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AN IMPACT OF URBANISATION ON THE SHALLOW GROUNDWATER CHEMICAL OUTFLOW IN THE VICINITY OF THE KAUNAS CITY

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Abstract. Kaunas city inhabitants use water supplied from a shallow aquifer that is not protected from direct pollution. All municipality well fields pump out infiltrated Nemunas and Neris rivers water. The quality of river water in urban areas often does not meet the sanitary requirements. Many people in the city outskirts use often polluted water from shallow wells. Therefore, groundwater protection and its quality improvement is an important problem for Kaunas city. Methods of investigations were based on previous hydrogeological, engineering geological, geological, hydrological investigations and field works. A shallow groundwater outflow in urbanised territories depends on technical factors. The highest outflows appear in the alluvial valley soils. In these territories, the outflow module is 10–15 l/s km^2. The smallest shallow groundwater outflow modules occur in territories covered with till and clay — <0.7 l/s km^2. Shallow groundwater outflow depends on solid surface cover. Outflow modules in most urbanised territories are 1.5–2.0 times smaller than in pure gravel soils. A chemical outflow depends on the intensity of shallow groundwater outflow and the groundwater pollution. The highest chemical outflow module forms in polluted areas with high shallow groundwater outflow (polluted valley areas covered with alluvium gravel). The lowest chemical outflow values form in comparatively uncontaminated loam and clay soils. The shallow groundwater chemical outflow in urbanised territories is 4 times higher than in the natural territories.

Key words: groundwater, groundwater outflow, groundwater chemical composition, urbanised areas.

Abstrakt. Mieszkańcy Kowna używają wodę pochodzącą z płytkiego poziomu wodonośnego, nie chronionego przed bezpośrednim zanieczyszczaniem. Z kolei miejskie studnie pobierają wodę rzeczną, przepływającą z Niemna i rzeki Neris. Jakość tej wody często nie spełnia wymogów sanitarnych dla terenów miejskich. Również wielu mieszkańców na obrzeżach miasta używa wody z płytkich, często zanieczyszczonych studzien. Dlatego też ochrona wód podziemnych i poprawa ich jakości jest ważnym problemem Kowna. Metody badań tego problemu opierają się na dawnych badaniach i pracach terenowych: hydrogeologicznych, geologiczno-inżynierskich, geologicznych i hydrologicznych. Przepływ płytkich wód podziemnych na terenach zurbanizowanych zależy od warunków fizycznych. Najszybszy przepływ występuje w aluwialnych glebach dolinnych. Na tych obszarach moduł przepływu wynosi 10–15 l/s km^2. Najmniejszy przepływ płytkich wód podziemnych ma miejsce na obszarach pokrytych gliną i iłem: <0,7 l/s km^2. Na przepływ tych wód ma również wpływ przykrycie powierzchni terenu. Dlatego też na większości terenów zurbanizowanych moduły przepływu są 1,5–2,0 razy mniejsze od występujących w glebach żwirowych. Przepływ związków chemicznych zależy od intensywności przepływu płytkich wód podziemnych oraz od stopnia ich zanieczyszczenia. Najwyższy współczynnik odpływu chemikaliów występuje na obszarach zanieczyszczonych z wysokim przepływem płytkich wód podziemnych (zanieczyszczone obszary dolinne pokryte żwirowym aluwium). Najniższe wartości odpływu związków chemicznych występują w stosunkowo mało zanieczyszczonych glebach ciężkich i w iłach. Przepływ płytkich wód podziemnych zanieczyszczonych chemikaliami jest czterokrotnie wyższy na terenach zurbanizowanych, niż na obszarach o nienaruszonych warunkach przyrodniczych.

Słowa kluczowe: wody podziemne, przepływ wód podziemnych, skład chemiczny wód podziemnych, obszary zurbanizowane.

