Ecological incidents in Northern Adriatic Karst (Croatia)

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Abstract: In spite of growing efforts to preserve the quality of groundwater resources, accidental pollution is becoming increasingly frequent, resulting in long-lasting impact on the groundwater status. The consequences of ecological accidents are particularly expressed in karst regions, which are caused by the geological properties of the area where the groundwater aquifers are situated, as well as by hydrological circumstances which also influence the dynamic mechanisms of water flow and transportation of pollution in the karst environment. The paper stresses the hydrological component of karst aquifer function and the related role of hydrology in assessment of the hazards caused by accidental pollution and, once the accident has happened, in monitoring the situation and forecasting the possible impact on water resources. The analysis of ecological accidents in the karst has been made, based on the actual examples of accidents involving fuel substances recorded in the Northern Adriatic karst area in Croatia in the period from 1990 to 1998. The basic characteristics of the mechanism of water movement in the karst are presented from the hydrological standpoint, as well as the related risk of rapid transportation of pollutants into the parts of the aquifers used for water supply. The paper also contains proposals for possible approaches to protection of particularly valuable water resources in the karst from accidental pollution occurring in road transport.

Keywords: Accidental fuel contamination; Croatia; groundwater protection; karst hydrology; water resources

Introduction: Accidental contamination of the groundwater resources is a collateral damage caused by the technological and urban development. Frequency of such contamination has been on increase in the Northern Adriatic region of the Croatian coast, where water resources of strategic importance are located. Generally, the water quality is still satisfactory. Karst areas, such as the Northern Adriatic region described in this paper, are particularly susceptible to the effects of pollution. The groundwaters generally flow through privileged aquifer discharge conduits, and the karst medium is characterized by rapid pollution migration and dispersion into large areas and relatively poor capacity for water self-purification.

The present paper analyses several characteristic environmental accidents recorded within the subject area. Groundwater contamination has been the consequence of these accidents. A major environmental accident from 1997, when more than 120 m³ of mineral oil was spilled into the Pazinčica water course sinkhole located in the central part of the Istrian Peninsula, will be described in more detail. This accident imperilled the water supply well fields in the region. Additionally, as an example of long-term underground pollution, the Zvir II well field in the city of Rijeka is described. This well field has been out of operation for some ten years because of permanent contamination. The third example is that of accidental groundwater contamination caused by a spillage of 16 m³ of mineral oil from a tank truck near Obrov located in the neighboring Slovenia. This spillage caused contamination of several groundwater well fields on both sides of the state border. This example is used to underscore the fact that groundwater contamination does not recognize boundaries, and it therefore asks for adequate management of common water resources protection within the greater region (Rubinič et al., 1997). All three analyzed environmental accidents, like as the majority of accidents which occurred during the last decade in the Northern Adriatic region, have been caused by accidents during fuel handling and transportation. Therefore, these activities should be given priority when considering adequate protection measures.
Water flow and pollution transportation mechanisms in Karst

The karst is characteristic for its nonhomogeneous karst aquifers – complex zones of collecting and discharge that function as systems which have individual privileged inflow and outflow conduits. In privileged discharge conduits, the water regime is generally turbulent, and it lifts and carries along the suspended particles which are the main carriers of pollution brought into the underground. After the rainwater has infiltrated into the underground through the overburden, the groundwater generally moves through developed fissure systems characterized by comparatively short retention times. For that reason, there are no effects of filtration or pollutant adhesion on the aquifer rock mass, characterised by its homogeneous, finely structured media (Bonacci, 1987).

Groundwater contamination may have two causes:
• accidental contamination caused by accidents in various facilities or failures on vehicles used for transportation of hazardous cargo,
• contamination caused by polluter’s long-term adverse impacts.

The dynamics of contamination penetration into the underground aquifer depend on the position of the polluter relative to the hydrographic flows in the karst. If the contamination penetrates the already formed surface watercourses flowing into the underground as well defined sinkhole zones, or if they infiltrate karst underground in individual flow sections, the contamination will reach the dynamically most active part of the aquifer by privileged discharge conduits within a short period of time. However, if karst surface contamination penetrates the underground parts with an undeveloped hydrographic network of water courses, its infiltration into the aquifer is considerably slower. It is possible that the geological composition and structure of the area will prevent contamination from reaching the aquifer. In such cases, the contamination remains contained in the so-called natural pockets. Still, it is possible that relatively stationary pollution built up in the underground eventually reaches the aquifer by slow filtration after a long period of time and causes contamination even in the future (Ožanić et al., 1997).

Currently, monitoring of the pollution impact on water resources includes only the impacts related to the dynamic water reserves, namely the zone of relatively rapid changes in hydrological conditions of water reserves, so possible impacts on deeper aquifer sections are not considered. There is no doubt that the pollution impact is transferred to the deeper parts of the aquifer to a certain degree. Therefore, it is important to set up profile monitoring of water quality fluctuations in both aquifer and deep zones (below the sea level) where karstification processes are encountered.

