The importance of groundwater vulnerability maps in the protection of groundwater sources. Key study: Sarajevsko Polje

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Abstract

In order to ensure effective protection of groundwater sources, it is important to take into account all pollutants and activities that may present a potential risk. In the last period, as a useful tool in the protection of groundwater vulnerability mapping is applied. There are many methods for mapping groundwater vulnerability, some of which are more applicable than others. Although the use of and the choice of methods for assessing vulnerability depending on data availability, scale mapping, spatial distribution of data, hydrogeological and hydrological characteristics and many other parameters that serve as inputs for obtaining valid results.

In this regard, this paper will analyze several methods for assessing the vulnerability of groundwater, which can be applied to the source of groundwater in the Sarajevo area. After the analysis, the results of completed vulnerability assessment, and mapping of groundwater vulnerability in the exploration area will be displayed using the COP method. The results will be presented with the help of GIS tools and presented in the form of maps of vulnerability for the catchment area of Sarajevsko Polje.

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1. Introduction

Groundwater contamination is an increasing water resources problem. Since the remediation program is extremely expensive, the most reliable protection of groundwater sources is to prevent pollution. Development of groundwater vulnerability maps is one of possible techniques which aim to prevent pollution.

In order to ensure effective protection of groundwater, as the most important resource for water supply of the population, it is necessary to take into account all pollutants and all possible actions that should take place in the catchment area and where a potential risk to groundwater exists. However, to establish the impact of a pollution that can cause to the groundwater, first is necessary to determine the limits to which the groundwaters itself capable of prevent pollution, and to determine their „immune system”. The sensitivity of the aquifer or naturally existing sensitivity (internal sensitivity) is a measure that indicates the easiness with which water enters into aquifer and moves through it. This is property of aquifer, overhead rocks and hydrogeological conditions, and at the same time is independent of the characteristics of pollutants and sources of pollution. To be able apply source protection measures, except knowledge of the natural sensitivity; it is necessary to know the source and type of pollution. Thus, the concept of vulnerability is introduced into issue of groundwater protection. The vulnerability of the aquifer can be defined (according to U.S. EPA) as the ease with which the pollution, which is located on or near the surface, can penetrate to a given collector and represents the "existing natural features" of the geological composition of any saturated any aeration zone. According to Popescu (et al. 2008), vulnerability is the degree to which human or environmental systems are likely to experience harm due to perturbation or stress, and can be identified for a specified system, hazard, or group of hazards.

Assessment of groundwater vulnerability varies spatially and complexity from simple, high-quality, rigorous, expensive or/and very inexpensive to access. In all methods, the vulnerability of the aquifer is generally defined by a time-traveling droplet of water from the surface to the aquifer. Create maps of groundwater vulnerability is widely used in developed countries and is a very important tool for the protection of groundwater. Vulnerability maps are used extensively the past 30 years. Combining vulnerability maps with maps of potential pollutants of groundwater provide very good results in identifying risks. The risk of contamination of groundwater is defined as the probability that groundwater become contaminated to unacceptable levels, using the activity that occurs directly on or below the earth's surface. From the standpoint of groundwater protection is very important to define the zone of risk of pollution.

2. The choice of methods for mapping vulnerability areas Sarajevo Polje

Choosing a method for mapping the vulnerability of area Sarajevo Polje is a very important task. To date, there is no generally accepted standard method of mapping. The methods that are commonly used are DRASTIC, GOD, GLA, PI, COP and EPIK method, [1]. The possibility of applying certain a method on the analyzed area is depending on availability spatial distribution of data, the scale of mapping and hydrogeological characteristics of the terrain. After analyzing a number of different methods, in an area where there is not enough data, but where hydrogeological characteristics are recognize, it can be concluded that the DRASTIC method is appropriate. DRASTIC is the oldest and most frequently used method, but without the possibility of including the parameters that are characteristic only of the karst aquifer (infiltration conditions). For this reason is considered for area Sarajevo Polje is not suitable. GLA a method only considers the aeration zone and does not take into account the dominant infiltration routes that are typical for karst area. The disadvantages of the method GLA in karst areas are taken into account in the PI method, while for the pure karst areas recommended a method EPIK. PI and COP are
more modern versions of the EPIK method including many more parameters, and therefore it is possible to obtain detailed maps. By analyzing and comparing the various methods, it has been concluded that the area for Sarajevsksko Polje COP is the most applicable a method. The following are results of applying the COP method.

