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Impact of water and sewage management in rural areas on the quality of groundwater in lowland agricultural basin

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Abstract

In agriculturally used lowlands areas in Poland contamination of groundwater is one of most significant environmental problems. The paper presents results of analyses of the quality of groundwater in the upper part of the Wilga River basin (a right-hand tributary of Vistula River). The surface area of this part of the basin is 231.6 sq. km. The river basin was chosen for investigation due to a very good representativility for rural areas in the lowlands areas in Poland. The results of analyses of the chemical composition of water, indicate that the quality of groundwater is mostly influenced by farming. The locally very high concentration of nitrogen and phosphorus derived from the point sources such as the leaking settling tanks (or their lack altogether), improper storage of manure, as well as inadequate management of other waste resulting from livestock husbandry.

Key words: groundwater pollution, rural areas, agriculture, Poland

Introduction

In Poland, the most shallow water-bearing structures remain the basic source of water supply for the population living in rural areas. Both the low thickness of the aeration zone and lack of isolation from the surface create favourable conditions for the migration of pollutants to groundwater. As a result, the quality of water in many agricultural catchments does not fulfil the potable water standards. According to the Polish Environmental Protection Inspectorate (IOS), in 2000, waters of the highest quality (class Ia) were identified in 25.8% of the 350 research stations for groundwater. High quality waters (class Ib) accounted for 37.7% of the researched sample, the medium quality waters (class II) – for 22.2%, and the low quality ones (class III) – for 14.3%. The most serious incident of exceeding the adopted standards was observed in groundwater received from dug wells. The shallow Quaternary waters contain – among others – supra-standard quantities of nitrogen compounds ($N–NH_4$, $N–NO_3$, $N–NO_2$) and are characterised by high oxidisability and biological contamination. The low quality of groundwater is primarily due to various forms of agricultural activity. Inadequate breeding practices, fertilisation, use of pesticides, and – first of all – bad sewage management all result in the contamination of groundwater (Kowalik, 2001, *Condition*..., 2001).

Study area

In the years 1999–2000, research was conducted on the impact of agriculture on the quality of groundwater in the upper part of the of the Wilga River basin, a right-hand tributary of the Vistula River (Fig. 1). This is a closed research object, with a gauge profile located in the village of Oziemkówka (A=231.6 km^2) and fulfils all the criteria for a representative basin characteristic for the farming region of the Central Poland Lowlands (Jaworski and Szkutnicki, 1999, Suchożebrski, 2002a).

Denudation plains built of boulder clay and fluvioglacial sands, occasionally covered with dunes, intersected with river valleys dominate the basin's landscape and depressions filled with sandy fluvial and fluvioglacial accumulation deposits.

The basin of the Wilga River is a typical agricultural region. The results of air analysis in Jarczew as well as analyses of the chemical content of water indicate that it is agriculture and rural settlement that exerts the strongest impact on the quality of groundwater in this region (*Estimation*..., 2002). Among chemical substances discharged to the Wilga River basin with precipitation or through the interception of gas migrants from the atmosphere, sulphur and nitrogen compounds play a substantial role, even though their concentration levels and deposition are among the lowest recorded in Poland (*Report*..., 2002). The mineralisation of precipitation normally does not exceed 10 mg/l, which points to a low share of the atmospheric supply of ions in the shaping of the chemical content of groundwater in the Wilga River basin area (Harasimiuk, 1997).

