Designing a national groundwater quantity monitoring network on groundwater bodies with alluvial aquifers in Slovenia

Načrtovanje državne mreže za spremljanje količin podzemne vode na vodnih telesih podzemne vode z aluvialnimi vodonosniki

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Abstract: Five out of 21 groundwater bodies (GWBs), which have been delineated in Slovenia with regard to the EU Water Framework Directive (WFD), comprehend mostly alluvial high permeability aquifers. They cover approximately 10 % of the country area but contribute to about 50 % of all groundwater abstraction and to about 40 % of all drinking water to the Slovenian water supply system. The existing groundwater quantity monitoring network (GWQMN) mostly covers the areas within the GWBs which are of drinking water pumping interest. To meet all the requirements of WFD and to enable reliable assessments of the quantity status of GWBs, the existing old network has been redesigned with the help of GIS tools with the great emphasis on hydrogeological, geological and pedological characteristic of GWB. Described method of network design leads to 36 new monitoring sites on GWBs with alluvial aquifers. Redesigned national GWQMN provides better coverage of spatial differences within GWBs and shall provide data needed to better understand the groundwater regime in the GWBs.

Izvleček: Za potrebe ocenjevanja stanja podzemnih voda in njihovega upravljanja je bilo v Sloveniji določenih 21 vodnih teles podzemne vode v skladu z Vodno direktivo. Pet vodnih teles podzemne vode, s pretežno visoko prepustnimi aluvialnimi vodonosniki, se razprostira na približno 10 % Slovenije, vendar se iz njih črpa okoli 50 % podzemne vode, oziroma 40 % vse pitne vode. Obstoječa državna mreža za spremljanje količin podzemne vode je do sedaj dobro pokrivala le področja, ki so pomembna z vidika vodooskrbe. Glede na nove prostorske enote ocenjevanja stanja voda je bilo potrebno državno mrežo za spremljanje količin podzemnih vod izpopolniti in zadovoljiti zahtevam metodologije ocenjevanja količinskega stanja.

Scientific paper

Uporabili smo prostorsko analitično metodologijo v GIS tehnologiji, ki je upoštevala hidrogeološko, geološko in pedološko homogenost danega ozemlja ter pri analiziranju prostora upoštevali različne tipe in režime varovanja. Z opisano metodo smo določili 36 novih merilnih mest na vodnih telesih s pretežno aluvialnimi vodonosniki. Izpopolnjena državna mreža za spremljanje količin podzemne vode nudi boljšo pokritost prostorsko in hidrološko različnih območij znotraj vodnega telesa in zagotavlja boljše razumevanje režima podzemne vode v danem vodnem telesu.

Key words: groundwater, groundwater monitoring, groundwater monitoring network design, groundwater quantity, alluvial aquifer

Ključne besede: podzemna voda, monitoring podzemne vode, načrtovanje mreže, količina podzemne vode, aluvialni vodonosnik

INTRODUCTION

Under the EU Water Framework Directive[1], a total of 21 groundwater bodies[2] have been delineated in Slovenia, with mostly karst and fissured porosity aquifers (68.9 %), followed by aquifers with intergranular porosity (26.2 %) and special case of aquifers in napped tectonic structures and aquitards (4.9 %). Five GWBs (Figure 1) with mostly alluvial, high permeability aquifers are of special interest in this study as they contribute about a half of Slovenian abstracted groundwater, but their area cover just approximately 10 % of the country. In the year 2005, about 467×10^6 m^3 of groundwater was available and 116.4×10^6 m^3 abstracted from these GWBs.

The first groundwater quantity monitoring network (GWQMN) in Slovenia was established in the year 1952 when observers started GW level measurements in 20 private wells. This was the beginning of the national monitoring in the alluvial aquifers. The number of monitoring sites has changed with the time with regard to the Slovenian water policy. The maximum was reached in the year 1960 with 244 monitoring sites (Figure 2). In the year 2007 the national GWQMN has 128 monitoring sites in the alluvial aquifers within 5 GWBs.

