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Groundwater and road network interactions - case study from Slovenia

Medsebojni odnos med podzemno vodo in cestno mrežo - analiza na primeru Slovenije

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Abstract

The paper analyses the potential impacts of various state roads on aquifers in Slovenia. A short introduction about groundwater protection standards and an overview of current practice of groundwater protection from road network impacts is given. On the state level, the hydrogeological conditions were analysed according to the various categories of roads that cross them. According to this analysis, the ratio of the impact potential of the aquifer crossed by a road type is calculated on the state level. The ratio is represented as the quotient between the share of aquifer crossings by a type of roads and the share of a particular aquifer on the state level.

Kratka vsebina

V članku je obdelan potencialni vpliv različnih kategorij državnih cest na vodonosnike v Sloveniji. Podan je kratek pregled standardov za zaščito podzemnih voda in pregled vsakdanje prakse zaščite podzemne vode pred negativnimi vplivi s cest. Na nivoju cele Slovenije so bili glede na različne kategorije cest, ki prečkajo različne vodonosnike, analizirani hidrogeološki pogoji. Uveden je bil parameter potencialne obremenjenosti vodonosnika, ki predstavlja razmerje med deležem vodonosnika, ki ga prečka posamezna cesta in deležem posameznega tipa vodonosnika na nivoju celotne države.

Introduction

Road construction and operation is a specific activity that affects the environment and is, due to its linear component, mainly characterized by dividing the natural environment into two or more parts. The degree to which these parts are separated from one another depends on road category and on the sort and density of traffic. Because of emissions from traffic and the possibility of hazardous spills, roads present a risk to drinking water resources. Among several non-point pollution sources, roads present serious threat to groundwater and great care is needed for water resource protection from the negative influences from roads. According to older environmental standards, only roads of higher categories are usually constructed for groundwater protection. Older roads and roads of lower construction standards are not designed with protection meas-

ures, only dispersed drainage from road surface is present.

In the past Slovenia was crossed with various transit roads of international and national importance. Nowadays the roads from the past become motorways and other state roads that cross more or less important aquifers. Today in Slovenia, large motorway construction works are in progress. The motorways cross numerous water catchment areas, which calls for great caution during the construction and operation of motorways. Several important questions about groundwater protection from motorway runoff arose and various efforts were done during the planning and construction stage to protect groundwater resources from motorway pollution (Brenčič et al, 2000, Brenčič et al, 2001). Parallel to motorway construction, several local roads are reconstructed or totally rebuilt. Due to new environmental standards the aquifers must be protected also from their influences. For all these reasons, the need for a uniform determination of protective measures emerged in everyday practice.

Road network

Public roads are classified into state roads owned by the state, and local roads owned by communities. The categorisation of public roads has been made on the basis of the Decree on criteria for the categorisation of public roads. State roads are divided into seven categories. Motorways are the highest standard of all. They are intended for long-distance traffic and are an integral part of motorway connection with neighbouring countries. Expressways are reserved for traffic between the most important regional centres and the connections to motorways in the country and to the road system of neighbouring countries. Main roads are divided into two categories and are intended for traffic connections between centres of regional importance. Regional roads are divided into three categories and are intended for traffic connections between important centres of local communities. Local roads are divided into communal roads (over 13500 km) and public paths (over 17600 km). Table 1 and on Figure 1 present the types and lengths of roads for the year 2001.