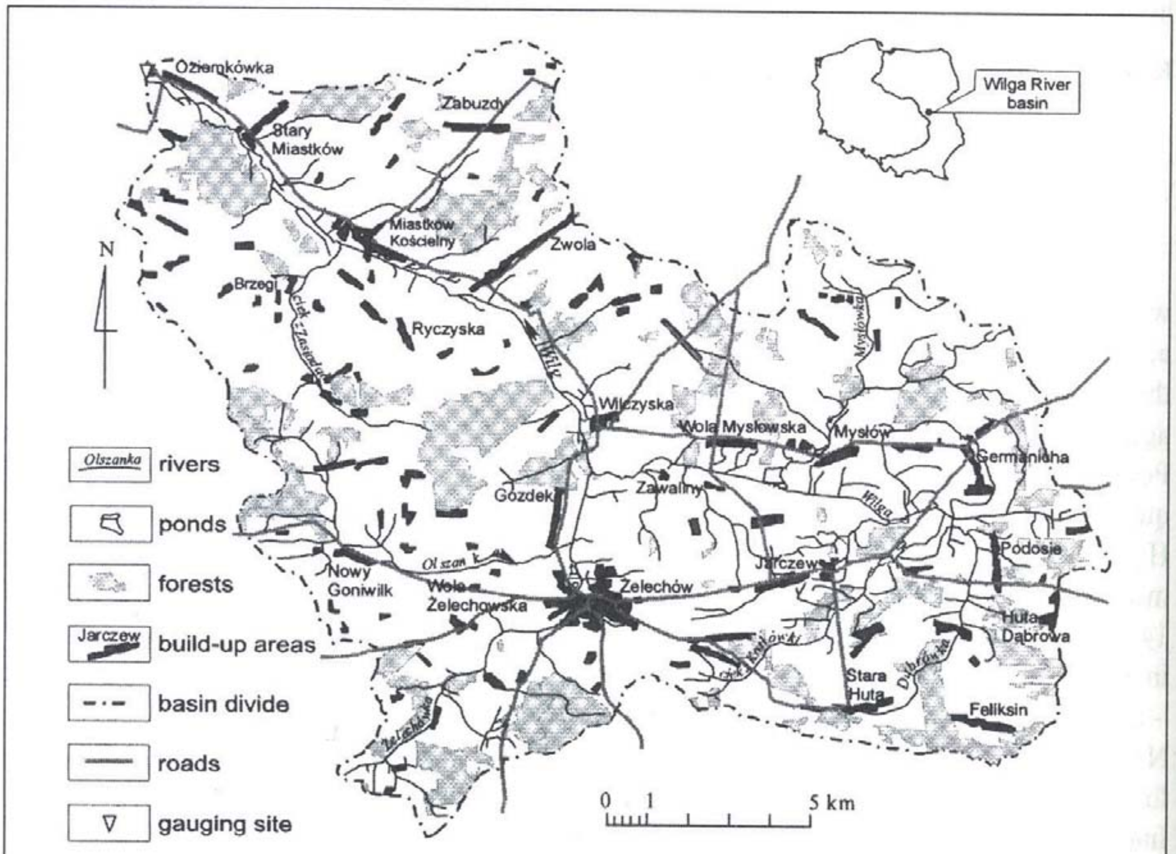

Fig. 1 Location of upper part of the Wilga River basin

In the shallow groundwater in upper part of the Wilga River basin, a high concentration of nitrogen, phosphorus, potassium and sodium is observed locally. According to the research of the Polish Geological Institute, in 1997, at the measuring station in Żelechów (the water table at an average depth of W_G= 7.8 m), exceeded levels of potassium and nitrates concentration were observed. At the same time, groundwater examined in Jarczew (W_G= 3.8 m) was included in the good quality water class (*Information...*, 1998).

Results and discusion

On the days: 28–29 December 1999, 31 March–01 April 2000, 23–24 August 2000, an examination of groundwater was carried out. During the exercise, samples were collected and chemical analysis of groundwater and snow was conducted (Fig. 2); only a selected set of selected groundwater contamination indicators was determined. Using MERCK tests, the content of the following ions was determined: NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}(PMB), Cl^-, in addition to the total hardness and pH reaction of SO_4^{2-} (in some samples). These indicators belong to a group regarded as the most useful in the assessment of groundwater contamination (Macioszczyk and Dobrzyński 2002, Nollet, 2000). During the collection of samples, measurements of the stages of groundwater in farm wells were performed.

