TYPES OF GROUNDWATER CONTAMINATION IN CITIES AND RISK ASSESSMENT: A CASE STUDY SVETLOGORSK, BELARUS

Valery S. Khomich, Tamara I. Kukharchyk, Vera N. Chuduk, Elena S. Makaeva

Institute for Problems of Natural Resources Use & Ecology National Academy of Sciences
Staroborysovski tract 10, 220114, Minsk, Belarus
Phone: (+375) 264 23 12 Fax: (+375 17) 263 24 13
e-mail: valery_khomich@mail.ru

Abstract
The results of detailed investigation of underground waters for one Belarusian city are given. Own monitoring data as well as results of the observations of Sanitation Service were used. Features and pollution level of underground waters for various functional city zones are shown. Structure of hydrochemical anomalies are analysed. A special attention is given to the study of dynamics of underground waters pollution in the dwelling area and in the impact area. A hazard of shaft wells water use for drinking purposes is stressed. Ecological risk is evaluated also for territories for vegetables growing with polluted ground waters.
According to the results, nitrate entry with water for the city inhabitants can make up to about 1.7 mg/kg day for the permissible dosage 1.6 mg/kg day. An intensive zinc anomaly was detected in wetland site which is extensively used by the population to grow vegetables and potatoes and thus, there is a hazard of zinc and other toxic elements entry into food chains.

Introduction
Underground waters pollution is one of the acute ecological problems in Svetlogorsk as well in many cities. It is common knowledge, that sources of underground waters pollution are numerous: industrial enterprises, power plants, municipal and public service, agricultural and technogeneous activities. Svetlogorsk is a young industrial city within 75 thousand people founded in 1961 in the bank of Berezina river (Dnipper basin, south-east part of Belarus). In Svetlogorsk here are more than 20 enterprises of various profiles. The largest volumes of sewage and solid wastes are formed at the following three enterprises: Chemical Plant (Khimvolokno Amalgamation), Pulp-and-Paper Integrated Works and Heat Power Station. Pollutants entry into underground waters takes place because of the imperfection of the technologies used and sewage cleaning, leakage during their transport, polluted waters filtration from sludge storages and filtration fields etc.
The risk of underground waters pollution is connected with the fact, that the pollution area is increasing towards the city water supply area. Besides, the areas with heavily polluted ground waters (close to the surface) are used by the local population and by the Vegetables Factory for growing agricultural products. The entry of polluted underground waters is also possible into the river Berezina, on the banks of which the city is located. The study objective is to find features of spatial structure and dynamics for underground waters pollution on the city territory and on its impact area; ecological risk evaluation in the context of underground waters pollution.