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INTRODUCTION

The impacts of urbanised areas on the groundwater outflows and the formation of its chemical composition are demonstrated on the case of Kaunas city. Kaunas is the second largest Lithuanian city (area — 15.7 thousand ha, population — 369 thousand). It is situated in the confluence of the largest Lithuanian rivers: Nemunas and Neris. The residents of the city use shallow groundwater which is not protected from direct pollution. The shallow groundwater aquifer accumulates the urban surface runoff water with dissolved chemical and microbiological substances which later on are discharged into rivers and springs. The polluted groundwater is accumulated by Nemunas and Neris rivers, deteriorating the rivers water quality. Thus, the analyses of the groundwater quality formation in urban areas may provide valuable information on its natural protection and self-cleaning capacity.

METHODS

The shallow groundwater outflow was investigated and evaluated using three methods:

- Hydrogeodynamic — using hydrogeological indices (thickness and extension of an aquifer area, and filtration coefficient), and hydrodynamic analytical calculation techniques used on the basis of hydrodynamic grids for typical fragments of groundwater aquifers.
- Hydrological — using *in situ* measurements of stream modules at shallow water periods or analysing long-term sequences of rivers-analogues and expanding their hydrographs (Cyzius, *et al*., 1998).
- Hydrological–hydrogeodynamic — using the results obtained by both methods when the technical conditions were more complicated.

The hydrodynamic method of groundwater outflow evaluation is rather universal and may be employed in investigations of territories with different degrees of technical disturbance. Yet, the application of this method requires rather detailed input data on hydrogeological conditions and filtration capacity of the rocks. The hydrogeological groundwater outflow evaluation techniques are very effective under the conditions of open areas and anthropogenically unaffected surface runoff (sewage water outlets, asphalt cover, etc.). The hydrological-hydrogeodynamic method is most effective in evaluation of shallow groundwater outflow in urbanised territories when it is predetermined not only by the main natural elements but also by technically modified infiltration recharge, and by elements of anthropogenic load.

Combination of these methods in the analyses of the typical fragments of technically natural territories (or catchments) provides a possibility of the results calibration by different techniques, i.e., by control of the reliability of the shallow groundwater outflow values with the use of the hydrodynamic grid, and by the hydrological measures data. The boundaries of the fragmented areas are determined according to the groundwater flow structure, predetermined mainly by the configuration of the natural or artificial outflow arteries (rivers, canals or other surface water bodies) and stream catchments or their parts.

The shallow groundwater outflow is estimated using hydrodynamic grids made by hydrodynamic analytical and digital techniques. Modules of groundwater flows discharged into the surface water bodies were evaluated for each typical hydrogeological territory on the basis of hydrodynamic grids. The groundwater flow modules were quantified using the following formulae (Sestakov, 1973):

$$Q_i = (Kh)_{i,j} \Delta H_{i,j} (b_{i,j} / l_{i,j}) \quad (1)$$

when:

Q_i — module of groundwater flow in "*i*" belts;

$H_{i,j}, b_{i,j}, l_{i,j}$ — parameters within the "*j*" segment of "*i*" belts: pressure differences, width, length;

K — filtration coefficient of rocks;

h — thickness of groundwater aquifer.

Followed by calculation of outflow module M for typical area F:

$$M = \frac{Q}{F} \quad [\text{l/s km}^2] \quad (2)$$

The technical impact on groundwater in the urbanised territories may be determined by a complex of hydrogeological investigations designed for evaluation of the quantity and quality of groundwater, degree of groundwater pollution, and geological conditions of aquifers, which predetermine the natural water capacity of self-cleaning. The following input data are necessary:

— hydrogeological groundwater bedding and formation conditions from all the city areas;

— groundwater flow direction and intensity of recharge and outflow;

— virtual chemical composition and quality status;

— virtual and potential groundwater pollution sources.

The available hydrogeochemical and hydrogeodynamic information is plotted on cartographic plans, which serve as a basis in working out the evaluation techniques of anthropogenic impacts on groundwater resources and quality. Correct measuring of the river modules comprises the principal methodical element in evaluating the groundwater outflow by hydrological methods.