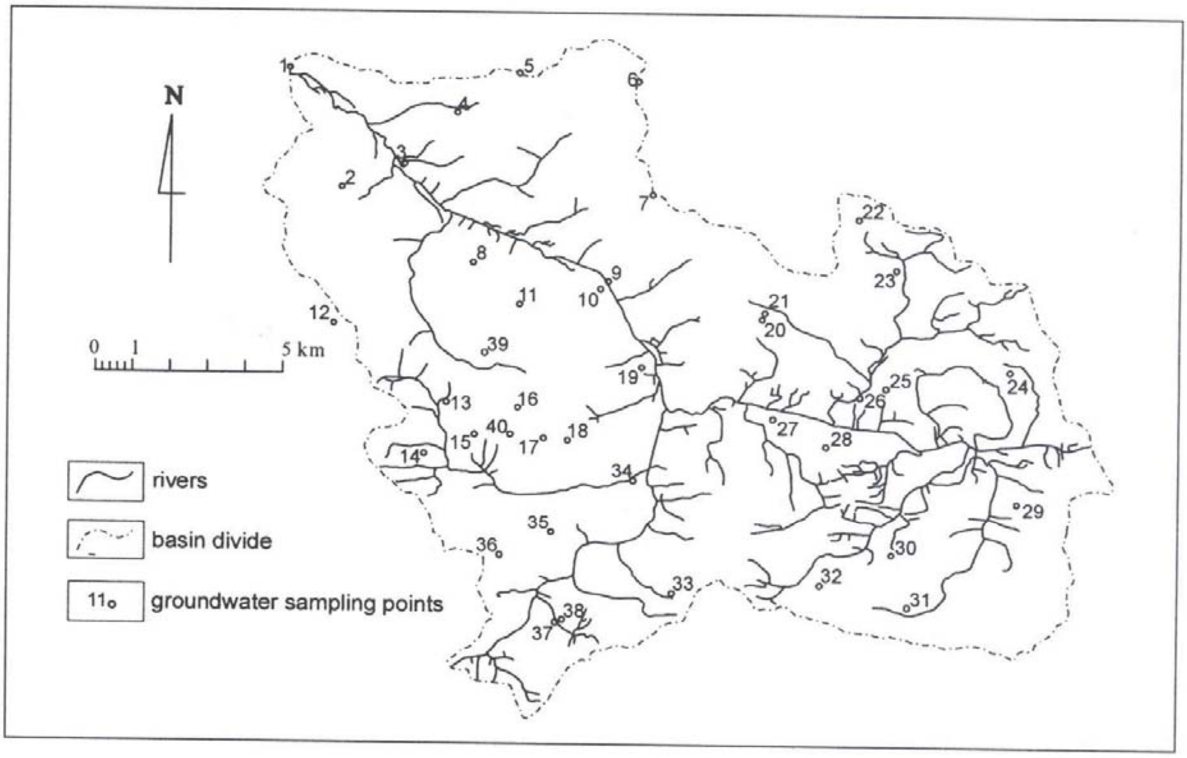

Fig. 2 Location of groundwater quality sampling sites in upper part of the Wilga River basin

Since groundwater alimentation is primarily connected with late-autumn precipitation and the melting of snow cover, the two series of tests were conducted in those two seasons. The tests conducted in winter (21 samples of groundwater and 2 samples of snow) were made in a period of thaw, preceded by a period of heavy snowfall. The melting of snow cover with the frozen ground led to both infiltration and surface runoff. In the samples of snow collected near the measurement points no. 12 (Łąki) and 29 (Stara Huta), pH<5 was determined; similarly low acidification values (pH 3.4–3.9) were revealed by Harasimiuk (1997).

The second series of tests (12 water samples) was conducted at the turn of March and April, following the spring thawing. It was a period of very high groundwater stages. In many farm wells, the groundwater table was near the very surface. In such periods, penetration of pollutants, also from overflowing cesspools and septic tanks, is considerably facilitated.

Subsequent tests were performed in August 2000, when chemical analysis of water samples from 29 wells was conducted.