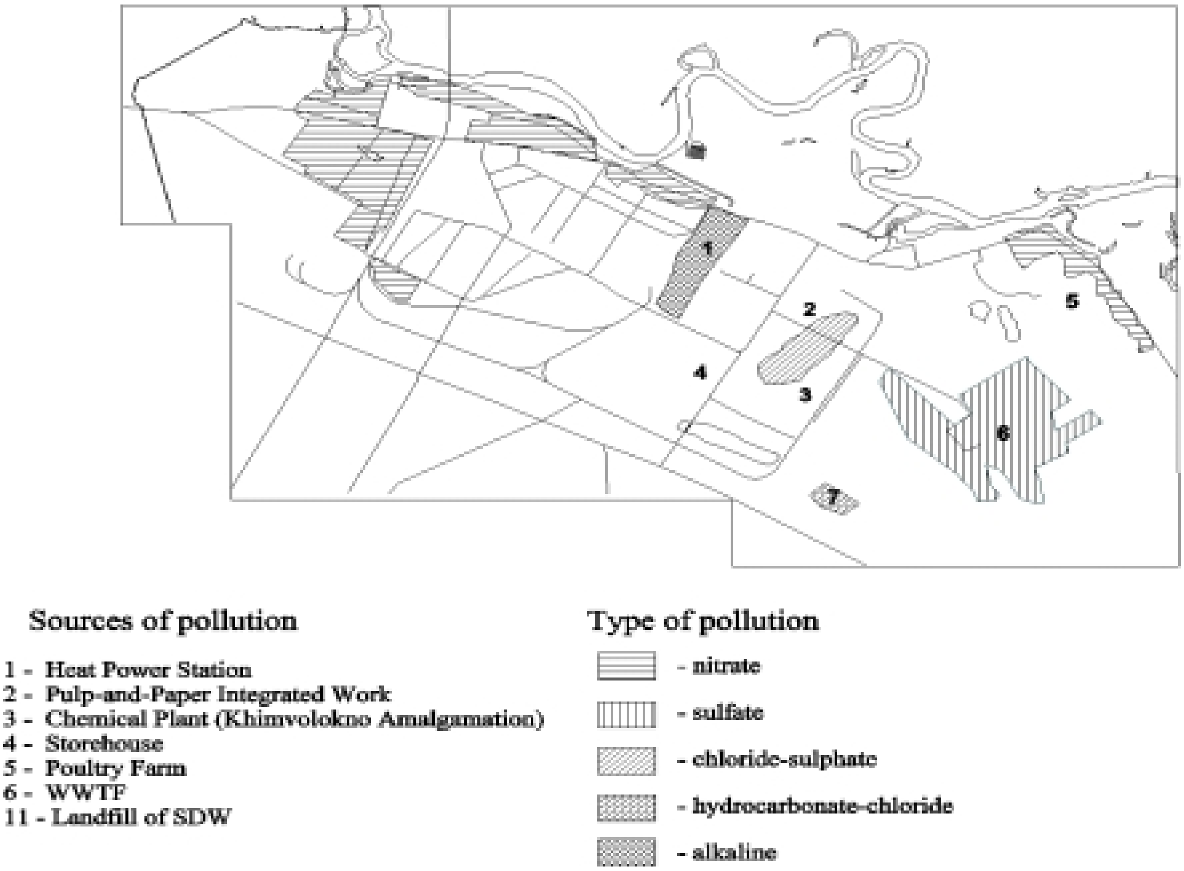
Objects and methods
Detailed studies of underground waters in Svetlogosk were carried out in 1999-2000. Underground waters in the impact area of the Waste Water Treatment Facilities (WWTF) and the dump of solid industrial wastes as well as Khimvolokno Amalgamation have been investigated since 1976. Sampling of underground waters is performed at fixed points from bore holes of the network mode, soil bore pits, shaft wells and water wells. (A network of bore holes making up to about 30 holes on the ground and on the pressure water-bearing horizon was created in the period of 1989-1991). Chemical analysis of water samples was carried out using the atomic absorption and hydrochemical (main ions) analysis. Besides, we used the results of the chemical and analytical laboratory at the Heat Power Station and the sanitation service. The water condition in wells used by the population for drinking purposes was evaluated for a 10-year period (more than 300 samples).

Results

The studies showed that hydrogeochemical anomalies different in genesis, area and pollutants content had been formed on the city territory and in its impact area. In respect to anion ratio and pH value the following types of underground waters pollution are singled out (Figure 1):

- nitrate water pollution in dwelling areas (the associated component in a number of cases is iron);
- sulfate underground waters pollution in the impact area of Khimvolokno Amalgamation, treatment facilities and the industrial wastes polygon;
- chloride-sulfate water pollution on the industrial site of Khimvolokno Amalgamation;
- hydrocarbonate-chloride water pollution in the impact area of the household wastes polygon;
- pH water increase in the impact area of the Heat Power Station (areas of alkali waters spreading).