So far, the existing groundwater quantity monitoring network mostly covered the areas within the GWBs which are of drinking water supply interest. To meet all the needs of WFD and to enable reliable assessments of the quantity status of GWBs, the existing network has been redesigned using GIS tools[3].

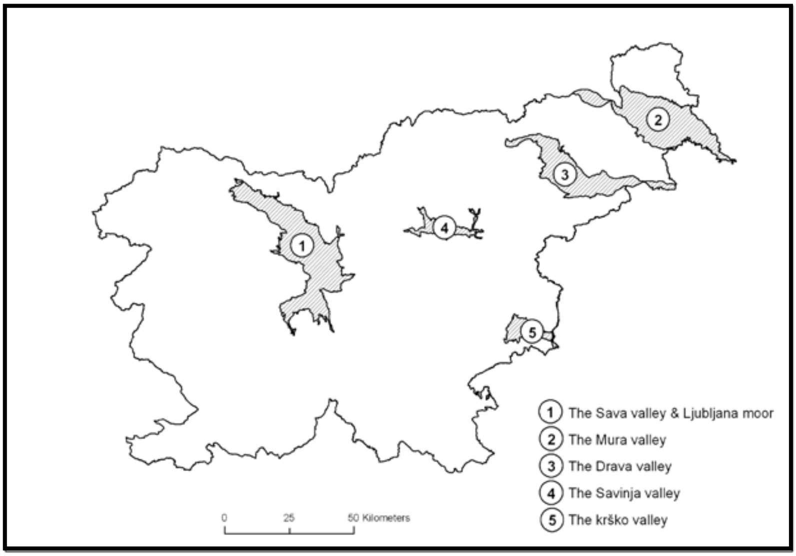
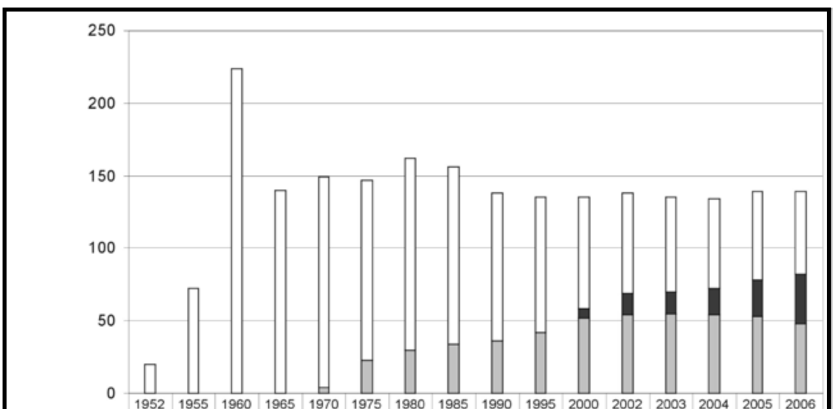


Figure 1. GWBs with mostly alluvial high permeability aquifers
Slika 1. Vodna telesa podzemne vode (VTPodV) s pretežno aluvialnimi vodonosniki



	1952	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2002	2003	2004	2005	2006
Monitoring sites	20	72	224	140	149	147	162	156	138	135	135	138	135	134	139	139
□ Observers	20	72	224	140	145	124	132	122	102	93	77	69	65	62	61	57
■ Data loggers											6	15	15	18	25	34
▨ Limnigraphs					4	23	30	34	36	42	52	54	55	54	53	48

Figure 2. Development of the national groundwater quantity monitoring network in Slovenia
Slika 2. Razvoj državne mreže za spremljanje količin podzemne vode

Designing the groundwater quantity monitoring network

The leading idea was to divide the area of GWBs into logical units according to the hydrogeological, geological and pedological characteristics (Figure 3) and afterwards to add areas protected by law. These protected areas include Natura 2000 sites established under the EU Habitats Directive (92/43/EEC)[4] and the EU Birds Directive (79/409/EEC)[5] as well as Drinking Water Protected Areas established under Article 7[6] of the WFD.

