Plate 8.7 Vulnerability of Groundwater Resources

Introduction

This plate shows the vulnerability of groundwater resources to potential pollutants throughout Switzerland.

There is no uniform method for determining the vulnerability of groundwater resources, and for this reason a specific multi-parameter approach was developed in the present context. This approach is based on the Groundwater Resources Map (plate 8.6), the Soil Suitability Map [5] and other hydrogeological data.

The principle of vulnerability

The term “vulnerability” refers to the sensitivity of a system in relation to a harmful external influence. In the case of groundwater, vulnerability is defined as the exposure to pollution through the influx of harmful substances into the aquifer.

Vulnerability is a relative characteristic that cannot be measured directly. It can be inferred from a combination of various parameters that are considered important for groundwater protection. The better the groundwater is protected against the influx of pollutants, the lower its vulnerability. This protective effect – and the degree of vulnerability resulting from it – can be qualitatively determined and classified according to the probability of pollutants reaching the groundwater table [11].

The transport of pollutants from where they are released on the surface to the groundwater is linked to the seepage of precipitation and the infiltration of river water. Consequently, the groundwater resources that lie under thick layers of less permeable material enjoy the best protection against the influx of harmful substances. Together with the unsaturated zone of the aquifer these layers act as a natural protection for groundwater resources. In addition to this hydraulic retention of harmful substances, specific exchange processes between the covering layers and individual types of pollutants, in particular filtration, sorption and biodegradation, also reduce contamination of the groundwater. These processes account for the particular retention capacity of the soil layer and increase its protective effect [11].

Once harmful substances have reached the saturated zone of an aquifer they are transported laterally with the groundwater flow. In unconsolidated aquifers the water flows slowly and evenly through the pores of the granular structure, which limits lateral migration of the substances. In contrast, pollutants in the saturated zone of heterogenous fissured and karstic aquifers tend to migrate along preferential flow paths; this can happen with extreme rapidity, especially in karstic aquifers.

Vulnerability in relation to protection

The principle of vulnerability is an important element in preventive groundwater protection. Vulnerability maps reflect the behaviour of pollutants in the ground and thus show which areas of a catchment are especially vulnerable to potential contamination and which enjoy a high level of natural protection. Nevertheless, the groundwater may be affected by mobile and persistant pollutants (nitrates or various plant protection substances), even in areas that enjoy a high level of natural protection.

In Switzerland the concept of vulnerability is used for defining groundwater protection zones in karst areas [1] and highly heterogeneous fissured aquifers [8]. The level of vulnerability determines the type of protection zone to be established (S1, S2 or S3; see plate 7.5). Protection zones are not necessarily arranged concentrically around a spring or well but may be distributed irregularly over the entire catchment, depending on geological and hydrogeological conditions. Since establishing protection zones entails limiting land use, this approach is suitable for the targeted protection of groundwater resources.

Multi-parameter approach to mapping

Vulnerability can only be mapped indirectly, using selected parameters. The procedure used here is described briefly below (see fig. 1,2,3). To begin with, all areas with productive groundwater resources in both unconsolidated and consolidated rock were taken into account on the basis of the 1:500 000 Groundwater Resources Map (plate 8.6). Subsequently, vulnerability and lateral migration capacity were determined for these groundwater areas in two separate steps (fig. 1). Vulnerability was not mapped for areas where there are no productive groundwater resources; in areas with multiple productive aquifer layers only the uppermost was taken into account.

In order to assess the vulnerability of an unconsolidated aquifer, the protective effect of the soil, of less to moderately permeable covering layers and of the unsaturated zone of the aquifer were combined (fig. 2), based on the following data.

The protective effect of the soil was allotted to one of four protection classes according to the physical characteristics of the 144 different soil types used by [4]. This process was based on the 1:200 000 digital soil suitability map of Switzerland [5].