In winter, in measurement points nos.: 1, 3, 19 and 35, concentration in excess of 3 mg PO_4^{3-}/l was revealed, and in points nos. 8 and 11–3 mg PO_4^{3-}/l (Fig. 3). Similar findings were obtained in spring and summer (points: 1, 3, 19, 35). These wells are mainly located in areas with favourable or very favourable conditions for the migration of pollutants to groundwater or in their direct vicinity (Fig. 2) (Suchożebrski, 2002a, b). Well no. 11, situated in an area with unfavourable conditions for the migration of pollutants to groundwater, was an exception. In winter, supra-standard concentration of ammonium (5 mg NH_4^+/l = 3.88 mg N–NH_4/l) and increased concentration of nitrite (1 mg NO_2^-/l = 0.3 mg N–NO_2/l) was revealed there (Fig. 4 and 5). Taking into account the low concentration of nitrate, this testifies to a recent anthropogenic contamination of water with organic substances; it also plausibly explains the high PO_4^{3-} content in groundwater. In spring, only exceeded NO_3^- levels was observed, while in summer no case of exceeding the permissible level of the selected contamination indicators was discovered. This testifies to the process of self-purification of groundwater.

In measurement point no. 35, representing areas with average conditions of pollutant migration to groundwater, concentration levels substantially exceeding 3 mg PO_4^{3-}/l were revealed (Suchożebrski, 2002a). In December 1999 and August 2000, the potable water standards for NO_3^- were also exceeded.

In summer, additional measurements of the quality of groundwater in the Wilga valley were performed (points nos.: 25, 26, 27, 28). These areas are characterised by very favourable conditions for the migration of pollutants to groundwater, which is mainly due to the relatively low thickness of the aeration zone and high permeability of soil. In measurement point no. 25, high nitrate content was observed (>3 mg PO_4^{3-}/l), while the values in the vicinity were much lower (1–1.5 mg PO_4^{3-}/l). In addition, in the same periods chemical analysis of groundwater in well no. 27 was carried out. In April, the ammonium concentration (2 mg NH_4^+/l = 1.55 mg N–NH_4/l) and the nitrite (0.25 mg NO_2^-/l = 0.08 mg N–NO_2^-/l) were higher than the permissible concentration values, which was a result of the penetration of organic pollutants from the farm in very favourable migration conditions, that is, a very high stage of groundwater (0.25 m). In August, only the values for nitrite concentration were higher than permitted (100 mg NO_3^-/l = 22.59 mg N–NO_3^-/l).