Hydrogeological spatial data layer comprises all known hydrogeologically distinct units within specific GWB and distinguish between different hydrological regimes, such as: areas with direct infiltration of rainfall into alluvial aquifer were separated from the areas fed by the runoff from the hills, as well as recharge from rivers and inflow from other aquifer systems. Perched aquifers were defined and delineated too. They overlay the lover hydrogeological unit. On Figure 4, an example of hydrogeologically distinct units is presented for the GWB Mura valley.

For each GWB pertaining catchment area was determined. Catchment area was divided in sub-catchment areas that represent catchments for each logically separated spatial unit. On Figure 5, as best and clear example among alluvial GWBs, a catchment area and its sub-catchment areas are presented for the GWB Savinja valley. In the case of trans-boundary GWB, the areas of groundwater inflow from another country and groundwater outflow from Slovenia were separated too.

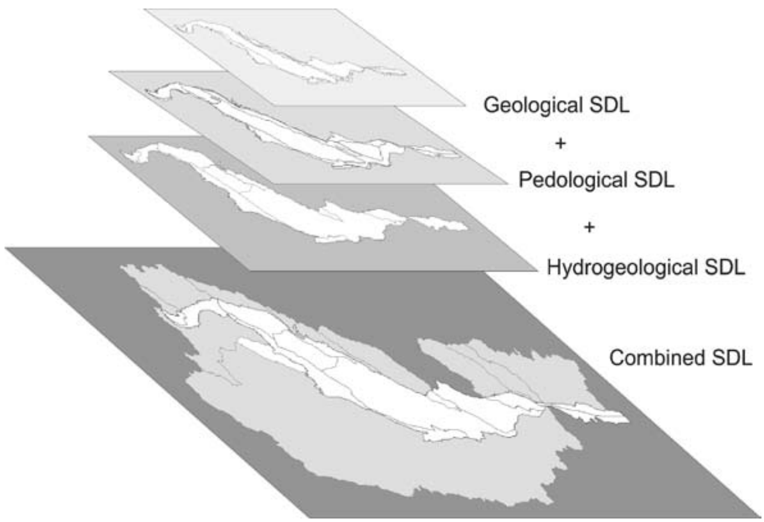


Figure 3. Concept of joining spatial data layers (SDL) into one logical subsystem of GWB
Slika 3. Koncept združitve prostorskih podatkovnih slojev (PPS) v homogeni podsistem vodnega telesa

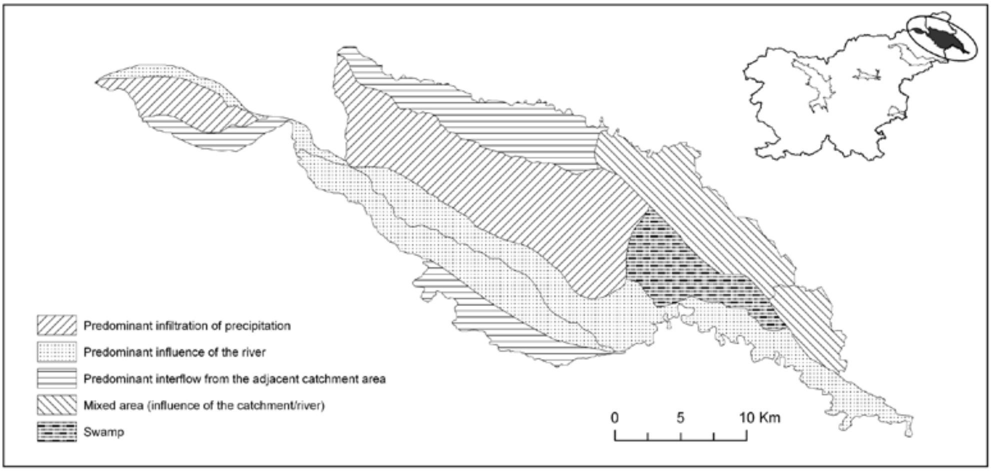


Figure 4. Hydrogeologically distinct units within GWB Mura valley
Slika 4. Hidrogeološko različna območja znotraj mej VTPodV Murska kotlina

