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GROUNDWATER CHEMISTRY CHANGES RELATED TO ECONOMIC AND TOURISM IMPACT IN THE ZAKOPANE REGION (PODHALE FLYSCH BASIN)

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Abstract. Pollution related to the increasing tourist traffic has become a major environmental risk for soil and groundwater in the Zakopane region. It was necessary to develop and modernise the water supply system, sewage plant, and waste landfill. Currently, water is supplied by the water supply system to about 90% of residents, although local groundwater catchments are often still in use. The shallow unconfined groundwater is highly sensitive to climatic and anthropogenic influence. It was confirmed by chemical composition analyses performed during the period of 1971–2001. Within this time interval, surface waters and groundwater were of the lowest quality in the 1980. After a series of environmental investments their quality significantly improved. In case of groundwater, this quality improvement was expressed by the increase of bicarbonate content and the general decrease of sulphide and chloride contents. Another alarming problem is a continuous increase of nitrate content. However, these components are not a threat to deep groundwater because of the insulating effect of the flysch shale strata.

Key words: groundwater chemistry changes, groundwater, groundwater contamination, Podhale Flysch Basin.

Abstrakt. Zanieczyszczenia powodowane przez wzrastający ruch turystyczny stały się głównym zagrożeniem środowiskowym dla gleb i wód podziemnych regionu zakopiańskiego. Konieczny stał się rozwój i modernizacja systemu zaopatrzenia w wodę, oczyszczalni ścieków oraz składowiska odpadów. Obecnie około 90% mieszkańców pobiera wodę z systemu wodociągowego, jeddnak lokalne ujęcia wód podziemnych są nadal używane. Płytkie, nieizolowane wody podziemne są bardzo podatne na wpływy klimatyczne i antropogeniczne. Potwierdziły to analizy składu chemicznego wykonane w latach 1971–2001. Najniższą jakość wody powierzchniowe i podziemne miały w latach 1980. W wyniku inwestycji środowiskowych ich jakość znacząco się poprawiła. W wodach podziemnych, wyraża się to wzrostem zawartości węglanów i generalnym zmniejszeniem zawartości siarczków i chlorków. Niepokojący jest stały wzrost zawartości azotanów, które jednak nie zagrażają głębszym wodom podziemnym, chronionym przez dobrze izolujące łupki fliszowe.

Słowa kluczowe: zmiany chemizmu wód podziemnych, wody podziemne, zanieczyszczenie wód podziemnych, podhalański basen fliszowy.

INTRODUCTION

The study area is located in southern Poland, north of the Tatra Mts. It includes the continuously developing town of Zakopane and its vicinities (Fig. 1). In terms of geological setting, this area covers the Zakopane fan and alluvial deposits of the Cicha Woda valley, characterised by low degree of natural protection from pollution penetrating down from the ground surface. It causes degradation of soils and groundwater. Therefore, there is a need to perform quality assessments with respect to both groundwater and surface waters. In this area, waters are threatened by tourism rather than by agricultural and industrial activity.

The Tatra National Park boundaries are crossed annually by 3 million visitors. Zakopane town is inhabited by about 30,000 people but during high seasons this number increases to 100,000. Tourism replaced such traditional activity fields as agriculture and shepherding in this region. The major potential

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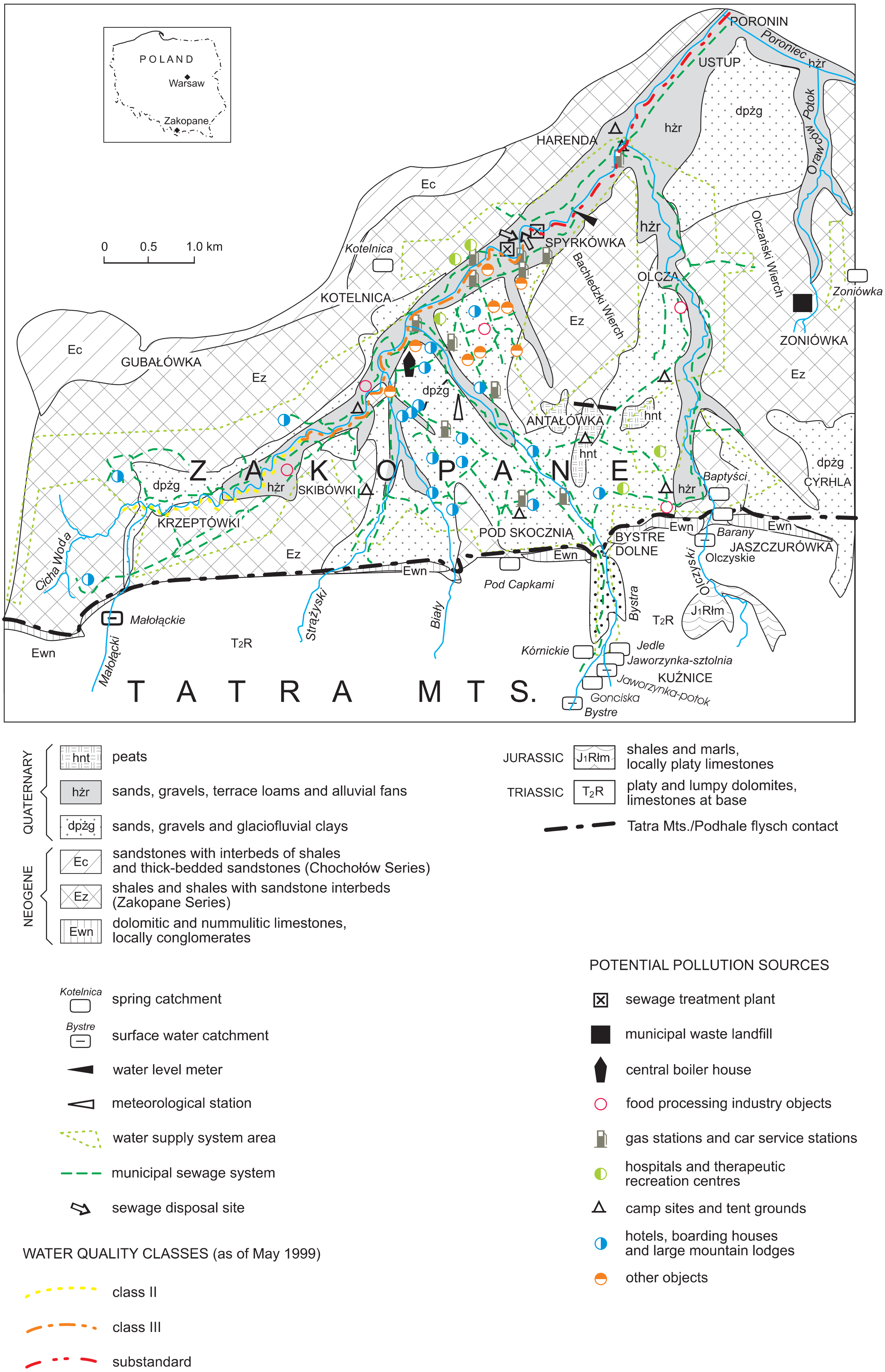