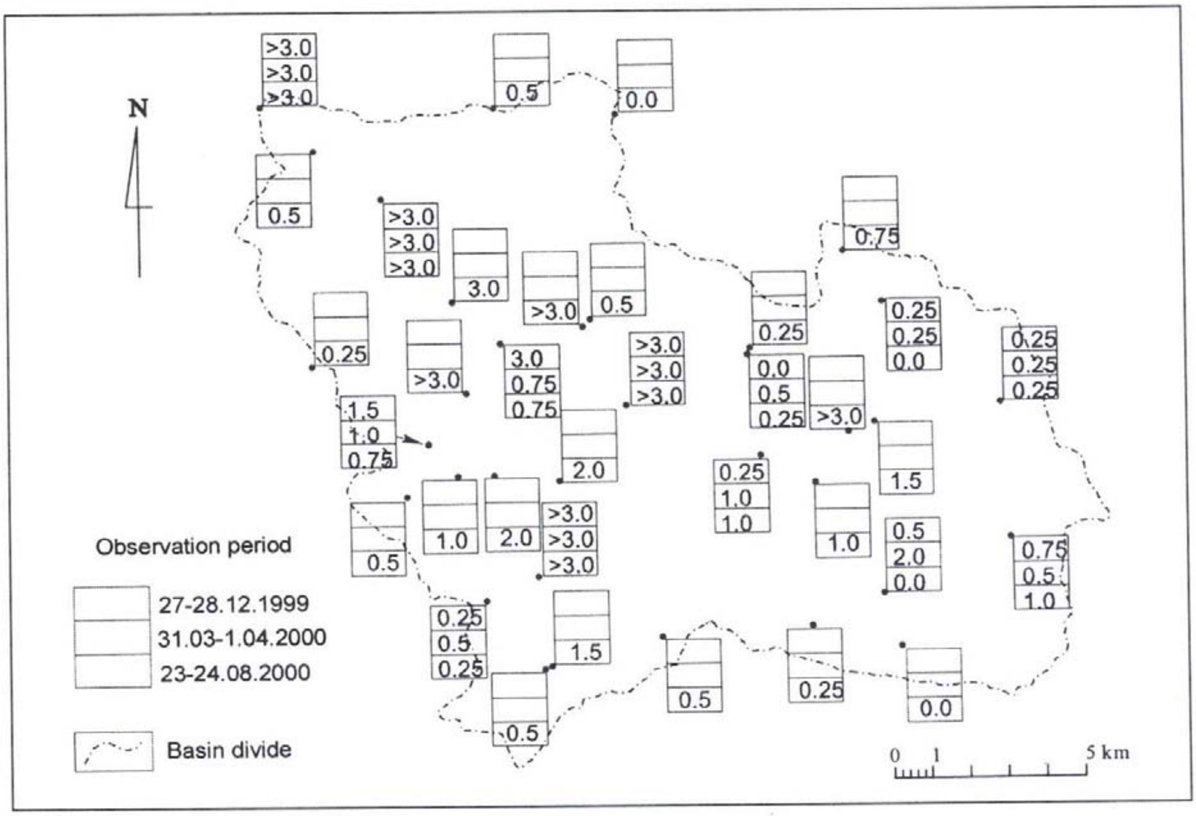

Fig. 3 Phosphates concentrations in groundwater in the Wilga River basin [mg/l]