At the first stage of the groundwater outflow evaluation, the urbanised territories are typified and regionally subdivided according to the peculiarities of hydrogeodynamic conditions. The principal scheme of the hydrogeodynamic regional subdivision is as follows:

— regions of the Ist rank are distinguished according to the groundwater drainage conditions of discrete geomorphological elements;

— regions of the II[nd] rank (sub-regions) are distinguished according to the lithomorphological units (spread areas) and groundwater lateral hydraulic link between these units;

— a more detailed subdivision is based on filtration capacity of rocks, thickness of groundwater aquifers, flow directions and configuration, and hydraulic gradient, i.e., on the elements necessary for groundwater outflow calculations (hydrogeodynamic grid);

A hydrogeochemical distinction was carried out within the bounds of the II[nd] rank regions, distinguishing the areas of similar concentrations of chemical elements in the groundwater drainage zone.

RESULTS

The fresh shallow groundwater in the environs of Kaunas city is lying at a depth of up to 150–200 m. The aquifers are unevenly distributed (Fig. 1). The groundwater is contained in the first sub-surface aquifer which is not protected from the surface pollution. The deeper aquifers of Kaunas region contain small amounts of groundwater. They are important as much as their discharges into the surface depressions replenish the groundwater resources and contribute to the formation of groundwater quality.

Groundwater bedding conditions. Two main types of groundwater bedding can be geomorphologically and hydrogeologically distinguished in the Kaunas city: in the plateau territory and in the largest rivers (valleys, Fig. 1). The groundwater of the plateau territory is usually contained by limnoglacial (lgIII) and glacial (glIII) or, in rarer cases, by fluvioglacial (fglIII) deposits – mostly in sand lenses and thin interlayers. The highest water table is observed in watersheds. Moving from the watersheds towards the rivers valleys, it is gradually falling down. Small streams and springy slopes of the Nemunas and Neris rivers valleys drain the aquifer.

The water-bearing alluvial (sand, gravel) deposits (alIV, abIII) of Nemunas and Neris rivers valleys are occurring in the river terraces. The alluvial groundwater is sometimes isolated from the interstitial aquifers by thin impermeable layers and forms with them a continuous hydraulically linked aquifers system. The groundwater table in the river valleys is appearing at a depth of 0.5 m and 0.8 m. The hydrodynamic regime of alluvial groundwater depends on the of river surface changes. The distance from the river predetermines the groundwater table variation amplitude. In the riverside areas, it may make up to 50–70% of the river's amplitude.

The Quaternary interstitial water horizons are unevenly distributed. Their thickness and lithological composition are rather variable. The thickness of water-bearing rocks — sands and gravels — ranges from 1–2 m, to a few tens of meters.

Chemical composition and pollution of groundwater in the outskirts of Kaunas city display the effects of anthropogenic processes: total mineralisation, concentrations of the sulphates, chlorides, and calcium salts, and the water hardness are twice and thrice as high as the background values. Concentrations of nitrates and some metals (zinc, copper, lead) in the city groundwater exceed the unpolluted groundwater values by 4–8 times. Concentrations of iron, manganese, chromium, and copper are comparatively small.

The industrial areas water is the most highly polluted. It is followed by water of the low buildings areas, which stand out for high values of nitrogen compounds (nitrates, nitrites) and some metals (zinc, lead, cadmium). The zones of low buildings are most dangerous from the ecological and sanitary aspects because they include many shallow wells used for drinking water supply.