Fig. 1. Location of the study area and geology of the Cicha Woda drainage basin

sources of groundwater contamination are objects associated with the highly increasing tourist traffic. In the 1990s, about 2 million tourists visited this area each year. Now the annual number of visitors is in excess of 3 million. This increased tourist traffic results in greater demand for water and causes the necessity to develop and modernise the sewage plant and the solid waste landfill (Fig. 1) required for proper environmental protection. Decreased water quality in this area indicates that there is much to do in the field of groundwater protection. In order to characterise the impact of tourism on the quality of shallow groundwater, data concerning groundwater and surface waters, collected over a 30-year period, were analysed against the background of the geological structure and potential pollution sources.

STUDY METHODS

To determine groundwater chemistry changes in Zakopane, data from three groundwater samplings, performed in 1971, 1985 and 2001 at the same groundwater measuring points, were used. Each analysis included determinations of calcium, magnesium, sodium, potassium, bicarbonates, sulphates, chlorides, and nitrates mineralisation. Due to hydraulic contact between groundwater and surface waters, results of Cicha Woda stream water analysis were also taken into account. In that case, the analytical range was extended to include determination of the BOD_5 index that is used to estimate organic contamination of water. Each sampling procedure and determinations methodology were consistent with general rules accepted in hydrogeological analyses. Verification of the results was made on the basis of statistical methods used in groundwater monitoring (Szczepańska, Kmiecik, 1998).

To determine causes of groundwater changes encountered over these three decades, potential contamination sources were identified (Fig. 1). Except for pollution sources identified as point sites, there were also spatial sources which contributed to chemistry of rainfall waters recharging shallow aquifer. Due to the development of tourism and the consequent growth in water demand in the Zakopane region, increase in sewage and solid waste capacity was observed and, therefore, it was essential to characterise water supply and sewage system management.

To estimate potential risk of the decreased water quality, the so-called DRASTIC system, based on geological, hydrogeological, climatic and soil factors analyses, was used.

Causes of the groundwater changes within the Zakopane fan were analysed largely on the basis of the author's own investigations. To complete the characteristics, data from the municipal water supply system company, sewage plant (SEWiK), District Mining Office in Lublin and from the Voivodship Inspectorate for Environmental Protection (WIOŚ report, 2002) were also used.

GEOLOGICAL SETTING AND HYDROGEOLOGICAL CONDITIONS

In terms of geological and topographical conditions, town of Zakopane is located in the Zakopane Depression blanketed with sands, gravels, and glaciofluvial clays (Fig. 1). Since these deposits accumulated upon varied relief (Bac-Moszaszwili *et al*., 1979), the thickness of Quaternary deposits is variable ranging from a dozen metres in the topmost part of the fan close to the Tatra Mts. to several tens of centimetres in its peripheral parts. On a regional scale, these deposits form a series of overlapping fans at mountain valleys mouths. Therefore, the whole clastic complex is referred to as the Zakopane fan. Ranges composed of flysch rocks, e.g. Antałówka and Olczański Wierch, have been preserved among Quaternary gravel deposits. Residual clays developed on flysch rocks. Sand and gravel deposits occur along the Cicha Woda stream and its tributaries, whereas peat bogs are associated with wetland areas.

Two overlapping groundwater circulation systems are observed in this area. One of them involves shallow unconfined groundwater which water table follows the topography (Małecka, Witkowski, 1981; Chowaniec, 2004). The other one involves deep groundwater of sub-flysch aquifers described by Małecka (1985, 1993, 2003). Its characteristics will be presented further in the text because deep waters are much less prone to contamination related to increased tourism traffic, than shallow waters. The shallow groundwater aquifer is composed of glaciofluvial and fluvial deposits overlying flysch shales (Małecka *et al*., 2002b). Locally, the aquifer is composed of alluvial deposits of river valleys, and of flysch rocks. Depth to the water table is variable, depending on the aquifer type. Investigations performed in year 2000 showed that depth to the water table in flysch deposits was the most variable, ranging from 0.12 m to 6.18 m b.g.l. In glaciofluvial and alluvial deposits, the water table was found at depths of 0.28–5.63 m b.g.l. and 0.3–2.57 m b.g.l., respectively. However, the most common depths were below 3 m b.g.l., regardless of the aquifer type.