The relevant data on protective layers overlying groundwater resources were recorded on a scale of 1:200 000 based on the Groundwater Resources Map. Permeability and thickness were determined for covering layers, and the distance between the land surface (or the lower limit of the covering layer) and the mean groundwater table was established for the unsaturated zone of the aquifer. The potential influx of pollutants through rivers directly connected with the groundwater cannot be explicitly taken into account using this approach.

In the case of groundwater resources in consolidated rock there are generally few data available for large-scale documentation of covering layers and the unsaturated zone of the aquifer, making it impossible to obtain consistent data for most areas or to draw up a map on a scale of 1:500 000. The method for determining the vulnerability of groundwater resources in consolidated rock therefore focuses primarily on the protective effect of the soil (fig. 2) and, in exceptional cases where data are available, on the protective effect of less permeable unconsolidated covering layers. Fissured and partly karstic consolidated rock is generally considered to have a low to moderate protective effect.

Data concerning groundwater resources, the protective effect of the soil, the permeability and thickness of the covering layer and the thickness of the unsaturated zone of the aquifer were combined in a geographical information system (GIS) which can be used to determine the vulnerability of each area according to the matrix model shown in figure 2. Figure 3 uses an example that is hydrogeologically typical of the Central Lowlands to show how vulnerability can be inferred from the protective effect of the soil, the covering layers and the unsaturated zone of the aquifer.

The assessment of the lateral migration capacity is limited to determining the type of aquifer from the point of view of its lithological character (unconsolidated or consolidated), the type of groundwater flow (through pores, fissures or karst), as well as flow velocity. Information on the lithological character of the aquifer and the groundwater flow type was obtained from the digital 1:500 000 geological map [2]. Owing to the lack of data on flow rate, the unconsolidated aquifers were classified according to their productivity as indicated in plate 8.6.

Mapping vulnerability

Each vulnerability category is shown on the map by a different colour. The percentages of the total surface area of Switzerland attributed to the different vulnerability or protection classes are as follows: 23 % very high vulnerability (low protection); 27 % high vulnerability (moderate protection); 16 % low vulnerability (high protection); 2 % very low vulnerability (very high protection); 27 % areas with non-productive groundwater resources; 5 % rivers, lakes, glaciers, firn.

Lateral migration capacity is indicated on the map by a pattern. The percentages of the various categories are as follows: 15 % consolidated rock with high lateral migration capacity; 26 % consolidated rock with moderate lateral migration capacity; 8 % unconsolidated rock with moderate lateral migration capacity; 46 % areas with low lateral migration capacity; 5 % rivers, lakes, glaciers, firn.

Regional characterisation

In the Central Lowlands, various different hydrogeological situations can be found within a relatively small area. In the majority of cases the level of protection is moderate to high. Unconsolidated aquifers in the floor of the valley that are protected by a thick covering layer or a thick unsaturated zone have a high to very high level of protection and therefore low to very low vulnerability (fig. 4). There are also highly vulnerable groundwater resources that lie under no, or very thin covering layers and with the groundwater table at a short distance from the surface, however. Figure 5 shows an example of this type of situation where natural protection is limited while figure 6 gives an example of the juxtaposition of well protected, deep aquifers and more vulnerable, shallow aquifers.

The Jura Mountains are characterised by calcareous zones with karst drainage where the level of protection is low to moderate. Figure 7 shows a hydrogeological situation typical of this region.

Most areas in the Alps also offer low to moderate natural protection: areas of calcareous rock (karst) or loosened or fissured crystalline rock provide limited protection, while that of the crystalline areas of the central massifs can be considered as moderate. The unconsolidated aquifers of the main Alpine valleys generally enjoy moderate to high protection.

Scope of application

The 1:500 000 overview map included in this plate shows the main pattern of groundwater vulnerability in Switzerland. It is therefore intended principally as a general planning tool, as a source of information for the general public or as a teaching aid [10]. Local hydrogeological conditions cannot be shown on a map of this scale, as they were not taken into account in the approach used. Groundwater vulnerability patterns in a local context may therefore differ from those shown on the map.

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