A groundwater protection system is a part of an integrated management and decision-making process which must encompass all the elements contributing to the management at control and higher levels.

The effect of change in water quality on ecosystem and population, and physical interaction between actions and resources utilization efficiency stimulate institutional mechanisms within a society to initiate organized resources management.

Overview and basic characteristics of recorded fuel-related accidents

Pazinčica Sinkhole Contamination (Istria, Croatia)

The Pazinčica is the largest surface watercourse in the central part of the Istria Peninsula which does not flow into the sea. Its surface course ends in an well defined sinkhole under vertical 120 m high rocks. The sinkhole entrance is at 185 m a.s.l. The Pazinčica drains water from an immediate about 83 km² large catchment area predominantly built of flysch. The mean annual discharge is 0.815 m³s⁻¹. The water course is torrential, so the observed discharges range widely from complete drying out of inflow from the catchment to maximum discharge of over 150 m³s⁻¹ (Rubinić and Kukuljan, 1996). It is assumed, based on the
position of the sinkhole with respect to the Istrian Peninsula and results of the groundwater tracing performed so far, that the highest groundwater tables in the Istrian karst aquifer are those in the greater Pazinčica sinkhole area. It has been determined that, due to its central position on the Istrian Peninsula and concentrated impact on the underground, the Pazinčica water directly affects a number of Istrian well fields. Therefore, it is evident that any contamination carried by the Pazinčica into the underground has direct impact on the potable water well fields. A major accident which happened early in October 1997, when over 120 m$^3$ of fuel oil spilled from the Pazinka Factory into the sinkhole zone, highlights the complexity of the karst water quality protection. The initiated activities were twofold, i.e. emergency cleanup of contamination in the Pazinska Jama sinkhole area and setting up of adequate water quality monitoring. Hydrology played a special role in these actions, both in monitoring the hydrological conditions and in forecasting the hydrological conditions in the surface and underground parts of the Pazinčica watercourse (Ožanić et al., 1997).

An additional obstacle encountered during this environmental disaster was the fact that the subject area was affected by an outstanding draught, unusual for that part of the year, so the inflow into the Pazinska Jama sinkhole by the Pazincica riverbed was only about 0.005 m$^3$s$^{-1}$. Thus, the cleanup and fuel oil removal activities were indirectly dependant on hydrological inflow forecasts based on catchment area precipitation forecasts and records. The hydrological conditions were also monitored in the underground and in the points of water outflow from the aquifer. Based on these data, and the results of earlier groundwater tracing results, forecasts were prepared on possible dynamics of contamination outflow from the underground.

The emergency spillout cleanup activities undertaken in the Pazincica sinkhole area lasted 12 days and were finished on 22 October, 1997. In this action, 421 m$^3$ of oil-polluted substances were collected, from which 123 m$^3$ of fuel oil was subsequently separated at the petrochemical plant facilities. Unfortunately, lack of accurate records impeded determination of the exact quantity of fuel oil which infiltrated into the underground. Regarding the total scale of spillout, even a comparatively small quantity which reached the underground must have resulted in deterioration of water quality in the Istrian underground.

Even before the described accident, there had been indications in some well fields of increased concentration of some pollutants. However, their values had never reached the levels recorded after the described environmental accident.

Hydrological condition and water quality monitoring has been set up on a number of well fields in the greater influence area where the contamination was expected to be detected. In some well fields, the recorded contamination levels have been several times higher than maximum allowable pollution concentrations, primarily those of mineral oils and total fat and oil. Maximum pollution concentrations in the outflow points were detected some two months after the accident at the Pazincica sinkhole. Subsequently, increased pollution (with evidently decreasing peaks) accompanied the occurrence of higher water waves.

The possibility should be considered that negative changes in water quality caused by accidental pollution affect not only dynamic water reserves which outflow at the well fields, but could also cause general deterioration of water quality in static water reserves in the Istrian aquifer. Therefore, the accidental pollution from October 1997, as well as other discharges of contaminated process and wastewater into the Pazinčica sinkhole, will have long-term global adverse effect on general quality of water reserves in the Istrian Peninsula.

Accidental gas oil spillout at Obrov (Slovenia)
The traffic accident on 12 October, 1994 caused spillout of 16 m$^3$ of gas oil at Obrov in Slovenia, some 5 km from the state border with Croatia. This environmental accident
happened in the area from which the waters, according to earlier hydrogeological analysis, gravitate towards the Rižana spring some 15.5 km from the accident site.

This spring is one of the major water supply sources in the Slovenian coastal region. Therefore, the Slovenian institutions initiated monitoring which primarily focused on detecting any contamination of this spring and the Osapska Reka spring some 17 km away, also in the Slovenian coastal region. However, due to doubts on possible hydrogeological interconnection with the Mlini spring in Croatia, or rather on the very border between the two states, the monitoring conducted by the Slovenian experts was extended to several water supply well fields in Northern Istria, including Sv. Ivan (17.5 km away), Bulaž (24.5 km away) and Gradole (38 km away).