Figure 1: Types of underground water pollution in Svetlogorsk city

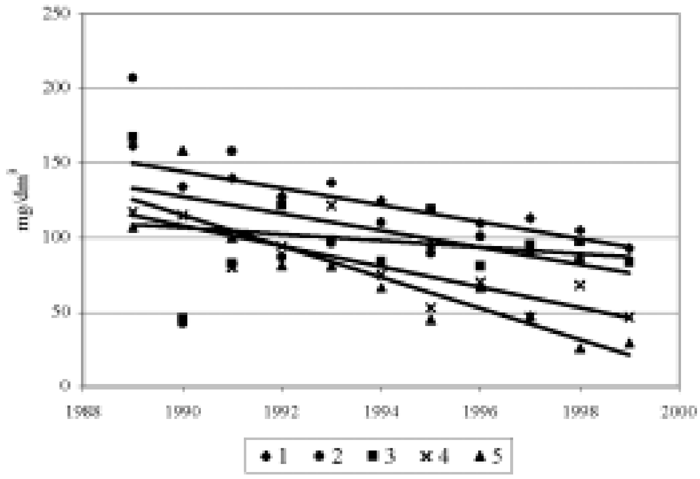


Underground waters condition in the dwelling area

Shaft wells water pollution used for drinking purposes represents the largest hazard. This is a typical problem of villages and individual building areas in cities. It was found out, that in all areas of individual building the first water-bearing horizon is rich in nitrates. Their highest concentrations were found in wells of the old city boroughs where irrespectively of the season the nitrate content exceeds 1.1 – 4.6 times the permissible concentrations limit (45 mg/dm^3). During a decade the nitrate content in the well water has noticeably decreased (Figure 2).

This tendency is typical of all city boroughs with individual building and can be explained by the decrease in fertilizers application on personal plots and agricultural lands. In a number of cases the exceed of permissible concentration limits for iron was registered in well waters.

Figure 2: Dynamics of nitrate content in the underground water of individual building areas in Svetlogorsk. Urban district: 1 – Svetoch, 2 – Nephtjanikov, 3 –western part of Shatilki, eastern part of Shatilki, 5 – Jakimova Sloboda.



Underground waters condition in the impact area of the WWTF

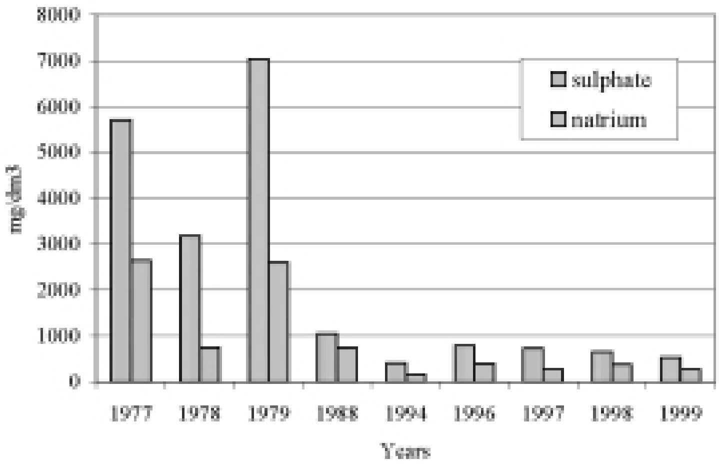
The most unfavourable situation for underground waters is found in the impact area of the WWTF. Ground waters mineralisation here makes up to over 2 g/dm^3, sanitation norms exceed here a large number of pollutants (sulfates, chlorides, iron, cadmium, organic contaminants, etc.). Water composition is azonal, mainly sulfate natrium. Underground pressure waters here are heavily polluted. Waters are sulfate natrium with a high mineralisation in the impact area of sludge storages, filtration fields and the industrial wastes polygon. Waters are hydrocarbonate with a high mineralisation (>1 g/dm^3) in the impact area of sludge ponds. The list of pollutants head organic substances, sulfates and ammonium nitrogen. Zinc, lead and cadmium are detected among heavy metals (Table 1).