Composition and quality of groundwater greatly depend on the lithology of the cover rocks and aeration zone (Table 1). Higher water mineralisation and concentrations of the main ions are typical for the groundwater in clayey aquifers. They also contain greater values of organic matter (according to the values of permanganate oxidation). The groundwater of sand and gravel deposits displays considerably higher (2 times) concentrations of nitrogen compounds — nitrates and nitrites in particular — and heavy metals. The distribution of chemical elements in the groundwater is associated with good sorption capacity of clayey sediments, able to retain many chemical elements. Concentrations of discrete chemical elements in groundwater display uneven territorial distribution. They depend on the character of pollution, rock lithology, groundwater flow structure, and the filtration rates.

Typical groundwater outflow regions have been distinguished. The calculated groundwater outflow modules for each region are given in Figure 2. Formation of the groundwater outflow in the Kaunas city depends on the natural and technical factors. The most important natural factors are: lithology, filtration capacity, thickness of water-bearing horizon, and geomorphology and orography of the territory which predetermine the drainage conditions, lateral hydraulic links and conditions for discharge of interstitial water-bearing horizons. The most important technical factors are: intensity of building development and asphalt cover, and the structure and state of the rainwater drainage system.

The highest outflow of shallow groundwater in the Kaunas city area occurs in the alluvial sediments of Nemunas and Neris rivers valleys where the groundwater is contained in inequigranular, highly permeable sands and gravels (Fig. 1). It has been formed as a result of atmospheric water infiltration and discharge of confined groundwater of deeper aquifers. The groundwater outflow module of these territories reaches 10–150 l/s km^2. Smaller module values (5–7 l/s km^2) form in the Nemunas and Neris valleys sectors composed of alluvial fine-grained sand, and in intensively built-up areas with a dense rainwater drainage network.

Similar outflow module values occur also in the lower parts of the Nemunas tributaries where they are slightly elevated by water discharge from the inter-moraine aquifers. Higher module values in the plateau — without direct drainage by streams — occur in the areas of fluvioglacial sand where they reach 2–4 l/s km^2. The smallest module values (not exceeding 0.7 l/s km^2) occur in the territories covered by loam and clay