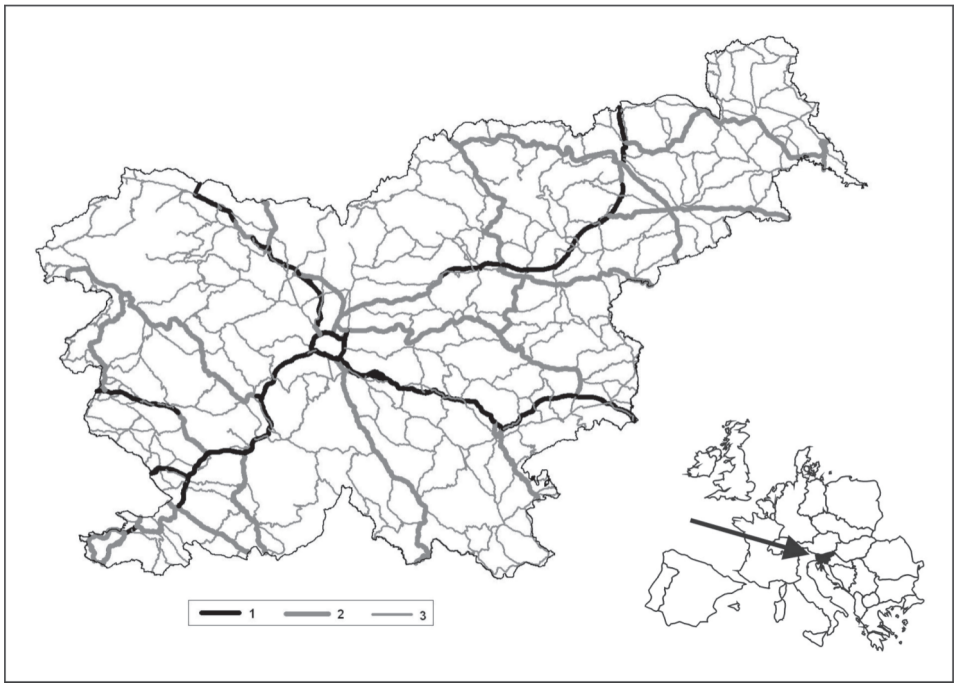

Figure 1. State road network in Slovenia (1 – motorways and expressways, 2 – main roads, 3 – regional roads)

Table 1. Categories and lengths of state roads in Slovenia

Category of road	*Total length [km]*
Motorways	353
Expressways	155
Main roads	1023
Regional roads	4724
TOTAL	6255

Legislative groundwater protection

In the Slovene legislation, the Water Act and the Environmental Protection Act require the protection of groundwater resources. The existing primary legislation is very general about the requirements for groundwater protection from road traffic influences. The measures for the protection of groundwater resources from the influences from roads are determined by regulations and governmental ordinances and more precisely with local community ordinances and by drinking water resource protection acts.

Comparison of different drinking water resource protection acts shows that the divisons of protected areas are not uniform across the country and that they depend on the type of the aquifer and on the year of their implementation. Usually protected areas are divided into several zones. The most general divison in the drinking water resource protection acts is the divison into inner and outer protected areas. The inner area is in the immediate vicinity of the capture site and comprises the physically protected capture site and the most vulnerable part of the recharge area. The outer area covers a part of the entire recharge area of the water resource.

An extensive analysis of drinking water protection ordinances in Slovenia was performed according to the protection measures required for the aquifer protection from negative influences from roads (Brenčič, 2001). A number of ordinances define restrictions and prohibitions of road construction. These restrictions are defined very diversely and refer to different categories of roads and paths. A greater part of the ordinances includes prohibition of building a certain road type in the inner protected zone. In some cases where road construction is prohibited, exceptions are permitted. In this case, road construction is permitted in accordance with spatial planning documents and regulations, taking into account preliminary regulations about groundwater protection. Measures for groundwater protection in outer protected areas are of a more general nature, prescribing road construction that prevents groundwater pollution.

Some more recently passed acts demand that newly constructed and reconstructed roads have a groundwater protection scheme and other projects dealing with road construction and maintenance. An important measure for the protection of water resources from negative impacts from roads are also technical engineering measures. These ordinances demand the following road construction elements: impermeable roadway, protective fencing (some acts define also an equivalently high curb), impermeable ditch at the foot of the embankment, a 2- to 3-m wide strip along the road inclined towards the ditch, impermeable embankment, impermeable sewerage, oil separators, from which water must be drained into impermeable sewage or through the drain into a stream with constant water.

One of frequently applied measures for groundwater protection from negative impacts from roads is also speed limit of vehicles. This measure is based on the fact that the risk for a traffic accident to happen decreases considerably with lower speed. The same is true also for possible spills of dangerous liquids from vehicle tankers. An analysis of ordinances including these provisions shows much diversity in speed limits. Speed limits can be divided into two groups. In the first group speed is limited for all vehicles, and in the second, restrictions refer only to vehicles transporting oil, liquid oil products and dangerous and harmful substances. Most common in both groups is the speed limit of 40 km/h, although there are also higher and lower limits. Speed restrictions in the second group apply only to the transport of substances, hazardous to groundwater. There is also a distinction between restrictions applying to the entire transport of dangerous substances, both for transit of goods and for local traffic, and between restrictions referring only to the transit of goods.

Limitations of transport over drinking water resource protection areas refer above all to substances hazardous to drinking water. These substances are defined in many diffe-

rent ways, with names such as: oil, liquid oil products, dangerous substances, harmful substances, dangerous liquids, dangerous chemical liquids and mineral oils. The number of descriptions indicates an inaccuracy of definitions.