Table 1: Heavy metals content in underground water in impact zones of WWTF, mkg/dm^3

Type of water	Index	Pb	Ni	Cu	Zn	Cr	Cd
Subsoil	mean	60	123	280	189	60	1.1
	min	10	28	36	48	10	0.3
	max	144	360	960	2592	178	3.9
Underground pressure	mean	11	34	44	50	26	0.1
	min	5	8	14.9	36	5	0.1
	max	26	116	102	74	80	0.2
Background value (1-3)	-	1.9	3.3	10	20	-	0.3
Permission concentration limit	-	30	100	1000	5000	-	1.0

The vast area of polluted underground waters is also found on the drained bog located between the industrial site of Khimvolokno Amalgamation and the WWTF. High pollution level was found both in compounds of basic salt composition and in organic compounds. Waters are highly mineralised (total mineralisation is over 1 g/dm^3) and in their composition are azonal sulfate natrium. The list of pollutants is rather wide: sulfates, ammonium nitrogen, natrium, iron, organic compounds. The ratio of permissible concentration limit exceed ranges from 2 to 10. Total mineralisation of ground waters for a 20-year period has decreased 4-5 times, natrium and sulfates concentration has decreased, respectively, too. The reasons for the concentration decrease of the basic salt composition compounds were sludge extraction and treatment and drainage amelioration at the end of the 70s – beginning of the 80s of the last century (Figure 3).

Figure 3: Dynamic of sulphate and natrium content in subsoil water on the drained bog located between the industrial site of Khimvolokno Amalgamation and the WWTF



The pollution dynamics of pressure waters is not homogeneous for the hydrogeochemical anomaly under study. One can clearly see a decreasing tendency of underground waters pollution to the north and to the north-west of the sludge storages. For the rest part of the anomaly in question the increase of water mineralization took place in the mid-90s and then its decrease. The variations are connected, first of all, with the dynamics of technogeneuos chemical loads. On the whole, the considered anomaly is characterized with the tendency towards pollutants concentration decrease in waters. At the same time, the level of underground waters pollution on this area remains rather high. Since this area is used for agricultural vegetation there is a hazard of pollutants accumulation in plants.

Underground waters condition in the impact area of Khimvolokno Amalgamation

An intensive hydrogeochemical anomaly has been formed on the industrial site of Khimvolokno Amalgamation where the area of polluted waters has mineralisation over 2 g/dm^3 and exceed in permissible concentration limit for sulfates, chlorides and natrium. The initial water composition has been considerably transformed; at present they are classified as calcium natrium. No mineralisation dynamics was traced for a ten-year period.

Underground waters condition in the impact area of the Heat Power Station

The impact of the Heat Power Station was, first of all, connected with the formation of alkali waters area. It can be explained by high emission volumes of fly ash into the air in the 60-70s of the last century (up to 40 tonnes/day). Fly ash is known to have an alkali environment reaction and to alkalify not only soils but also precipitation, surface and underground waters. In the impact area of residual oil storages underground waters are polluted with ammonium and nitrate nitrogen (the ratio of the permissible concentration limit exceed makes up to 2.3-8.3 and 1.1 respectively), iron (2-9.7 permissible concentration limit). In the impact area of ash dumps underground waters do not match the standards for ammonium nitrogen and iron (1.6 and 78 permissible concentration limit respectively). Waters are more clean on the industrial site of the Heat Power Station, however, there are cases of the norms exceed in iron content.

Underground waters condition in the impact area of the solid domestic wastes polygon

Underground waters pollution in the impact area of the household wastes polygon is connected with filtrate leaking. The ion sum of filtrate makes up to 7000 mg/dm^3, potassium concentration about 1000 mg/dm^3, natrium 420, chlorides 800 mg/dm^3. The following ions determine the water composition: Cl>HCO3/Na>Ca. The area of ground waters pollution stretches to the east and to the south-east from the polygon and matches the direction of filtrate leaking. Waters are highly polluted with ammonium and nitrate nitrogen, chlorides, iron. In a number of cases norms of total hardness and mineralisation are exceeded. Ground waters are classified as heavily polluted because of their high pollution with organic substances and multiple increases of permissible concentration limit for other normative factors.

Underground waters condition in the forest-park areas

City forest-park areas and adjoining forests tracts are characterized with more clean waters. Ground waters here have low mineralisation, acid, although chlorides and sulfates content exceeds the background (Table 2). The ion ratio in waters is different, that can be explained by the impact of precipitation and local sources. Pressure waters in non-polluted areas have mean mineralisation, neutral reaction, zonal water composition (HCO3/Ca>Mg).