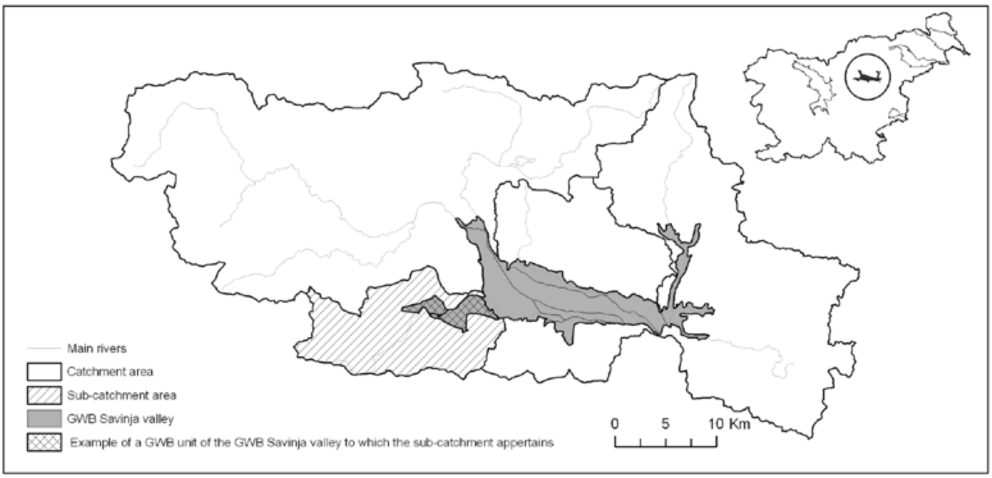


Figure 5. Catchment area and sub-catchments areas for the GWB Savinja valley
Slika 5. Zaledje in podenota zaledja prikazana za primer VTPodV Savinjska kotlina

The geological spatial data layer was constructed with the help of geological maps[7] (1:100000) and lithological cross sections, if available. In this layer, each GWB was divided into geological units according to the surface geology (Figure 6). Lithological cross sections were used for better understanding of the sub-surface geology.

Pedological spatial data layer consists of areas defined due to soil characteristic (Figure 7). The source of information in this process were the general digital pedological map of Slovenia[8] with soil types, map of mean soil depth[8] and map of mean textural soil classes in Slovenia[8].

All three spatial data layers were combined into one composite layer (Figure 3) with GWB units, representing areas with a similar hydrogeological regime, geology and pedology (Figure 8). Such an analysis of GWBs has enabled selection of new monitoring sites by the principle: each logically separated spatial GWB unit should have at least one groundwater monitoring site. Within these units, protected areas were also separated, represented by one monitoring site as a rule. In the areas with no hydrological data of groundwater monitoring, the area of the groundwater body was divided due to aquifer systems defined by Geological Survey of Slovenia[9], and the density of network was adjusted accordingly.

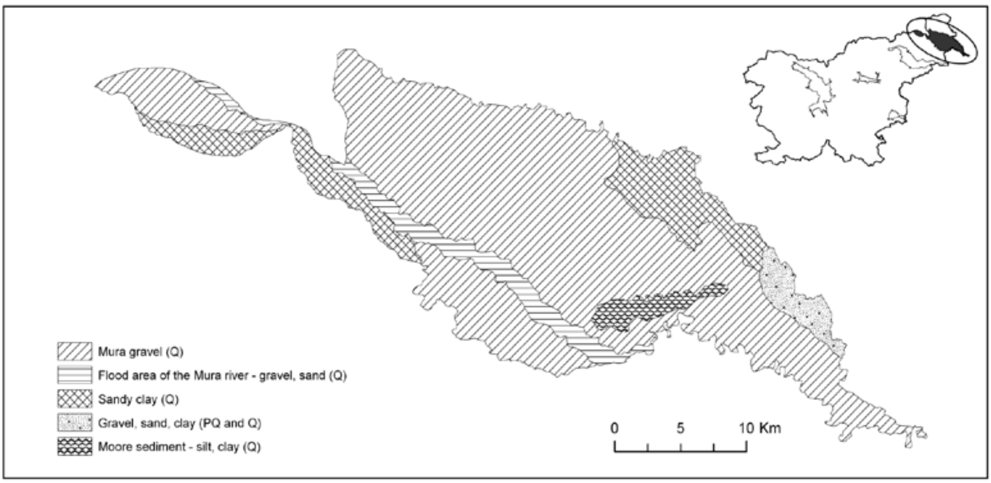


Figure 6. Geological units within GWB Mura valley
Slika 6. Geološke enote znotraj mej VTPodV Murska kotlina