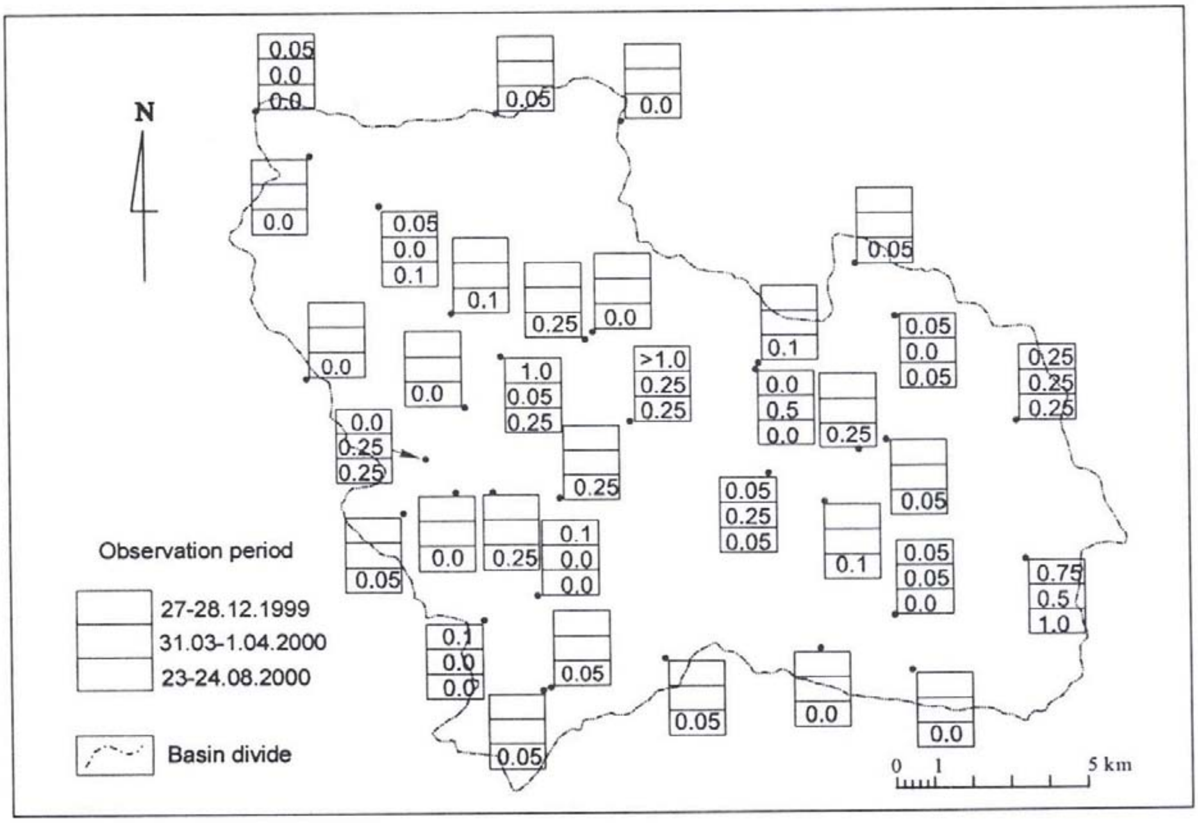

Fig. 4 Nitrite concentrations in groundwater in the Wilga River basin [mg/l]

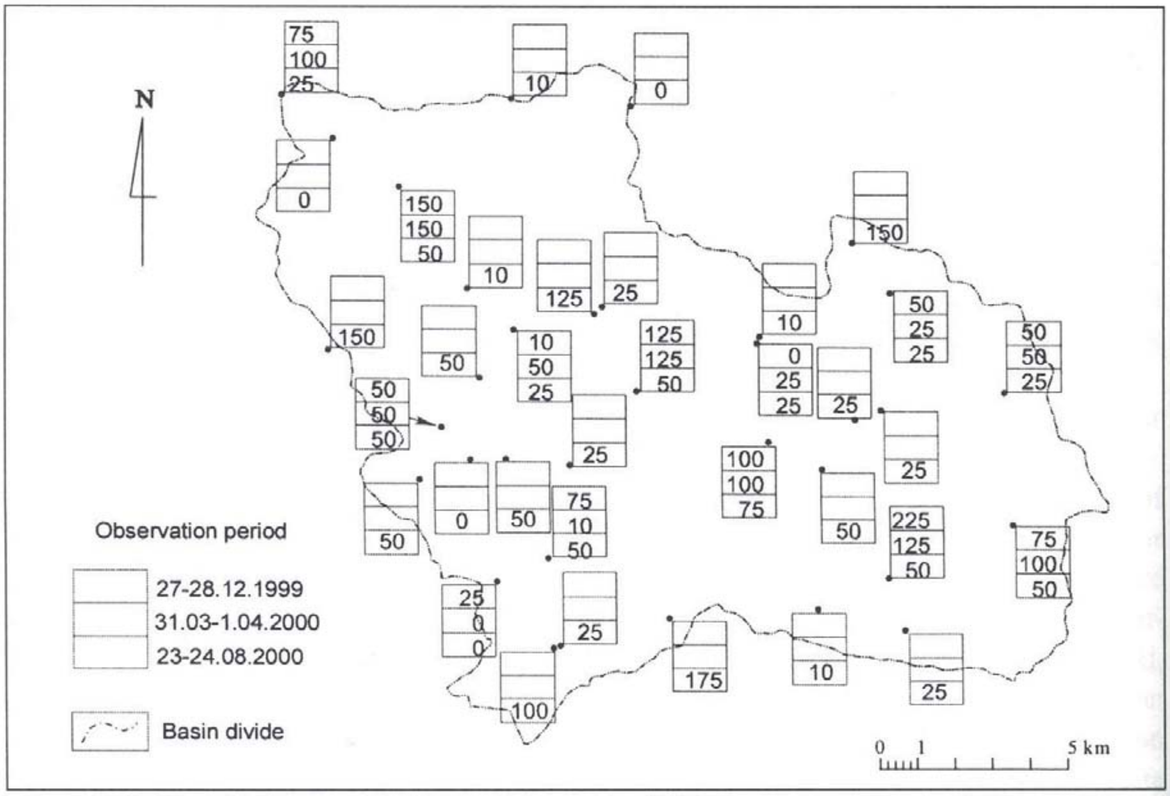

Fig. 5 Nitrate concentrations in groundwater in the Wilga River basin [mg/l]