Most acts require that protected areas should be marked with adequate road signs. The importance of signs varies from one act to the other. As a rule, only the designation of protected areas along roads and ways is demanded.

Methods

Groundwater represents an important part of the hydrological cycle. Its amount and role depends on the hydrogeological characteristics of the area. Most of drinking water in Slovenia is supplied from groundwater resources and their protection on the national level is of vital importance.

A general protection of groundwater on the national level requires information about potential impacts of different types of roads and aquifers. These data should present general overview that can form the basis for decision making in further environmental planning steps and proper groundwater protection.

GIS tools (Arc View 3.1) were used to analyse the potential impact analysis between roads and aquifers. Information layers of hydrogeological map and road network map were cross-covered and ratios of different interactions were calculated on the basis of predefined common elements. The ratios of single road category lengths in a course above the single type of aquifer to the total length of all state roads and to the lengths of single road type were calculated. This ratio is defined as the crossing ratio:

$$C_r^{aq} = \frac{L_r^{aq}}{L_r}$$

where
C_r^{aq} – crossing ratio of road type r on the aquifer ^{aq} on the state level
L_r^{aq} – length of single road type on the aquifer ^{aq} on the state level
L_r – total length of single road type on the state level

To estimate potential impact of road pollution to the aquifers on the state level the impact potential was introduced:

$$P_{r_i}^{aq} = \frac{C_r^{aq}}{x_{aq}}$$

where
P_i^{aq} – impact potential of the aquifer ^{aq} on the state level
x_{aq} – share of surface area for a particular aquifer type

Impact potential should be interpreted as the level of enlarged or reduced pollution risk according to the average pollution from roads on the state level.

Results

The aquifers of intergranular porosity are the most important. They build 22 % of the country and they are positioned in the tectonic depressions and valleys in the central and north-eastern part of the country. They represent major water resources for the population living in bigger cities. Karst aquifers in limestone rocks are also very important. They build 32 % of the area and are mainly present in the southern and western part of the country. The characteristics of the aquifers with fissure porosity are very similar to those of the karst aquifers and cover about 15 % of the area. Double porosity rocks cover 11 % of the area. The rocks that can be classified as low permeable build 20 % of the country. The general hydrogeological map of Slovenia is represented in Figure 2.

Table 2. Crossing ratios and impact potential for all state roads in Slovenia

Type of aquifer	Crossing ratio [%]	Impact potential
Intergranular	41	1,86
Karst	24	0,75
Fissured	11	0,73
Double porosity	11	1,00
Low permeable rocks	13	0,75

Crossing ratios and impact potential for all state roads are given in Table 2. Crossing ratios for single road types are given in Table 3 and Table 4 presents data for impact potential of single road types.