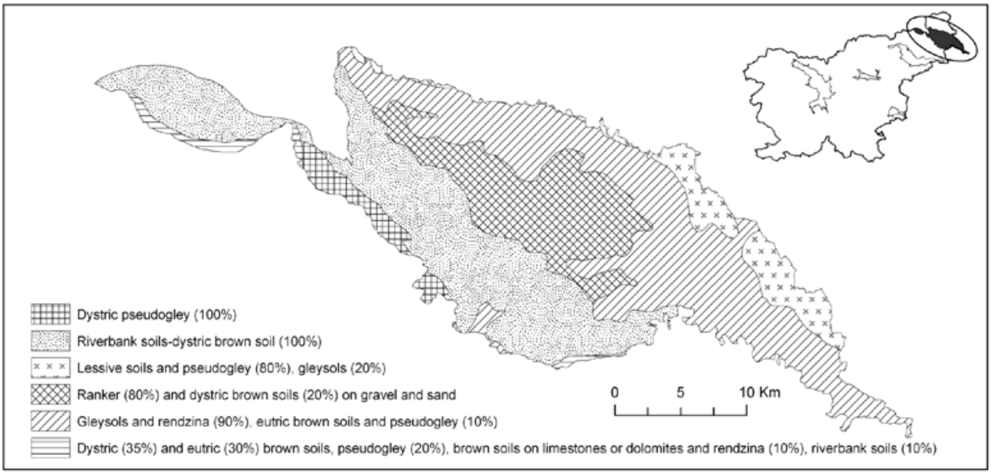


Figure 7. Soil Characteristics within GWB Mura valley
Slika 7. Tipi tal znotraj mej VTPodV Murska kotlina

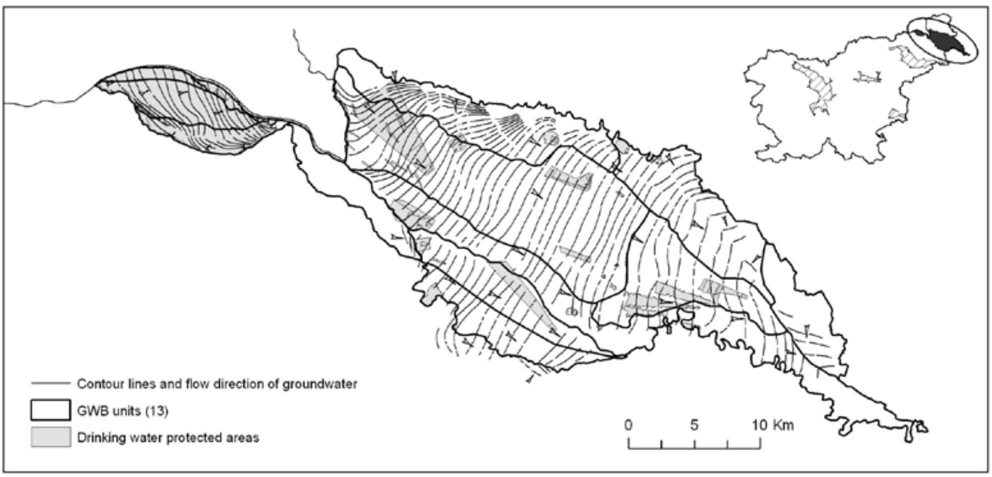


Figure 8. Spatial data layer with the GWB units (13) indicating the similar hydrological regime, geology and pedology (example for GWB Mura valley)
Slika 8. Prostorski podatkovni sloj z območji (13), kjer je podoben hidrološki režim, geologija in pedologija (primer za VTpodV Murska kotlina)

Table 1. Main alluvial GWBs (Figure 1) with existing and new monitoring sites
Tabela 1. VTPodV s pretežno aluvialnimi vodonosniki (slika 1) z obstoječimi in novimi merilnimi mesti