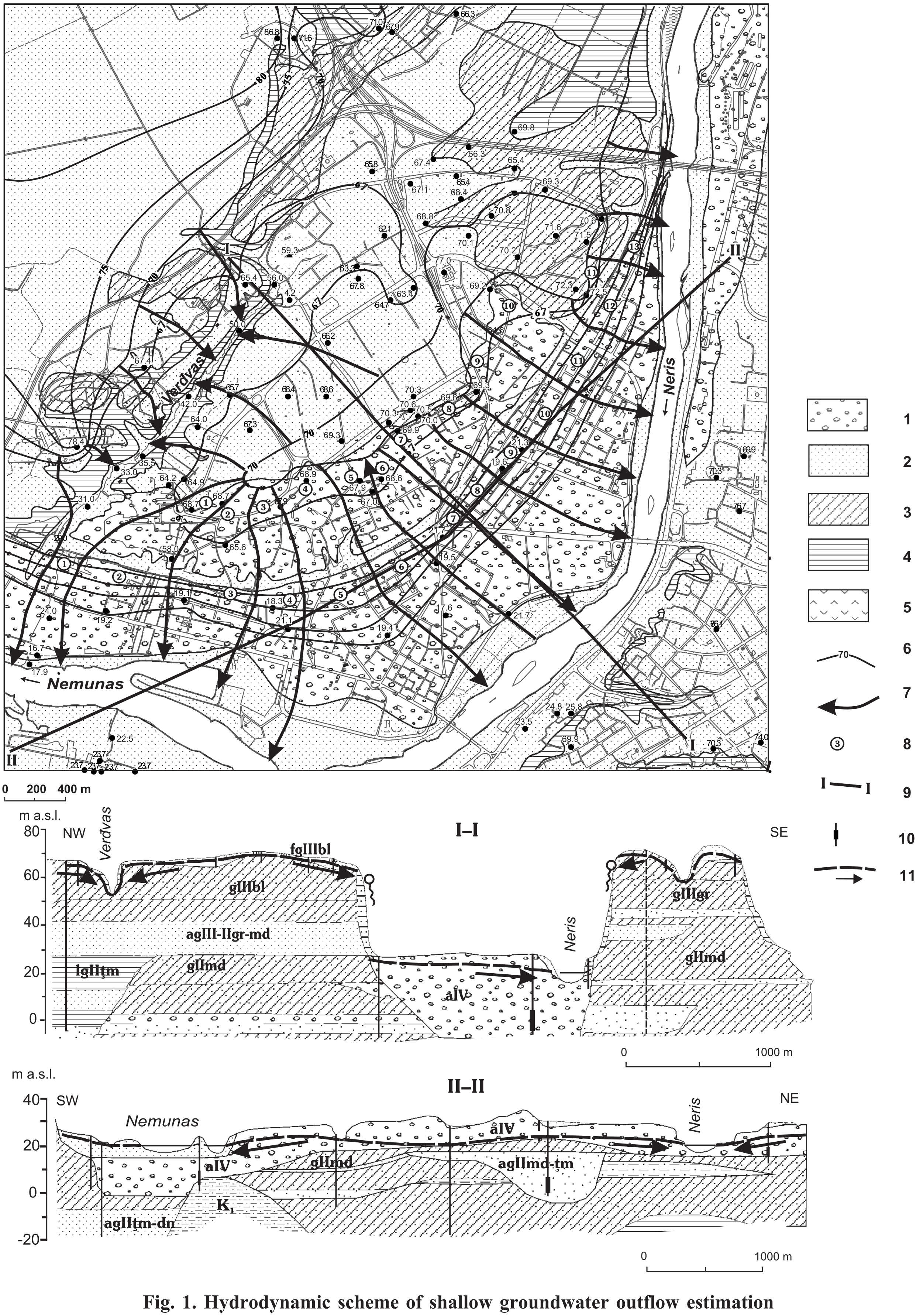

Fig. 1. Hydrodynamic scheme of shallow groundwater outflow estimation in contact of alluvium and fluvioglacial sediments

1 — gravel; *2* — sand; *3* — loam; *4* — clay; *5* — peat; *6* — hydroisohypse; *7* — direction of shallow groundwater flow; *8* — number of a hydrodynamic block; *9* — cross-section; *10* — borehole; *11* — groundwater table

Table 1

Main statistical parameters of groundwater chemical composition in different sediments (mg/l)

Lithology	Parameter	pH	TDS	HCO_3	SO_4	Cl	Ca	Mg	Na+K	Hardness*	CODMn*	NH_4	NO_3
Gravel	number	302	83	150	352	354	135	134	54	320	232	275	327
	average	7.33	844	450	125	77	131	47	69	9.8	6.2	0.831	49.4
	median	7.30	787	427	110	61	128	43	42	9.7	3.1	0.120	32.8
Sand	number	673	107	391	713	716	356	356	209	642	278	432	463
	average	7.30	688	431	142	101	135	45	301	10.3	4.4	0.233	41.7
	median	7.30	645	403	120	57	126	39	41	10.0	3.2	0.120	24.1
Loam	number	254	76	255	287	288	248	249	181	262	51	61	78
	average	7.20	940	534	191	91	160	53	70	12.3	7.5	0.432	21.3
	median	7.20	876	500	147	62	142	51	46	11.3	5.6	0.120	6.8
Clay	number	134	27	117	149	150	115	114	60	118	51	41	57
	average	7.24	964	558	165	82	155	58	72	12.5	7.8	0.193	22.5
	median	7.27	851	525	121	45	135	56	49	11.6	3.9	0.080	10.6
Peat	number	23	6	22	22	23	20	20	13	22	3	7	6
	average	6.80	661	504	165	93	122	50	56	10.9	31.5	1.714	24.1
	median	6.70	606	372	102	78	87	34	46	7.5	26.4	0.400	4.9