This shallow aquifer is significantly recharged by both infiltration of rainfall and lateral inflow from the Biały Dunajec river basin. Pore waters in the valley form a single aquifer of constant hydraulic gradient (0.012% within the Zakopane fan). Permeability coefficient values are variable: of the order of 1×10^{-3}, 1×10^{-4} m/s, but also 1×10^{-5} and 1×10^{-6} m/s (Małecka, 1993; Małecki, 1997). Recharge of the aquifer by infiltrating rainwater is particularly important in the Tatra foothill zone (Małecka, 1988, 1989; Małecki, Matyjasik, 2001) where average annual precipitation is 1,500 mm (the greatest annual precipitation in Poland). Hence, water chemistry in this area is dependent upon the precipitation type. Moving away from the Tatra Mts., an increasing influence of the Zakopane water supply and sewage system management is observed (Małecki, 1987; Małecka, Małecki, 1993; Oleksynowa, 1993). In the southern part of Male Karpaty Mts. (Slovakia), an anthropogenic influence of Brastislava agglomeration on groundwater quality was also documented (Fľaková *et al*., 2001, 2004).

Groundwater in crystalline rocks is usually poorly mineralised and responds very sensitively to anthropogenic pollution. However, the composition of subsurface water is a very complex function of several factors, such as composition of the infiltrating water, petrologic and mineralogical composition of subsurface rocks and dynamics of groundwater flow rock/water interaction (Małecki, Matyjasik, 2002).

WATER SUPPLY AND SEWAGE SYSTEM MANAGEMENT

The water supply system is the main source of water for residents of Zakopane. In the 1970s, the municipal water supply system provided water from springs located on northern slopes of the Tatra Mts., near Kuźnice. An emergency water intake was installed on the Bystra stream in Kuźnice because of annual fluctuations in spring discharge. The average total discharge was 173 l/s (622.8 m^3/h), with water withdrawal of 150 l/s (540 m^3/h) (Małecka, Małecki, 1993). An additional water capture was built on the Pod Capkami spring near a ski jump, raising the average water discharge by several to a dozen of l/s. In the northern sector of Zakopane, on the Kotelnica slopes, a series of flysch springs were captured to built a local water supply system for a number of nearby located buildings.

Compared with the 1970s, water demand increased recently by 27%, and water consumption reached 16,500 m^3/d (687.5 m^3/h). The Zakopane water supply system uses currently four surface water intakes (Bystra, Olczyski, Jaworzynka and Małołącki streams) and five spring water intakes (I — a series of springs near Kuźnice-Kórnickie, Jaworzynka-sztolnia, Jedle and Gonciska, II — Barany and Baptyści springs at Jaszczurówka, III — Pod Capkami spring, IV — Zoniówka spring, V — Kotelnica spring) (Fig. 1).

The total production ability of surface water and groundwater intakes is approximately 706 m^3/h, and comes mostly from the Kuźnice intakes. The Zakopane water supply system serves 90% of residents, but it is planned to develop the system to provide water to 95% of residents by 2010.

In terms of physical and chemical parameters, the analysed waters are characterised by high quality, meeting all the requirements listed in the regulation issued by the Ministry of Health, dated November 29, 2002, and concerning drinking water quality (DzU No. 203, it. 1718). However, bacteriological analyses show that the water quality widely varies. It refers in particular to the Kuźnice intake. Therefore, prior to pumping into the water supply system, the water is chlorinated.

The current length of the water supply system pipeline is 197.8 km, whereas the sewage system pipeline is around 50 km shorter, covering 75% of the Zakopane area, only (Fig. 1). With time this situation has changed, as evidenced by the fact that in the 1970s only the centre of Zakopane had a sewage system. In areas of dispersed development, on the Gubałówka slopes and in Kuźnice, Cyrhla, Jaszczurówka and Olcza, sewage used to be discharged into surface streams or septic tanks without any treatment. Only large buildings such as hospitals, therapeutic recreation centres, and hotels had their own sewage treatment systems.

In the recent years many public buildings have been connected to the municipal sewage treatment system. It was, therefore, necessary to develop and modernise the Spyrkówka mechanical-biological sewage treatment plant, built in 1938.

