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# THE RISK OF CONTAMINATION OF THE FIRST AQUIFER IN THE CENTRAL PART OF THE ŚWIĘTOKRZYSKIE VOIVODSHIP (MHP-814 PIEKOSZÓW)

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**ABSTRACT**

The purpose of this study is to assess the local variation in the first aquifer's intrinsic vulnerability to pollution and identify potential sources of pollution that can affect groundwater quality. The analysis included 29 representative groundwater intakes from the map sheet MHP-814 Piekoszów (Świętokrzyskie Voivodship). A map was created with the marked intakes, the degree of their intrinsic vulnerability to pollution and existing hazards. Intakes potentially threatened by anthropogenic pollution were indicated. The compiled study has an informative function and can be used to make land use maps in municipalities, design protection zones, and create scenarios of threats to the groundwater intakes from specific pollution.

**Keywords:** groundwater intake, well, first aquifer, pollution, hazard, MHP-814

## INTRODUCTION

Groundwater should be protected from anthropogenic contamination, as it serves as the primary source of providing the population with water suitable for drinking (Krogulec, Gurwin & Wąsik 2021; Woźnicka, Przytuła & Palak-Mazur, 2021). Legal protection under the Polish Water Law (Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 14 października 2021 r. w sprawie ogłoszenia jednolitego tekstu ustawy – Prawo wodne) includes both the resources (quantity) and the chemical composition of groundwater. To ensure adequate water quality and protect their resources, protected areas are established for groundwater reservoirs and protection zones for water intakes. There is also an obligation to carry out agricultural production in a way that prevents the pollution of the waters with nitrogen compounds from agricultural sources (Department for Environment, Food and Rural Affairs [Defra], 2009). In addition, groundwater quality monitoring is carried out to report on the chemical status of groundwater, track its changes, and inform about risks on a national scale. According to the Water Law, monitoring is necessary to manage groundwater resources and assess the effectiveness of protective measures taken.

To plan appropriate actions for the protection of groundwater intakes, it is necessary to know the intrinsic vulnerability of the groundwater to contamination (Al-Mallah & Al-Qurnawi, 2018; Steiakakis, Vavadakis & Mourkakou, 2023). The intrinsic vulnerability determines the risk of migration of conservative contaminants from the ground surface to the first aquifer. Conservative contaminants do not undergo ion exchange processes with the soil–water environment or

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do not undergo biodegradation. Intrinsic vulnerability is related to the geological structure, the hydrogeological parameters and the aquifer recharge conditions of the aquifer. Recharge conditions depend on the aeration zone's thickness and the soil types through which contaminants migrate vertically from the land surface to the aquifer (Duda, Witczak & Żurek, 2011). Vulnerability classes were created based on the mean residence time (MRT), which is related to the exchange of water in the profile of the aeration zone during the natural hydrological cycle, assuming a multi-year average infiltration of annual precipitation (Duda et al., 2011). There are five vulnerability classes depending on the estimated seepage time ($t_a$) in years: A1 – aquifer at very high risk $t_a < 2$; A2 – aquifer at high risk $t_a <$ 2−5 >; B – aquifer at medium risk $t_a <$ 5−25 >; C – aquifer at low risk $t_a <$ 25−100 >; D – aquifer practically not at risk $t_a > 100$.

According to the described methodology, a map of the intrinsic vulnerability to contamination has been created for Poland. Duda et al. (2011) prepared a map for assessing shallow groundwater of the first aquifer from the land surface (water table < 2 m) and a map for assessing the vulnerability of the major underground water reservoirs (abbreviation in Polish GZWP). The maps were made on an overview scale of 1:500 000 and are illustrative and strategic on the national scale. Available maps via GeoLOG application in the Central Geological Database (geolog.pgi.gov.pl), curated by the Polish Geological Institute − National Research (Institute Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy [PIG-PIB], 2023a), first aquifer sensitivity and quality at a scale of 1:50 000 are based on different methodological assumptions, other source materials and different data preparation technology. Therefore, the local differences between the maps can be large. In the literature, there is a lack of work that considers the potential risk of contamination of individual groundwater intakes from existing sources of pollution. Duda et al. (2011) indicate the need to make them. Such studies would be useful for mapping land use planning, environmental protection and municipal water planning – including the establishment of protection zones for groundwater intakes. Identified intrinsic vulnerabilities of shallow groundwater to pollution can be used to create risk scenarios from specific contaminants, such as heavy metals. These, in turn, are subject to ion exchange processes in soils (Nartowska, Kozłowski & Kolankowska, 2017), which often lead to changes in soil properties (Nartowska, 2019) and weak protective barriers in landfills. It is important to note that the maps and overview scale do not take into account the potential hazards present on the surface of the land and therefore do not present a complete assessment of the risk of groundwater contamination (Liggett, Lapcevic & Miller, 2011). Potential sources of groundwater contamination include, but are not limited to, landfills (Koda et al., 2023; Podlasek, Vaverková, Koda, Jakimiuk & Martínez Barroso, 2023), agricultural land (Zhang, Qin, An & Huang, 2022), petrol stations (Bai et al., 2019) and industrial plants (Jain, Thakur, Garg & Devi, 2021).