	The Sava valley & Ljubljana moor	The Mura valley	The Drava valley	The Savinja valley	The Krško valley
Area in km^2	774	591	429	109	97
Number of areas with the similar hydrological regime, geology and pedology (GWB units)	28	13	12	7	6
Number of existing monitoring sites (GW monitoring program 2007)	41	24	18	19	26
Number of new monitoring sites	**28**	**1**	**3**	**2**	**2**
Total number of monitoring sites	**69**	**25**	**21**	**21**	**28**

RESULTS AND DISCUSSION

Checking the existing GWQMN with the help of described method has shown that majority of the existing monitoring sites within relevant GWB fits well into this new concept of network design. Anyhow, redesign of existing national GWQMN still led to certain number of new monitoring sites (Table 1) which will be added to the GWQMN. On Figure 9, for example, the existing and planned monitoring sites are presented for the GWB Sava valley and Ljubljana moor.

Following the design study phase in the office, field inspection has begun and is still in progress, with the purpose to confirm or to reject the chosen new locations. The GWQMN will be completed with the new monitoring sites gradually, till the year 2013, within the project: "Upgrading of hydro-meteorological system for monitoring and analysis of waters in Slovenia" [10].

CONCLUSIONS

Described method of network design has enabled easier selection of monitoring sites and has facilitated the set up of better GWQMN. Redesigned national GWQMN shall provide better data needed to understand groundwater regime in the GWBs, enable reliable assessments of the quantitative status of a GWB, shall facilitate the national groundwater quality monitoring network redesign and offer additional data for a modeling of groundwater flow in the alluvial aquifers.