3. Geographic Features of the catchment area Sarajevo Valley

The Sarajevo Valley is a space between mountain depressions and is between the massive Bjelasnica and Igman on the southwest as well as the low mountains and middle mountains on the northeast. The valley generally stretches in the NW-SE direction and there are low mountains and middle mountain areas on the southeastern slopes of Trebević and on the northwestern slopes between valley peaks, see Fig 1. The mean altitude of the bottom of the valley is approximately 515 m. The lowest height above sea level is found in the north of the valley (in Reljeva, 493 m) and points of slightly higher heights are in the catchment area and enlargements of the Željeznica, Kasindolka, Tilava, Miljacka and Zujevina Rivers.

On the basis of geological composition and geomorphological set, it can be differentiated into two morphological units, i.e., (i) the mountainous rim and (ii) the Sarajevsko Polje, which contains the valley bottom at the Miljacka River. The area of the mountain rim has two special features, which have different hydrogeological features conditioned by different structures that display composition structure and surface composition. They are the highest mountain peak, mountain areas of middle height and the belt of the low rim. The highest mountain peaks are approximately 1000 m and higher and their structures are dominated by karstified limestone and dolomite. These include Bjelašnica, Igman, Trebević, Jahorina, Crepoljsko and similar mountain areas of middle heights (700 to 1000 m) and are morphologically more complex. The lowest part is composed of complex tertiary sediments and a quaternary plateau is formed from these sediments from different ages. The Sarajevsko Polje together with the alluvial plateau of the Miljacka River composes the second largest morphological location within which freshwater Triassic complexes cover the deposits of gravel-sand sediments of different widths, [2].

Fig. 1. Topological location of the Sarajevo Valley and the display of 1-st, 2-nd morphological section and the main groundwater source Sarajevsko Polje, [2].
Into second largest morphological section is located the main groundwater source zone named Sarajevsko Polje, which is a surface about 13 km². At the source zone are located 36 water wells, several facilities for artificial infiltration - lagoons and drainage wells. This area represents the main source of water supply to Sarajevo, from which it provides about 90% of the demand for water.

Natural recharge of groundwater is carried out by infiltration of water from the river Željeznica, river Bosna, Večerica and streams Stojčevac; inflow of groundwater from massive Igman-Bjelasnica through peripheral contour and through the lower hydrogeological layers; and by vertical infiltration of precipitations. Within the karst zone of a broader exploration area of Sarajevsko Polje, a certain amount of water are accumulated and discharged through the overflow springs like Semizov bunar, Megara, Bunica, Stojčevačka vrela and Vrelo Bosne. Mountains Igman and Bjelasnica are recharge of waters exclusively through the infiltration of atmospheric water, mainly in the sinkhole zones and fractured systems. Catchment area of groundwater source Sarajevo Polje includes practically a partial catchment area: of river Željeznica till water station -VS Ilidža, of river Bosna till water station -VS Plandište, and a partial catchment area of river Zujevina till water station -VS Blazuj. A major impact on the recharge of groundwater reservoirs have water from the mountains Igman and Bjelasnica, which partly belong to the basin of the river Bosna. The broader catchment area of the groundwater source is mainly mountainous character (about 90%) and the area is about 1250 km², see Fig.1.

4. General Characteristics of the COP Method and its Application to the source Sarajevsko Polje

COP method is presented by the Department of Hydrogeology at the University of Malaga-GHUMA (Spain), as well as the standard method of mapping the vulnerability of groundwater in karst aquifers (VIAS, 2002). Methodology is designed to be applied flexibly in different regions of Europe, in accordance with the available data, and available time and financial resources, [1]. A high percentage of karstification of the catchment areas of groundwater sources Sarajevsko Polje preferred application of this method. COP is an acronym derived from the initials of vulnerability factors used in this method. The method uses three basic factors that make up her name: O (overlaying layers) - overlapping layers which covers the aquifer, C (flow concentration) - concentration factor of groundwater flow and P - precipitation.