Table 2: Chemical composition of underground water of forest-park area

N of sample	Year	pH	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	NO_2^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	NH_4^+	Sum ions
Subsoil water													
74	1996	3.9	48.8	21.3	29.6	7.0	ND	16.0	4.8	1.8	-	4.2	133.6
			37.6	28.1	29.0	5.3	ND	52.9	26.4	5.3	-	15.4	
145	1999	3.62	42.7	28.4	1.6	4.2	ND	6.1	1.8	14.0	0.4	5.4	104.6
			43.7	49.9	2.1	4.2	ND	22.1	11.0	44.3	0.7	21.8	
146	1999	4.51	24.4	31.9	15.3	1.6	ND	3.0	0.9	14.0	0.9	0.7	92.7
			24.4	54.7	19.4	1.6	ND	17.0	8.5	67.9	2.6	4.1	
Underground pressure water													
9a	1999	7.49	183	10.6	25.5	0.3	ND	51.8	17.3	6.7	0.7	0.7	296.56
			78.2	7.8	13.9	0.1	ND	59.2	32.9	6.7	0.4	0.8	
36a	1999	7.42	201.3	4.3	9.1	0.6	0.1	47.8	14.0	4.6	4.0	1.1	286.9
			91.1	3.3	5.2	0.3	0.1	60.9	29.8	5.1	2.6	1.6	

[1] – upper line – mg/dm^3; lower – %; ND – not detected

Ecological risk evaluation

The results obtained show the existence of several types of ecological risk on the territory of Svetlogorsk and in its impact area: connected with tap water pollution with iron and suspended substances; connected with water consumption from shaft wells in the individual building areas; connected with vegetables and other agricultural products cultivated on the areas with polluted ground waters. (The first type of risk will be minimized after finishing the construction of the city deironing station and is not considered here). We used the value of 21 ml/kg body mass a day as an average water consumption norm for the ecological risk evaluation of the population consuming water from shaft wells (Exposure Factors Handbook, 1997). Nitrate content in underground waters of shaft wells in the dwelling part of the city during the last three years ranged within 74.5-88.9 mg/dm3 averaging to 83.2 mg/dm3. According to the data obtained, nitrate entry with water for the city inhabitants can make up to about 1.7 mg/kg day for the permissible dosage 1.6 mg/kg day. The ecological risk for the population can increase in case of consumption of vegetables and other agricultural products polluted with nitrates. As it was stated above, the ground waters pollution with heavy metals including zinc takes place on the bogged area between the industrial site of Khimvolokno Amalgamation and sludge storages. An intensive zinc anomaly was detected here in soil mainly of hydrogenic origin. This area is extensively used by the population to grow vegetables and potatoes and thus, there is a hazard of zinc and other toxic elements entry into food chains.

Vegetables sampling and analysis showed their considerable pollution with zinc on the area under study. Zinc mean concentration in vegetables made up to 77.6 mg/kg. For mean norm of vegetable consumption 4.3 g/kg body mass a day (Exposure Factors Handbook, 1997) a dosage for zinc makes up to 0.33 mg/kg body mass a day. It is a bit higher than the permissible dosage of oral zinc consumption equaled to 0.3 mg/kg body mass a day.

References

(1) Ivanov V.V. Ecological geochemistry of elements. Reference book/ Ed. By E.K.Burenkov. Book 3. Noskow, Russia, (1996) (In Russian)

(2) Ivanov V.V. Ecological geochemistry of elements. Reference book/ Ed. By E.K.Burenkov. Book 5. Noskow, Russia (1997) (In Russian)

(3) Schvartsev S.L. Foundation of hydrogeology. Hydrochemistry. Novosibirsk, Russia, (1982) (In Russian)

(4) Exposure Factors Handbook / Volume I – General Factors // EPA/600/p-95/002Fa. Office of research and Development National Center for Environmental Assessment US Environmental Protection Agency. Washington, DC 20460, USA, (August, 1997)