Chemical analysis points to a considerable contamination of groundwater with nitrates in many locations in the basin. During the winter tests, supra-standard content of NO_3^- ion was revealed in 15 of 21 groundwater samples, with nearly all samples (with the exception of point 8) representing areas manifesting favourable conditions for the migration of pollutants to groundwater. The tests were conducted during a thaw, which caused the infiltration of retained water in the snow cover. Thaw water with an acid reaction (pH<5 near measurement points nos. 12 and 29) could cause the discharge of substances retained in the soil. This might one of the reasons explaining high NO_3 concentration in shallow groundwater.

The infiltration of thaw water could cause the movement of chemical compounds from the soil to groundwater. High groundwater stages could also facilitate easier washing out of pollutants from the leaking and overflowing cesspools and septic tanks. In 7 of the 12 collected samples, concentration levels in excess of 10 mg $N–NO_3^-$/l (44.27 mg NO_3/l) were revealed. Typically, the concentration of this ion was lower than in the winter period.

In the vegetation period, some of the nitrogen compounds are utilised by plants. In the warm season, their denitrification takes less time – hence the lower number of the water samples (13 of 29), where supra-standard concentration of NO_3^- was recorded in summer. In the majority of samples collected in points located in areas with favourable conditions for the migration of pollutants to groundwater (areas with low inclination, in agricultural use, characterised by a shallow aeration zone built of easily permeable deposits), supra-standard NO_3^-concentration was recorded, with the exception of measurement wells nos. 25 and 26. Well no. 26 was located on the slopes of the Mysłówka valley, at a little distance (about 500 metres) from well no. 25 and about 2.5 to 3 metres higher. It is characterised by a much lower concentration of phosphate and chlorides, and a higher concentration of nitrites and nitrates in the water. This point represents the areas with average conditions for the migration of pollutants to groundwater (higher thickness of the aeration zones built of not so permeable deposits, higher inclination gradients).

Chemical analysis of 5 water samples, of the 6 collected in farm wells located in areas characterised unfavourable conditions for the migration of pollutants, revealed a low nitrate content. In one measurement point (no. 18), supra-standard NO_3^- content was recorded, accompanied by increased concentration of NO_2^-, PO_4^{2-} and Cl^-. The low depth of the aeration zones made the infiltration of pollutants from the farm easier. In point 17, representing similar migration conditions and situated several hundred metres away (albeit in a different partial basin), the water corresponded to the standards. In point 32, situated in an unfavourable area for the migration of pollutants to the groundwater, chemical analysis showed a very low concentration of phosphates (0.25 mg PO_4^{3-}l), chlorides (2 mg Cl^-/l) and nitrates (10 mg NO_3^-/l); no trace of ammonia or nitrites was found in the water.

As a rule, the concentration levels of chlorides in the groundwater samples were low (Fig. 6). Only in 3 samples collected in winter, 1 sample collected in spring and 2 samples collected in summer, they exceeded 100 mg Cl^-/l. Values in excess of 300 mg Cl^-/l were recorded in winter in measurement point no. 20 located in the village of Wólka Ciechomska, although the concentration of chlorides was much lower in spring and in summer.