Therefore, presented here is a study in which (i) the intrinsic vulnerability of the first aquifer to contamination was determined at 29 local deep wells within the hydrological map sheet of MHP-814 Piekoszów, Świętokrzyskie Voivodship; (ii) the radius of the water runoff area to each well intake has been calculated; (iii) hazards to groundwater intakes were identified.

## MATERIAL AND METHODS

### Characteristics of the study area

*Location*

Sheet MHP-814 covers parts of the municipalities of Łopuszno, Strawczyn, Piekoszów, Mniów, Małogoszcz Sitkówka – Nowiny, Chęciny, Radoszyce, and Miedziana Góra. The sheet area is bounded by coordinates 20°15'00" and 20°30'00" of east longitude and 50°50'00" and 51°00'00" of north latitude (Fig. 1). The area is a fragment of the Małopolska Highlands. In hydrographic terms, it is located in the river basin of the Nida, and its small fragments in the catchment areas of the Kamienna and Pilica rivers.

*Hydrogeological conditions*

Figure 2 shows the depth cartography of the study area. The disposable resources of this area are 347 $m^3$ per 24 h. The Triassic ($T_1$, $T_2$), Devonian ($D_2$), Permian ($P_3$) and Jurassic ($J_3$) horizons have the highest


**Fig. 1.** Topographic map of the study area

Source: PIG-PIB (2023a).

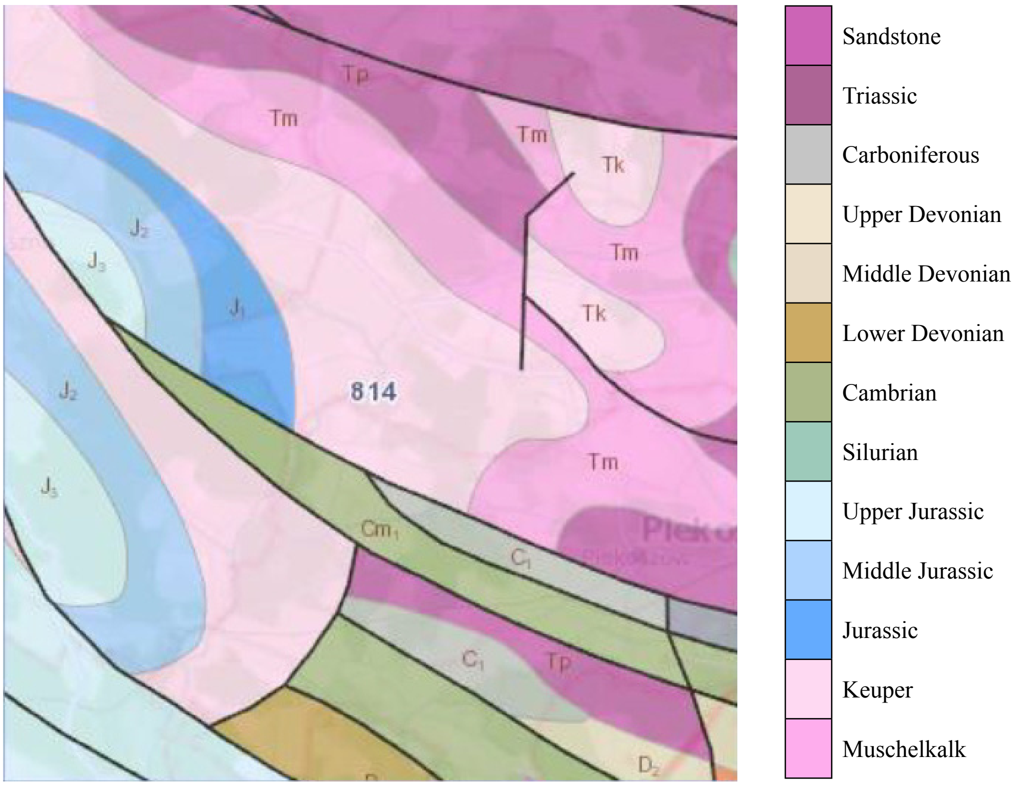



**Fig. 2.** Cartography of the depth of the study area (MHP-814)

Source: PIG-PIB (2023a).

groundwater potential (Table 1). The remaining 40% of the area is without prospective usable horizons (Prażak, 1997).