Table 1

Reduction of the pollution by the sewage plant in Zakopane in 2000 (SEWiK data)

Selected components		BOD_5 mg O_2/dm^3	$N-NH_4$	$N-NO_2$	$N-NO_3$	N_{tot}	P_{tot}	Total suspension	Cl^-
			mg/dm^3						
The Spyrówka sewage plant									
2000	input	122.8	8.6	0.11	0.9	12.7	3.8	81.2	32.6
	output	9.6	1.8	0.13	6.6	9.3	2.3	10.6	27.7
	reduction (%)	92	79	—	—	26	40	87	15
w.s. and s. e. d. c.	output	15	—	—	—	20	1.5	30	—
The Łęgi sewage plant									
2000	input	195.5	9.8	0.15	0.99	16.7	6.6	196.9	31.2
	output	34.0	2.76	0.33	2.68	7.6	2.7	28.1	28.0
	reduction (%)	83	72	—	—	54	59	86	10
w.s. and s. e. d. c.	output	9	—	—	—	14	1.0	30	—

w.s. and s. e. d. c. — water supply and sewage effluent disposal consent

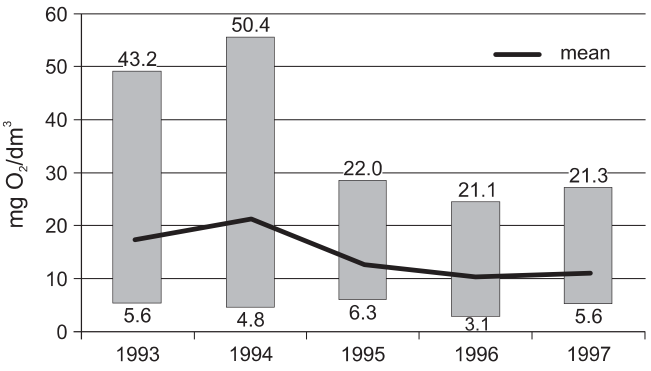

Fig. 2. Extreme and average BOD_5 values of water samples from the Cicha Woda stream at the Zakopane-Harenda measuring point

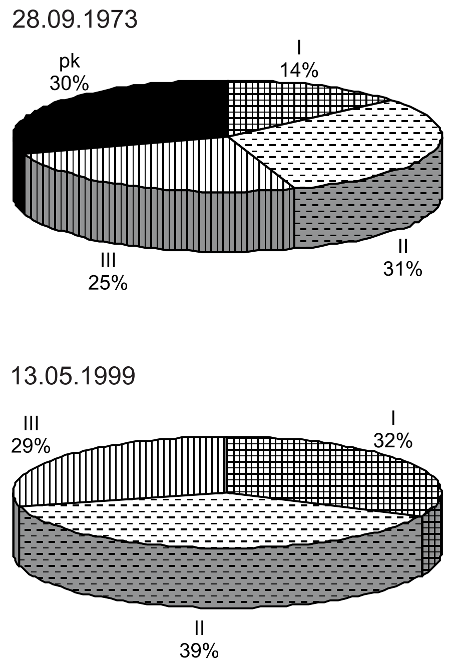

Fig. 3. Percentage contribution of water quality classes of the Cicha Woda stream determined from the BOD_5 index

The sewage plant capacity was 6000 m^3/day, and the plant was overloaded already in the 1970. Its development and modernisation have taken place in 1993–1996. Currently, this is a modern, automated mechanical-biological sewage treatment plant supported by chemical removal of phosphorous compounds. Its capacity is estimated at 14,000 m^3/d. The municipal sewage treatment system was developed by building in 1990 a Łęgi sewage plant. Its capacity was 15,000 m^3/d, and the treatment process involved mechanical, biological, and chemical methods.

The highest amount of sewage is produced during summer and winter seasons as a result of increased tourist traffic. These are also periods of greater amounts of contaminants in sewage.

Effectiveness of the sewage treatment plants is reasonably high, except for removal nitrogen compounds (N-NO_2 and N-NO_3) as shown in Table 1. The used treatment technologies yield the best effects in sewage purification for BOD_5 (biological oxygen demand) and suspension reduction. Nevertheless, the Łęgi sewage plant showed exceeded BOD_5 standards defined by the water supply and sewage effluent disposal consent. Exceeded total phosphorus limits have also been reported. Purified sewage passes to Cicha Woda stream waters (Fig. 1). Investigations show that the stream water quality varies along the flow line. With respect to physical and chemical indices (NO_2^-, NO_3^-, NH_4^+, Cl^-, PO_4^{3-}, total suspension) and biochemical indices (BOD_5, coli titre), the Cicha Woda stream water, from the Małołącki stream to Zakopane suburbs, has been classified as Class II quality water. Within the Zakopane town's borders, its quality decreased to Class III, whereas downstream from the sewage plant, the water is classified as substandard water (Fig. 1).

The water's natural purification process in the stream is limited, with a distinct increase in the concentration of chlorides, nitrates, nitrites, ammonia, phosphates, and bacteriological contaminants because of an excessive discharge of sewage (Tabaczniuk, 1999). High energy of stream waters quickly reduces the negative effect of sewage discharge (Małecka *et al.*, 2002a). It refers mainly to nitrates and phosphates. No reduction of easily degradable organic compounds (from BOD_5 data) is observed, probably due to permanent supply of these compounds not only from the sewage plant but also from other pollution sources. Monthly measurements performed in 1993–1997 by the Voivodship Inspectorate for Environmental Protection in Nowy Sącz indicate that the minimum BOD_5 values at the Zakopane-Harenda measuring point ranged from 3 to 6 mg O_2/dm^3, while the maximum values exceeded 50 mg O_2/dm^3, particularly early in that period (Fig. 2). After 1995, BOD_5 values decreased by over 50% and slightly exceeded 20 mg/dm^3. The research period covered 5 years because in July 1998 the Nowy Sącz Inspectorate terminated its chemical investigations of the Cicha Woda stream.

By comparing the BOD_5 index values along the stream profile from 1973 (Małecka, Małecki, 1993) and 1999 (Tabaczniuk, 1999), it has been found that water quality significantly improved. On the basis of these analyses, water is classified as Classes I to III. As compared to 1993, there was an increase in contribution of water Class I, and the total reduction of substandard waters (Fig. 3).