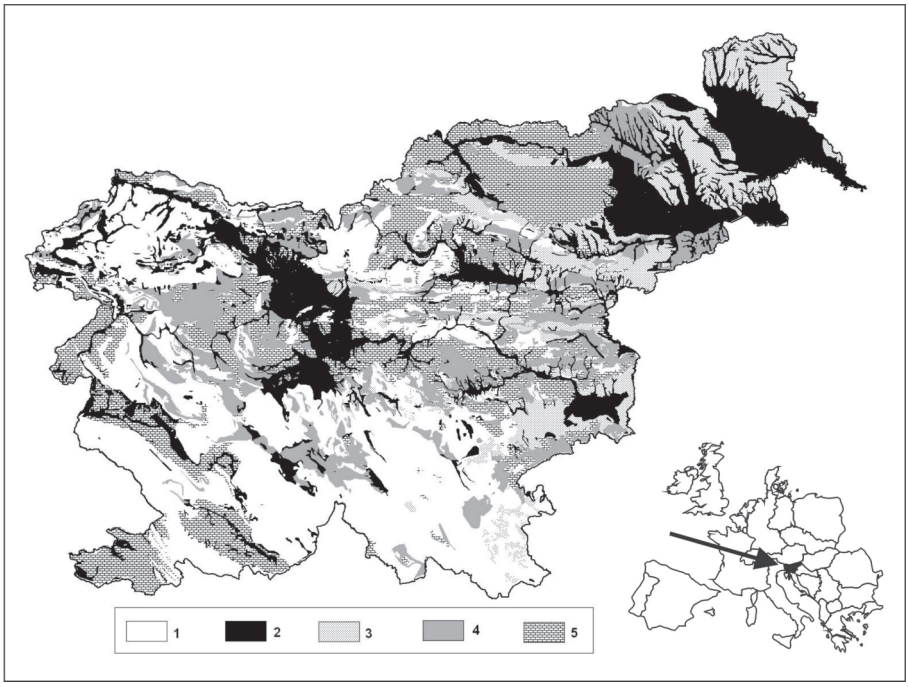

Figure 2. Generalized hydrogeological map of Slovenia (1 – karst aquifers; 2 – intergranular aquifers; 3 – double porosity aquifers; 4 – fissured aquifers; 5 – low permeable rocks)

Table 3. Ratio of aquifers crossed by various categories of roads

Type of aquifer	Motorways C_{ri}^{aq} [%]	Expressways C_{ri}^{aq} [%]	Main roads C_{ri}^{aq} [%]	Regional roads C_{ri}^{aq} [%]
Intergranular	51	43	57	35
Karst	22	16	17	25
Fissured	10	8	8	12
Double porosity	9	15	5	12
Low permeable rocks	8	18	14	16

Table 4. Impact potential for various categories of roads

Type of aquifer	Motorways	Expressways	Main roads	Regional roads
Intergranular	2,30	1,97	2,57	1,59
Karst	0,69	0,51	0,52	0,78
Fissured	0,65	0,50	0,53	0,79
Double porosity	0,84	1,39	0,48	1,08
Low permeable rocks	0,41	0,88	0,69	0,82

Discussion and conclusions

Increasing road traffic and road operation represent a serious threat for water resources and greater care is needed for their protection from the negative influences from roads. In Slovenia drinking water is mainly supplied from groundwater and consequently 22 % of the country's surface has already been covered with – existing or proposed – water protection zones. In the hydrogeological reports for groundwater protection and water protection ordinances great care is given to groundwater protection from road influences. These documents provide standardized measures for the protection of drinking water resources from negative impacts of roads. The protection measures differ according to the protected aquifer type.

Intergranular aquifers cover 22 % of the state. They are concentrated mainly in tectonic depressions and in river valleys where settlements are very dense. Due to the country's natural properties roads run mainly along the valleys. To estimate the average influence of roads on groundwater the crossing ratio and impact potential were introduced on the state level. The crossing ratios and impact potential show that all state roads run mainly across intergranular aquifers. On the average 41 % of all state roads cross intergranular aquifers. Impact potential of road pollution on intergranular aquifers is 1,86. Similar data can be found for particular type of roads. The highest impact potential is from main roads; it is represented by the value of 2,56. Other high standard roads have slightly lower values. The lowest value of impact potential on intergranular aquifers was determined for low standard roads. This fact can be interpreted as a consequence of low standard roads having been built in rural and remote areas where other types rather than intergranular aquifers prevail.

Supposing that traffic density is similar for each road group, the total input of pollutants from permanent traffic is much higher in intergranular aquifers than in other aquifers. The situation is different in the case of incidental pollution. Karst aquifers are the most extensive and vulnerable aquifers in Slovenia. According to the crossing ratio and impact potential they are loaded with values less than 1. It is well known that the spreading of pollution in these aquifers is very fast and as a consequence, they must be protected from road impacts with high protection standards in spite of the fact that their potential traffic load is on the average lower than on intergranular aquifers.

Further work on groundwater road impact analysis is needed. The information about traffic type and density must be incorporated into the interaction analysis of aquifers and roads. Data about emissions from roads in to the fields must be also included.

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References

Brenčič, M. 2001: Analysis of standardized measures for the protection of drinking water resources from negative impacts of roads. - Acta hydrotechnica, *19*, 137–153, Ljubljana.

Brenčič, M., Ajdič, M., Ločniškar, A., Petkovšek, A., Prestor, J. & Žmavc, J. 2000: Zaščita podzemne vode na območju avtocest. In: A. Gostinčar (ed.), 5. slovenski kongres o cestah in prometu. - Družba za raziskave v cestni in prometni stroki Slovenije, 1- 9, Ljubljana.

Brenčič, M., Prestor, J. & Ločniškar, A. 2001: The analysis of the influence of highways construction on groundwater in Slovenia. In: K.P., Seiler & S., Wohnlich (eds.), New Approaches Characterizing Groundwater Flow, 467 – 471, Balkema, Rotterdam.