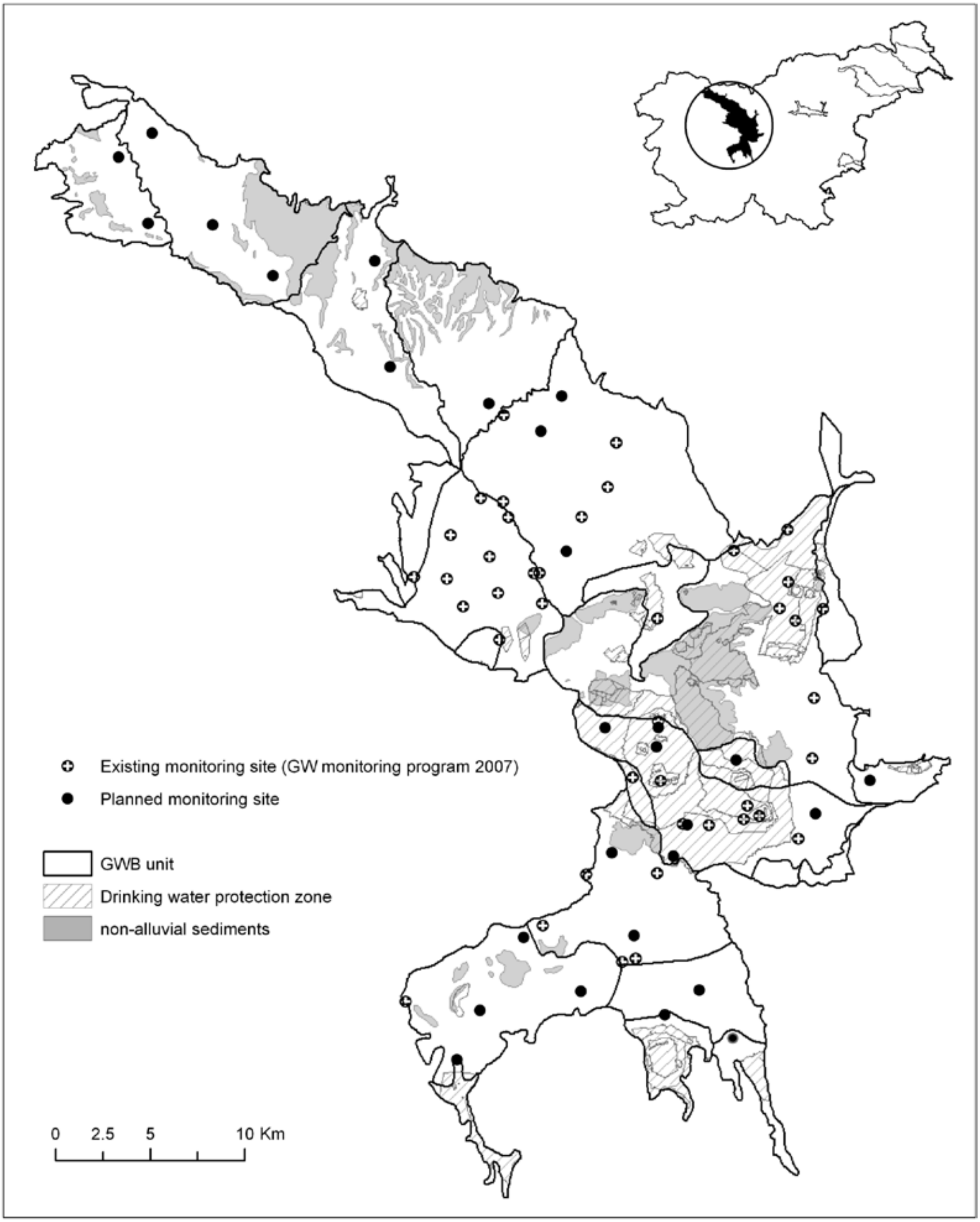


Figure 9. Existing (41) and planned (28) monitoring sites for the GWB Sava valley and Ljubljana moor

Slika 9. Obstoječa (41) in planirana (28) merilna mesta na VTPodV Savska kotlina in Ljubljansko barje

POVZETKI

Načrtovanje državne mreže za spremljanje količin podzemne vode na vodnih telesih podzemne vode z aluvialnimi vodonosniki

Državna mreža za spremljanje količin podzemne vode na vodnih telesih podzemne vode s pretežno aluvialnimi vodonosniki (slika 1), vključuje večinoma obstoječe objekte, kot so: piezometri, vrtani vodnjaki in kopani vaški vodnjaki, ki prvotno niso bili namenjeni za spremljanje globine do podzemne vode v sklopu državne mreže. Državna mreža je bila v preteklosti usmerjena predvsem na območja, ki so bila pomembna za vodooskrbo. S sprejetjem Evropske vodne direktive - VD (EU Water Framework Directive (WFD)) in z definiranjem 21 vodnih teles podzemne vode na območju Slovenije, se je koncept za spremljanje količin podzemne vode prilagodil VD. Da bi zadostili potrebam VD, mora Slovenija spremljati in oceniti količinski status vodnih teles v skladu z zahtevami VD in z mrežo optimalno pokriti celotno vodno telo podzemne vode. Tako smo z novim pristopom načrtovanja državne mreže za spremljanje količin podzemne vode na vodnih telesih s pretežno aluvialnimi vodonosniki preverili, kako dobra je pokritost vodnih teles z dosedanjo mrežo in v primeru nezadostne pokritosti optimalno pokrili območja znotraj vodnih teles z novimi merilnimi mesti. Pri tem smo uporabili prostorsko analitično metodologijo v GIS tehnologiji, ki je upoštevala hidrogeološko, geološko in pedološko homogenost danega ozemlja ter pri analiziranju prostora upoštevali različne tipe in režime varovanja.

Vodilna ideja metodologije je bila razdeliti območja vodnih teles na logične enote glede na hidrogeološke, geološke in pedološke karakteristike danega ozemlja. Tako smo za vsako vodno telo s pretežno aluvialnimi vodonosniki (za 5 teles – slika 1) kreirali tri prostorske podatkovne sloje, ki smo jih potem združili v skupen prostorski podatkovni sloj:

- Hidrogeološki prostorski podatkovni sloj,
- Geološki prostorski podatkovni sloj,
- Pedološki prostorski podatkovni sloj.