Pollution discharged by the sewage plant and the subsequent water's natural purification process are extremely important for the Cicha Woda stream, since this stream is the main source of water for the Nowy Targ town located about 20 km to the north.

SOLID WASTE LANDFILL

The municipal solid waste landfill is another object threatening the natural environment of Zakopane. It is located at the Orawców stream near the "Zoniówka" housing estate, east of Olczański Wierch (Fig. 1). The construction of the landfill started in 1984 and it occupies now an area of approximately 2 ha. It was intended to be a modern landfill with a permanent sanitary control. Due to a number of defects made during construction works, the landfill has not been properly developed. Besides, not only household waste but also waste from hospitals, therapeutic recreation centres, and the sewage plant has been stored there.

Data analysis shows that the amount of waste is closely dependent on seasonal tourist traffic. For example, the amount of waste in August 2000 amounted to 1557.8 t, i.e. over twice as much as in November 2000 (699.9 t). This has a direct reflection in the chemical composition of both surface and ground waters. An increase in total mineralisation and content of all ions (with the greatest contribution of chloride and sodium) is observed in the Orawców stream, down flow from the waste landfill (Fig. 4).

The presence of groundwater pollution near the waste landfill is proved by water samples analyses from piezometers distributed around. The piezometers were installed by District Mining Office in Lublin in order to monitor water quality. Laboratory measurements performed in May 2001 showed that the groundwater contains a wide variety of ions and is characterised by mineralisation ranging from 343 mg/dm^3 (upgraded by the landfill) to 5,230 mg/dm^3 (downgraded by the landfill) (Tab. 2). The greatest variations in ion contents were observed for sodium, potassium and chloride, and to a lesser extent for sulphate.

The results indicate that this area can be considered as a very high environmental risk area (Małecka *et al*., 2002a).

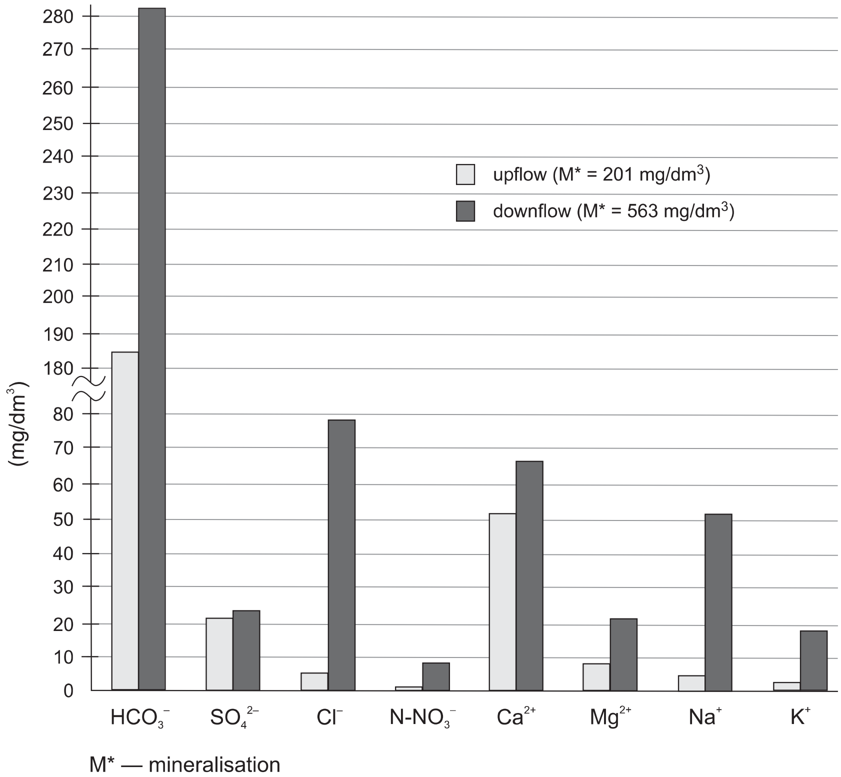

Fig. 4. Water chemistry changes in the Orawców stream around the municipal waste landfill

Table 2

Comparison of selected physical and chemical parameters of groundwater samples from piezometers installedaround the "Zoniówka" landfill (May 2001)

Piezometers	pH	Content [mg/dm^3]									
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$Fe_{tot.}$	Mn^{2+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	Dry residue
Upgraded from landfill	7.25	57.31	5.55	4.16	0.66	0.070	<0.01	8.86	17.70	176.9	343.0
Downgraded from landfill	7.20	139.7	116.5	423	131	0.17	3.70	717.9	54.3	1354	5230

OTHER POTENTIAL POLLUTION SOURCES

In the urban area, food processing industry is the most hazardous to soil and groundwater environment, with particular regard to the Skibówki dairy which operated already in the 1970s and in the Cicha Woda stream waters caused significant increase in BOD_5 (Małecka, Małecki, 1993). A specific type of hazard is posed by hospitals and therapeutic recreation centres which, after preliminary disinfection by chlorination, discharge sewage to the municipal sewage system.

Increasing environmental hazard has recently been posed by tourism (hotels, boarding houses, hostels and camping sites), filling stations, and car service stations (Fig. 1). Significant development of lodging base has recently taken place, as compared to the 1970s. It refers in particular to private boarding houses. Worth noting are also camp grounds and tent sites located along the streams. Some of them are not connected to the sewage system. It is notable that most of the described pollution sources are located within the area of glaciofluvial or alluvial deposits (Fig. 1). They pose a direct hazard in particular to groundwaters which are still willingly used by the residents despite the existence of the properly operating municipal water supply system.