Through factor O is taken into account the protective function of aeration zone (Ol-litology factor) and the characteristics of the soil layers (Os-soil factor). Quantification of factor O, which is a function of the characteristics of soil cover, was performed by adding the factor Os and Ol: O = Os + Ol. For the determination of factor Os are used parametric texture and thickness, while the factors Ol is based on parameters lithological composition and fractures, thickness of each individual layer and hydraulic conditions.

By using GIS tools O map is created, [3]. As the main input was used hydrogeological map. Analysis was carried out in a way that for each chronological-stratigraphic unit is determined necessary coefficients, and the budget was carried respectively for each spatial unit separately. In Figure 2 is shown O map.
Factor C represents the degree with concentration of flow to the karst channels, which are directly linked to saturated zone, thus indicating that the protection capabilities are reduced. Through the establishing the value of factor C should be evaluated different layers ability to perform a protective function, and preserve of aquifer of penetration and transport of pollutants. In order to appropriately treat the problem of concentration of flow, to determine this factor have developed two scenarios. The first scenario applies to the catchment area of the sinkhole, as well as the catchment areas of streams that sink. The second scenario covers the rest of the area for which calculation is implemented. In our case, the catchment areas of the first scenario are determined for sinkhole location for which is identified a direct connection to the occurrence of water through peripheral contour of the source zone of Sarajevo plain.

In the area for which it is necessary to apply the first scenario the value of factor C depends on the distance from the sinkhole, i.e. of distance from rivers that sinks, as well as the topographical characteristics, i.e. of slope of the terrain and vegetation. Unlike of the first scenario, in the second scenario, except the terrain and the presence of vegetation; significant impacts on it have the characteristics of the surface layer, and the percentage of the presence of karst and permeability. The slope of the terrain and the presence of vegetation, i.e. the absence of vegetation in an area, not an equal sign in the first and second scenario, rather their impact on the entry of pollutants is quite different. Thus, the value of the factor C is obtained by calculation from these two scenarios. The spatial distribution of the final value of C factor is shown on the map of factor C, see Fig 3.
P factor represents the total amount, frequency and duration of precipitation, as well as the intensity of external factors that are considered to be the most influential for amount and level of infiltration. P factor is obtained by adding of factor precipitation (Pq) and intensity of of precipitation (Pi)) for the relevant catchment area: \( P = Pq + Pi \). Results obtained after the relaxation are shown on the map \( P \).

4.1. The results of calculations by the COP method

After the integration of the results obtained in the calculation of O, C and P of factor, the results obtained with the help of GIS tools analyzed and presented in the the form of vulnerability maps for the
catchment area of the source Sarajevsko Polje, see Fig 5. It should be noted that the calculation carried out for each spatial unit that is the size of 20x20 meters separately by all input parameters.

Fig. 5. Vulnerability Map - COP index catchment area of Sarajevsko Polje, [3]

4.2. Assessment of the degree of risk of pollution

To assess the degree of risk of groundwater pollution the whole catchment area, hazard index is first calculated. For the assessment of hazards were used all potential contaminants in catchment area, of the sewage, septic tanks, car wash, petrol stations, hotels, quarries, roads, landfills, cemeteries, to the industry.

Fig. 6. Hazards map of the catchment area Sarajevsko Polje, [3]

Overlaying map and hazard map vulnerability, of risk index map was obtained.
5. Concluding Remarks

In this paper is presented using the COP method for determining the vulnerability of the catchment areas of groundwater sources in Sarajevsko Polje. Identification of the risks to groundwater is a very time-consuming process that needs to take into consideration any possible contamination and all activities that take place within the area. All types of risks should be shown in the map of risk, and then the risk assessment carried out by comparing map of groundwater vulnerability with the hazard maps, regardless of whether the contamination happened or needs to happen.

In addition to the previously mentioned folders that represent the basis for the risk assessment, it is necessary to have good data on hydrogeological and geological characteristics, groundwater levels, as well as the conditions of recharge and discharge observed aquifer. For a preliminary assessment of risk is necessary to know the description of the whole observed area, starting from data on which substances-species contamination is done, the conditions of infiltration, i.e. the amount of recharge, the assessment of exposure to pollution and many other parameters.

Generally, the assessment of groundwater vulnerability is potentially useful management tool for all major decisions on preventive protection of groundwater. The process of estimating the vulnerability of groundwater is very long and dynamic process, which, if established by legal regulations in each country, may be the best tool for the fight against pollution of groundwater.

References