Based on available results obtained by the Slovenian experts (Kogovšek, 1995), it has been determined that the pollution was detected shortly after the incident at the Rižana spring (after 14 days). To a smaller scale, it has also been noticed at the Osapska Reka spring in Slovenia and the Mlini spring in Croatia. The Croatian team monitoring results (Urumovic, 1996) have shown that the accidental contamination effects should be expected to be more widespread because the increased concentrations of mineral oils and total fats (above the maximum allowable concentrations) which might be related to the subject accident have also been detected in the Sv. Ivan spring (16 days after the incident) and in the Bulaž spring (175 days after the accident). The mineral oil contamination was detected after 208 days in the furthest Gradole spring which has its predominant replenishment area further towards the south from the accident site. It is interesting that, according to the monitoring results of the Croatian team of experts, maximum pollution concentrations at the Croatian springs were detected long after the first contamination wave had passed. The maximum pollution concentration at the Bulaž spring was recorded on the 329th day after the accident, and at Mlini, Sv. Ivan and Gradole springs on the 398th day after the subject tank truck accident. This confirms that the resulting contamination was of regional character. Interpretation of data related to the monitoring conducted by the Slovenian and the Croatian side has considerably contributed to an increase in the comprehensive understanding of the hydrological and hydrogeological elements of water phenomena in the analyzed area. Since the acquired data were separately analyzed and interpreted by each side, direct collaboration of state institutions active in the region is necessary in order to obtain more adequate input data for preservation of water resources in the area.

Zvir II well field contamination (Rijeka, Croatia)

The Zvir II well field is located on the outskirts of the urban zone of the city of Rijeka. The intake structure consists of 400 m long access gallery excavated several metres above the sea level, in karstified rocks of the Lower Cretaceous. Within the gallery, six wells had been bored enabling tapping of groundwater reserves. For over ten years the facility has been considered as an investigation and exploitation well field, however, it is still not in use. One of the reasons behind such a situation lays with detected leakage of fuel oil into one of the wells. The tracing had confirmed that the leakage is coming from the fuel oil unloading area within the Kozala Heating Plant located immediately above the water intake at about 90 m a.s.l. For years, cleanup works have been carried out and about 5 t of fuel oil has been collected in the collecting separator. Due to a lateral leakage from the separator, it actually holds one third of total contamination, so it is anticipated that about 10 t of contamination has been washed out and away remedied during the cleanup activities (Goatti, 1999). Although the primary leakage source within the Kozala Heating Plant has been remedied, the Zvir II well field is still contaminated because the exact amount and scale of contamination which penetrated the underground is not known. Therefore, there is no exact knowledge of the contamination retained in the overburden above the well field.
Since this is the pollution in the zone of direct overburden interface with the active zone of groundwater communication, the process of contamination leakage into the underground has been a long-term one. In order to stimulate this process, the remediation activities included flushing of the contaminated area with cold and hot water containing chemicals allowed for use in well fields flushing. The results of the flushing water chemistry monitoring indicate that there is an obvious improvement in the Zvir II well field conditions. Improvement in water quality at the water intake should be expected after several additional flushing operations (Goatti, 1999).

Conclusions

Frequent groundwater contamination events, including the examples of extreme accidental contamination in the Northern Adriatic karst described in this paper, point to the complexity of the problem. It is clear that the water resources quality preservation has become an acute problem for which an effective solution is being sought, and it is a pursuit which must be undertaken actively both by the experts initiating and undertaking individual actions and the general public. The problem is that, with the exception of the traffic accident at Obrov where the quantity of fuel which infiltrated the underground was known, the quantity of pollutant is not known either in the Zvir II or in Pazinčica sinkhole case. In these latter cases, we are dealing with tens or over 100 m$^3$ of fuel, so the power plant operators should be involved before the accidental contamination turns into disaster.

The groundwater resources protection measures usually become more intensive when an accidental contamination of an aquifer happens. Since the groundwater in an aquifer remains there for tens and more years, the aquifer contamination may last for a number of years. This particularly applies to karst aquifers, the non-homogeneity of which enables rapid penetration of contamination over large distances. The hydrological component in monitoring of contamination, when it happens, and the forecast of possible pollution transportation effect and dynamics, is very important for successful implementation of the cleanup activities.

Preventive protection of groundwater is certainly imperative. Environmental, social and economic, and in extreme cases even public health consequences of the groundwater contamination, are several times higher than the costs of adequate protection. Groundwater protection is a complex issue which demands an interdisciplinary approach and engagement of experts in different disciplines. Such protection should be integrated into the groundwater use and management planning and investigation processes.

References