SPATIAL CONTAMINATION

Except for the pollution sources identified as point sites, there are also spatial sources which contribute to the chemistry of rainfall waters recharging the shallow aquifer.

For spatial contamination of rainfall water, the amount of acid-forming sulphur and nitrogen compounds emitted to the atmosphere is of the greatest significance. The emission of sulphur compounds, resulting from coal and coke combustion for heating purposes, is the especially important problem for the Orawa-Nowy Targ Basin during winter seasons. Currently, there is an ongoing project conducted by *Geotermia Podhalańska Company* to replace the traditional energy carriers by ecological energy sources derived from thermal waters. This project started in the communes located along the Biały Dunajec valley: Nowy Targ, Zakopane, Szaflary, Biały Dunajec, Kościelisko, and Poronin.

Three components present in rainfall water: sulphur, nitrogen and dust, being the air pollution indicators, have been monitored by the Voivodship Inspectorate for Environmental Protection. In the study area, an automatic measuring station is located on the Zakopane Równia. The station performs observations of a range of parameters concerning atmospheric air quality, as shown in Table 3. The data indicate that sulphur and NO_2 concentrations are lower than permissible limits. Only the amount of particulate matter is beyond the allowed limits (PM10).

Table 3

Average annual concentration of SO_2, NO_2 and particulate matter in the air of Zakopane–Równia Krupowa (Raport WIOŚ, 2002)

Pollution location		Pollutant	Average annual concentration	Average annual limit*
locality	street		μg/m³	
Zakopane	Równia Krupowa	SO_2	15	40
		NO_2	18	40
		particulate matter (PM10)	49	40
		CO	1020	10 000
		Pb	0.030	0.5
		Cd	0.0009	—
		Ni	0.0012	—
		Cr	0.002	—

* based on the Regulation of the Ministry of the Environment, July 6, 2002 (DzU No. 87, it. 796)

Dust particles can remain in suspension for a long time because of poor air movement within the topographic basin. Except for pollution emitted from local boiler houses, household stoves and road traffic, there is also long-distance pollution coming from Silesian and Ostrava-Karvina agglomerations, and from Cracow. Gaseous pollution can be carried over thousands of kilometres distances, whereas particulate matter pollution occurs close to the emission sources (Hryniewicz, Przybylska, 1993).

As a result of a number of complex processes in the atmosphere, pollution is carried by rainwater into the soil and groundwater environment. Data collected by the Voivodship Inspectorate for Environmental Protection in the area of the Małopolska Voivodship (WIOŚ report, 2002) indicate that sulphates (as much as about 45% of total pollution), and to a lesser extent chloride and calcium (<15%), are the most common constituents introduced into the environment. Moving away from the Tatra Mts., the effect of precipitation on groundwater chemistry decreases, but the influence of sewage pollution and water management is still observed (Małecki 1987; Małecka, Małecki, 1993). It results in a local increase of soluble ions content in water.

GROUNDWATER

Despite of a number of objects which cause degradation of shallow groundwater, most of the population of Zakopane and surrounding areas receives water from wells and springs. Chemical analyses of that groundwater were already performed in the 1970. as this region is especially valuable in terms of nature conservation. The analyses were made of fresh water (mineralisation <600 mg/dm^3) representing mostly a bicarbonate-calcium-magnesium variety. Over a couple of decades, the chemical type of the water has not changed, although some variations of individual components contents were observed.

Groundwater chemistry changes observed in the Zakopane fan over the period 1971–2001 are illustrated in Fig. 5. Spectrum of cation species has not changed over this period. In case of anions, a significant increase in sulphate and chloride concentrations at the expense of bicarbonate was observed as compared to 1970. Nitrate concentrations were generally at lower levels averaging about 2 mg NO_3/dm^3 and not exceeding 12 mg/dm^3 (Małecki, 1997). The present-day investigations show that the bicarbonate concentration is similar to that of the 1970. with average values below 200 mg HCO_3/dm^3. Sulphate and chloride concentrations significantly decreased indicating an improvement in water quality (Tab. 4). However, it is contradicted by a progressive increase in nitrate content. Its average concentration was about 13 mg NO_3/dm^3, reaching the maximum values in the 1980.

The results obtained indicate that the background concentrations, varying in this area between trace amounts and 1.6 mg NO_3/dm^3, were significantly exceeded. Average concentrations of other ions, despite much variations over the analysed period, did not exceed the background values. Taking into consideration the entire data population, contribution of analyses of the background accounted for over 80% (Małecka, Małecki, 1993).