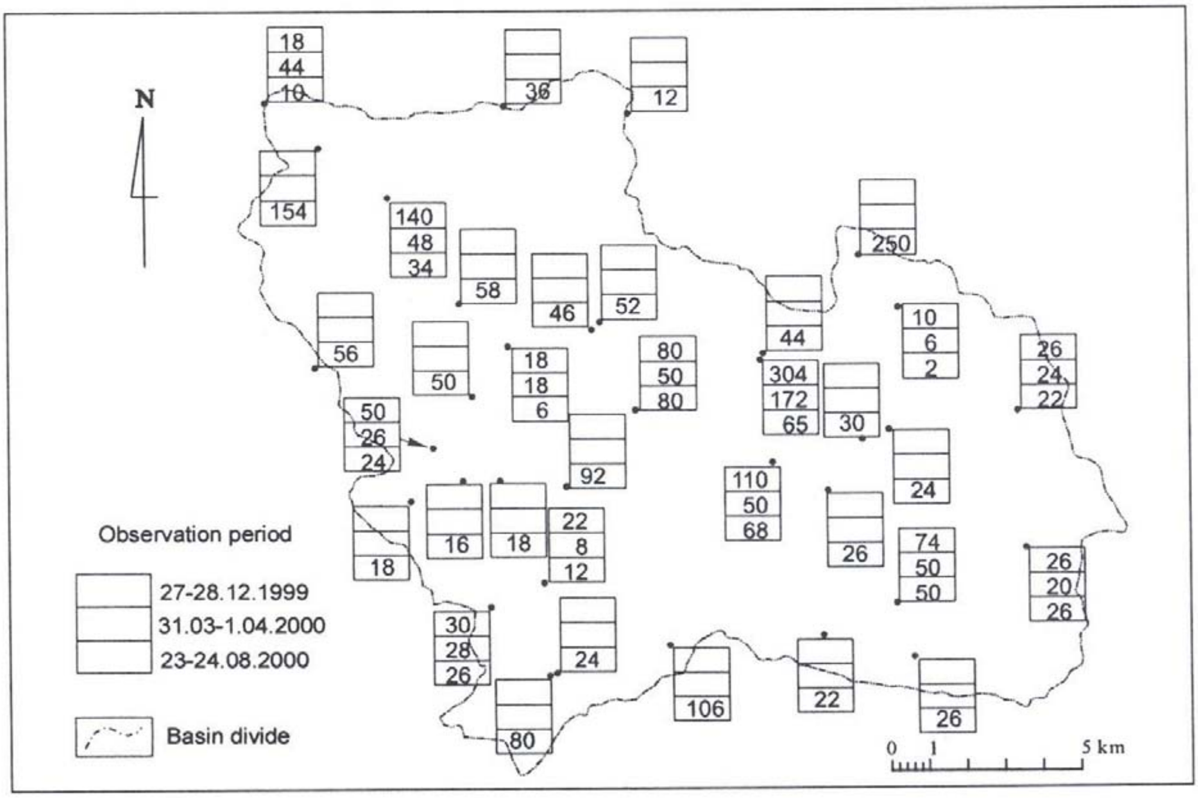

Fig. 6 Chloride concentrations in groundwater in the Wilga River basin [mg/l]

The sulphur ion SO_4^{2-} is the basic indicator used for the assessment of migration of pollutants to groundwater (Farmer, Graham, 1999; Macioszczyk, Dobrzyński, 2002). The concentration of sulphates in groundwater exceeded the margin value for potable water only in 1 sample collected in spring. In measurement point no. 7, situated in the village of Zwola, 300 mg SO_4^{2-}/l of water were revealed. However, the concentration level of this ion in groundwater is higher in winter, which is probably due to the oxidisation of sulphur released by man into the geochemical circulation during the fuel combustion process in the cold time of the year.

Conclusions

The results of chemical analyses indicate that the groundwater in the researched area is in many places contaminated with organic substances. Frequently this is permanent organic contamination of a local character (point contamination), probably a consequence of leaky septic tanks (or their lack), improper organic manure deposition and storage of faecal and farm sewage. With an insufficient number of water mains in this area, the local population uses farm wells for tapping groundwater. We encounter similar problems in many agricultural catchments in Poland. It is primarily point contamination sources from built-up areas that are responsible for the contamination of groundwater. Unfortunately, in many cases the development of the water network in villages is not accompanied by the extension of their sewage systems. Easier access to water leads to its increased consumption, and therefore to increased production and discharge of larger quantities of wastewater. Some wastewater and liquid manure from farms is utilised as a natural fertiliser and spilt in the fields. In this way, area sources of underground water contamination are formed, which leads to further deterioration of the quality of groundwater.

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