Lithology	Parameter	NO_2	Fe	Mn	Cu	Zn	Pb	Cr	Ni	Cd	F	CO_2a
Gravel	number	281	205	71	71	71	71	55	65	31	30	15
	average	0.406	0.200	0.030	0.035	0.505	0.070	0.053	0.147	0.005	0.270	5.3
	median	0.028	0.096	0.020	0.017	0.140	0.030	0.015	0.023	0.004	0.136	0.0
Sand	number	442	295	76	76	74	74	40	63	40	49	258
	average	0.316	0.237	0.021	0.020	0.291	0.019	0.018	0.013	0.004	0.215	6.3
	median	0.025	0.100	0.007	0.010	0.115	0.013	0.010	0.014	0.003	0.190	0.0
Loam	number	62	32	8	8	8	8	5	6	5	7	203
	average	0.255	0.151	0.027	0.032	0.137	0.018	0.017	0.018	0.003	0.112	5.0
	median	0.021	0.080	0.013	0.011	0.105	0.019	0.015	0.015	0.003	0.090	0.0
Clay	number	42	26	15	15	14	14	13	15	13	9	90
	average	0.037	0.111	0.038	0.010	0.358	0.018	0.010	0.018	0.003	0.209	1.7
	median	0.000	0.057	0.009	0.007	0.088	0.018	0.009	0.015	0.003	0.218	0.0
Peat	number	6	1	1	1	1	1	1	1	1	1	20
	average	0.089	0.200	0.280	0.018	0.100	0.033	0.030	0.040	0.006	0.729	21.3
	median	0.046	0.200	0.280	0.018	0.100	0.033	0.030	0.040	0.006	0.729	0.0

* total hardness — meq/l; COD_{Mn} — permanganate oxidation (mgO_2/l)

layers. The groundwater outflow is considerably reduced (by 1.5–2.0 times and more) by a solid urban surface cover.

Intensity of dissolved solids depends on the groundwater flow intensity and groundwater pollution. The highest modules of groundwater outflow (over 10 l/s km^2) in Kaunas occur in the polluted areas of Nemunas and Neris valleys covered by alluvial sand (Fig. 2). The dissolved solids in the highly polluted loamy soils reaches 1 g/s km^2 only, due to the low groundwater

Fig. 2. Shallow groundwater outflow of Kaunas city

1 — shallow groundwater outflow area; *2* — boundary of outflow area; *3* — module of shallow groundwater outflow [l/s km^2]; *4* — well field; *5* — boundary of the city; *6* — shallow groundwater outflow module

outflow values. The smallest values of dissolved solids outflow (up to 0.25 g/s km^2) occur in the relatively clean, loamy and clayey soils. In comparison with the natural groundwater chemical outflow (Kondratas *et al*., 1996), the dissolved solids outflow from urbanised territories is up to four times higher (up to 3 g/s km^2 in the clean water of sand–gravel deposits, and more than 10 g/s km^2 in urban areas).

CONCLUSIONS

Formation of groundwater discharge greatly depends on technical factors. The highest groundwater outflow forms in the alluvial valley deposits where groundwater is contained in inequigranular sand and gravel. The groundwater of such areas forms as a result of atmospheric water infiltration and confined water discharges from the deeper aquifers. The smallest groundwater outflow modules occur in territories covered by loam and clay deposits. The solid cover of urban surfaces considerably reduces the groundwater outflow: the groundwater outflow module in the intensively built-up areas is by 1.5–2 times lower than in the open areas composed of gravel deposits.

The intensity of dissolved solids outflow depends on the groundwater outflow intensity and the groundwater pollution. The highest modules of chemical outflow form in the polluted territories with high values of groundwater outflow. The highest chemical outflow values occur in the sectors of polluted rivers valleys covered by alluvial sand. The smallest values of chemical outflow are characteristic for relatively clean loamy-clayey soils. The chemical outflow in the urbanised areas is by up to 4 times higher than the outflow in the relatively natural areas.

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