Comparing archival analyses with present investigations results of water samples collected from springs and hand-dug

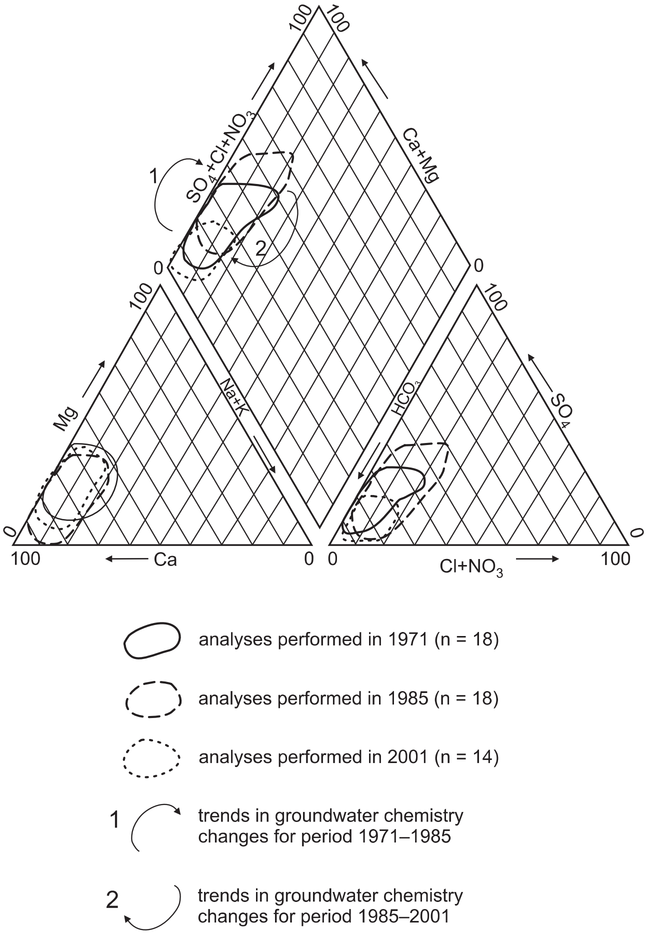

Fig. 5. Trends in groundwater chemistry changes of the Zakopane fan in 1971–2001

wells, it was found that the Kotelnica spring, located on the Gubałówka slope (Fig. 1), shows a similar decreasing trend in sulphates concentration, and the increasing trend in nitrates concentration as that detected in waters from hand-dug well (Fig. 6). The Baptyści spring, situated at the Tatra Mts./Podhale flysch contact (Fig. 1), and remaining beyond the influence of the town of Zakopane, was characterised by a constant water chemistry over a long period. However, the increase in average nitrate concentration, typical of the whole region, has also been observed during the last years in this area.

Anthropogenic influence and natural waters pollution was also documented in Liptovska kotlina basin (Slovakia) (Ženišová, Fľaková, 2001).

The so-called DRASTIC system (Krajewski, 2000) was used to assess the potential risk of groundwater pollution posed by various objects harmful to the environment. This system is based on analysis of geological, hydrogeological, soil, and climatic factors. Calculations from data obtained from 33 measuring sites (Fig. 7) enabled the assessment of the groundwater pollution potential risk as moderate (for 51% of measuring sites) and high (for 49% of measuring sites) (Kowalska, 2002). Analysis of the spatial risk of groundwater pollution indicates that the Zakopane fan, composed of glaciofluvial deposits, and alluvial stream valleys are the most highly endangered areas (Fig. 1, Fig. 7). A slightly better situation is observed in areas of strongly sloping topography: southeastern Gubałówka slopes, Bachledzki Wierch, and Olczański Wierch where the pollution is brought by rain runoff rather than subjected to infiltration into groundwater.

Residual weathering mantles, overlying the shale sequence, are a good insulator favouring protection of groundwater. Hence, lithology of the shallow subsurface is the major factor influencing the amount of risk caused by pollution to shallow groundwater, still willingly used by the residents. The contaminated groundwater does not directly affect deeper waters since the shale flysch strata are an efficient insulator protecting artesian and subartesian waters from direct effects of human activity (Małecka, 1980).

