoA Directives for Standardized Procedures to be Followed by the Authorities of Regions, Capital of Prague, Municipalities and Prague Urban Districts in order to Provide Population with Emergency Supply of Drinking Water under Emergencies and States of Crises with the Help of Emergency Water Supply Service. Government Bulletin for the Authorities of Regions and Municipalities, Vol. 9, Article 3, 2011, pp. 42-46.

[5] The National Institute of Public Health (NIPH). Emergency Water Supply by Drinking Water. (Methodological Recommendation of the NIPH - The Reference Centre for Drinking Water). Prague: NIPH, 2007.

[6] U.S. EPA. Drinking Water Standards and Health Advisories Tables. Washington DC: U.S. EPA, 2009. [on line]. [2012-04-07]. URL: <http://www.epa.gov/waterscience/criteria/drinking/dwstandards.pdf>.
[7] Ministry of Agriculture of the Czech Republic (MoA CR). Methodological Instruction of the MoA CR for the Selection and Maintenance of Resources for Emergency Water Supply. Bulletin of the MoA CR, 2002, article 3, pp. 1-10.
[8] Bozek, F., Urban, R. Risk Management. 1st Ed. Brno: University of Defence, 2008 pp. 24, 57. ISBN 978-80-7231-259-7.
[9] Gogu, R. C., Dassargues, A. Current Trends and Future Challenges in Groundwater Vulnerability Assessment Using Overlay and Index Methods. Environmental Geology, 2000, Vol. 39, No. 6, pp. 549-559.
[10] Bumbova, A., Bozek, F., Caslavsky, M., Dvorak, J. The Identification of Threats to the Source of Emergency Water Supply. In ESREL 2012 Conference, Helsinky, 2012, 9 p. [In print].
[11] Warner, M. L. - Preston, E. H. A Review of EIA Methodologies. Washington, D.C.: U.S. EPA, 1974.
[12] Wells, G. Major Hazards and their Management. 1st Ed. Rugby: The Institution of Chemical Engineers, 1997. ISBN 0-85295-368-2.
[13] Fishburn, P.C. Utility Theory for Decision-Making. 1st Ed. New York: J. Wiley & Son, 1970.