Hidrogeološki prostorski podatkovni sloj
Hidrogeološki prostorski podatkovni sloj vključuje vsa znana hidrogeološko različna območja znotraj danega vodnega telesa in tako razlikuje med različnimi hidrološkimi režimi. Izdvojena so bila tudi območja z visečo podtalnico. Območja s prevladujočo direktno infiltracijo padavin v aluvialni vodonosnik smo tako ločili od območij, ki se večinoma napajajo iz zaledja. Izdvojili smo območja, kjer reka napaja vodonosnik in območja, kjer je dotok podzemne vode iz drugih vodonosnih sistemov. Slika 4 prikazuje hidrogeološke enote znotraj VTPodV Murska kotlina. Za vsako vodno telo smo definirali odgovarjajoče zaledje, ki je razdeljeno na več pod-zaledij. Vsako pod-zaledje odgovarja enemu izdvojenemu območju znotraj vodnega telesa. Na sliki 5 je primer zaledja in pod-enote zaledja prikazan za VTPodV Savinjska kotlina. Ločili smo tudi cone dotoka podzemne vode iz sosednjih držav ter cone iztoka podzemne vode iz Slovenije.

Geološki prostorski podatkovni sloj

Geološki prostorski podatkovni sloj je nastal na podlagi osnovne Geološke karte, znanih litoloških presekov vodnih teles in litologije pridobljene iz vrtin iz baz GeoZS in Oddelka za hidrologijo podzemnih voda. V tem podatkovnem sloju je vodno telo razdeljeno na območja glede na geologijo na površju vodnega telesa. Litološke preseke smo uporabili za boljše razumevanje geologije pod površjem. Na sliki 6 so prikazane geološke enote znotraj mej VTPodV Murska kotlina.

Pedološki prostorski podatkovni sloj

Pedološki prostorski podatkovni sloj je sestavljen iz območij, ki smo jih določili glede na karakteristike tal določenega vodnega telesa. Podatke o tipih tal smo pridobili iz osnovne pedološke karte Slovenije, karte o povprečni globini tal v Sloveniji ter karte o povprečnem teksturnem razredu tal v Sloveniji. Na sliki 7 so prikazani tipi tal znotraj mej VTPodV Murska kotlina.

Združitev vseh treh prostorskih podatkovnih slojev

Vsi trije podatkovni sloji so bili združeni v en prostorski sloj, ki predstavlja območja s podobnim hidrogeološkim režimom, geologijo in pedologijo. Združen prostorski podatkovni sloj je prikazan za primer VTPodV Murska kotlina na sliki 8.

Takšen pristop k izpopolnitvi mreže nam je omogočil preveritev obstoječe mreže in izbor novih merilnih mest oz. lokacij po načelu: vsaka logično izdvojena enota na vodnem telesu mora biti pokrita z vsaj enim merilnim mestom. Na območjih, na katerih ne razpolagamo s hidrogeološkimi podatki, so bila območja znotraj vodnega telesa izdvojena na podlagi vodonosnih sistemov, ki jih je določil GeoZS, temu primerno je bila prilagojena gostota mreže.

Preveritev državne mreže za spremljanje količin podzemne vode na vodnih telesih z opisano metodo je pokazala, da se večina obstoječih merilnih mest znotraj danega vodnega telesa dobro vklaplja v opisani koncept izpopolnitve mreže. Opisana metoda je pripeljala do 36 novih lokacij na petih vodnih telesih s pretežno aluvialnimi vodonosniki. Po končanem kabinetnem delu smo začeli s terenskimi ogledi novih lokacij z namenom, da potrdimo ali ovržemo le-te.

Opisana metoda omogoča lažjo izbiro novih lokacij oz. merilnih mest in olajšuje postavitev optimalne državne mreže za spremljanje količin podzemne vode na vodnih telesih s pretežno aluvialnimi vodonosniki. Takšna mreža nam bo zagotavljala bolj kakovostne podatke za poznavanje hidroloških režimov na danih vodnih telesih in bo omogočala zanesljivo oceno količinskega stanja vodnih teles. Olajšala bo izpopolnitev državne mreže za spremljanje kvalitete podzemne vode in zagotovila dodatne podatke, ki jih potrebujemo za modeliranje toka podzemne vode v aluvialnih vodonosnikih.

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