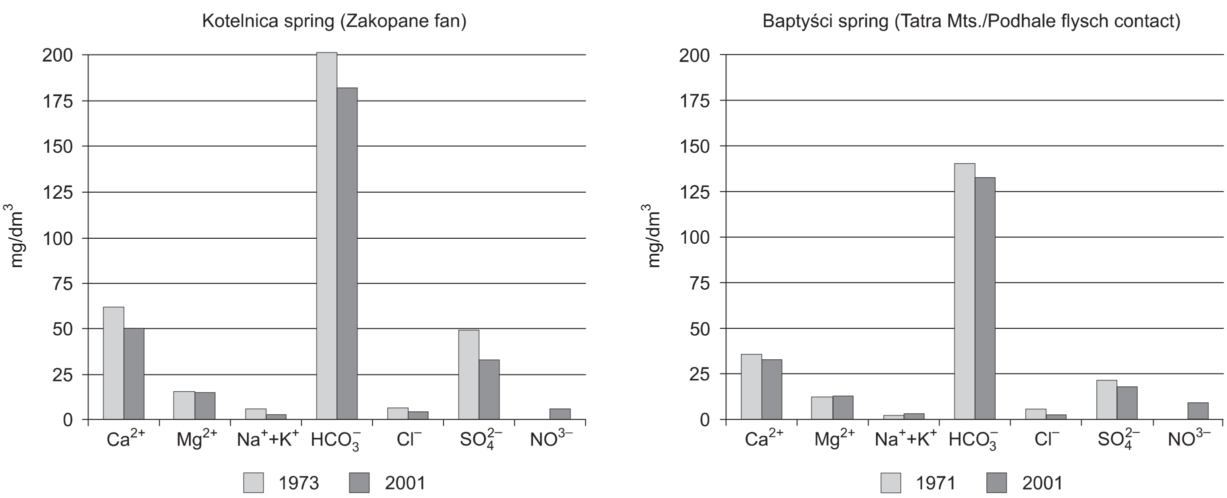

Fig. 6. Comparison of water chemistry from the Kotelnica and Baptyści springs

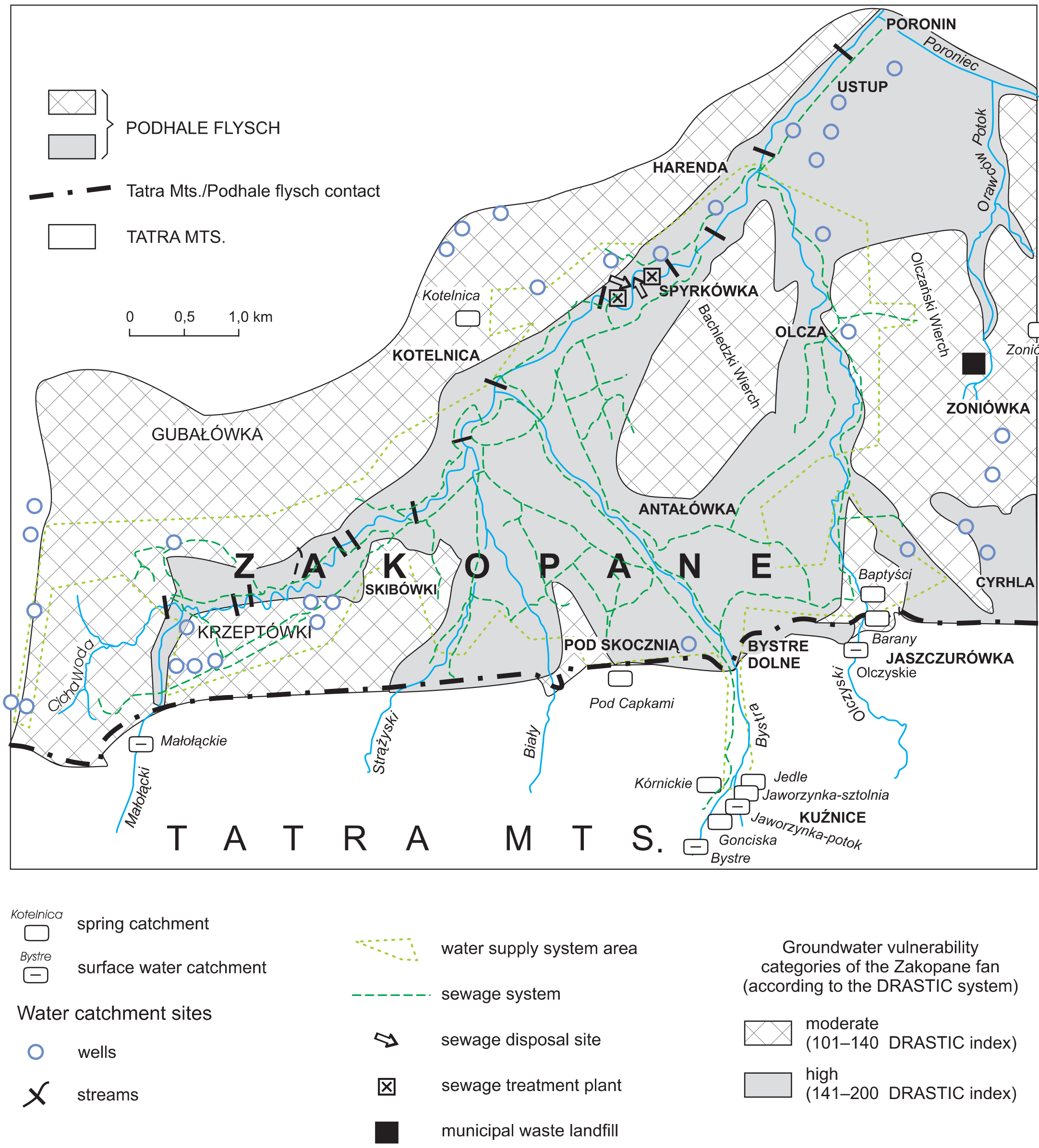

Fig. 7. Location of water sampling sites against the background of the groundwater potential risk

CONCLUSIONS

Despite developing tourism in the Zakopane region, investments in favour of environmental conservation have yielded expected results in terms of improvement of both surface water and ground water quality.

Analysis of percentage contribution of groundwater quality classes, according to the BOD_5 index, performed for the examined section of the Cicha Woda stream, shows a more-than-double increase in contribution of class I water and total reduction of substandard water, as compared with year 1973. The improvement of groundwater quality manifested itself by the increase of bicarbonate content and overall decrease of sulphate and chloride contents. In spring waters the chloride content decreased twice whereas in well waters it decreased as much as six times. An alarming problem is the continuous increase of nitrates content in waters from both hand-dug wells and springs. High nitrate ion content results from the fact that the sewage treatment plant, despite its modernisation, has not resolved the problem of reduction of nitrogen compounds in sewage. Moreover, there is a disproportion between development of water supply system and sewage system. Nevertheless, nitrates are significantly reduced in water through the natural attenuation process. Similar properties are typical of phosphates. Since the groundwater vulnerability is moderate and high, there is a need to endeavour to reduce the effects of potential pollution sources to the minimum level. This is in particular necessary in the case of the municipal waste landfill around which the groundwater is degraded. It would also be favourable to better develop the sewage pipeline system which is now less developed than the water supply system. Contaminated surface waters and shallow groundwater do not pose a risk to deep groundwater since they are separated by impermeable flysch shales.

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