Within the sheet, three major underground water reservoirs are identified that require special protection: GZWP 414 Zagnańsk, GZWP 416 Małogoszcz and GZWP 417 Kielce (Fig. 3; Prażak, 1997).

In the area of sheet MHP-814, there is good quality. However, as a result of poor isolation between the surface layers of the ground and the aquifer, anthropogenic water contamination occurs in places and must be treated. Within Ruda Strawczyńska, there are increased indices of manganese and iron and – occasionally – nitrogen compounds, which are of a short nature (Prażak, 1997).

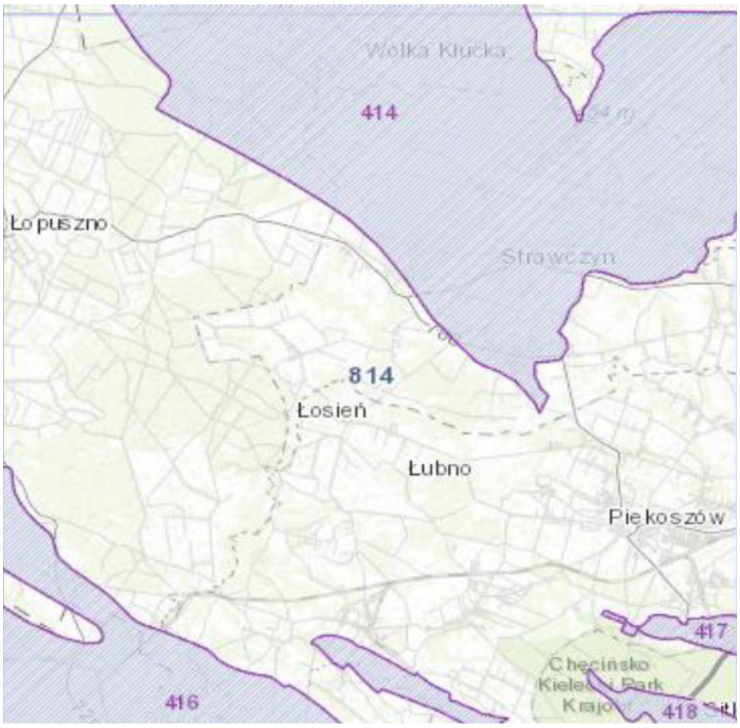
## Methodology

The concentration of industrial activity in an area, including intensive groundwater exploitation and adverse hydrogeological conditions, are the main fac-

**Table 1.** Characterisation of aquifers of high utility significance, within sheet MHP-814

| Stratigraphy/Lithology | | Depth to aquifer [m] | Aquifer thickness [m] | Aquifer | Filtration coefficient [$m \cdot h^{-1}$] |
|---|---|---|---|---|---|
| $T_2$ | sandstones marls | 5−20 | 10−100 | unconfined | 0.003−0.36 |
| $T_1$ | sandstones marls conglomerates | 5−20 | 10−150 | unconfined/confined | 0.003−0.36 |
| $D_2$ | limestones dolomites | 5−30 | 10−150 | unconfined | 0.003−3.6 |
| $P_3$ | sandstones marls conglomerates | 5−15 | 10−150 | confined | 0.003−3.6 |
| $J_3$ | limestones, marls | 5−30 | 10−150 | unconfined | 0.003−0.36 |

Source: own elaboration based on PIG-PIB (2023b).




GZWP 414
$T_1$, $T_2$ fractured-pore reservoir

GZWP 416
$J_3$ karstic fissure reservoir

GZWP 417
$D_2$, $D_3$ karstic fissure reservoir

**Fig. 3.** The major underground water reservoirs (abbreviation in Polish GZWP) that require special protection within sheet MHP-814 Piekoszów

Source: PIG-PIB (2023a).

tors that affect the threat to groundwater quality. It is possible to assess the potential threat that arises from the geological and hydrogeological structure of the site and the current threat that additionally arises from existing sources of pollution. The potential threat is determined by the vertical seepage of contaminants from the surface of the land into the aquifer (Krogulec, 2004; Krogulec & Trzeciak, 2017; Krogulec, Sawicka & Zabłocki, 2019). The method of assessing the intrinsic vulnerability of groundwater to contamination based on determining the migration time of conservative contaminants from the land surface to the aquifer is the method most commonly used in engineering practice alongside rank methods (Kondratiuk, 2013).

The MRT or the water exchange time ($t_a$) was calculated using the following formula (Witczak & Żurek, 1994; Duda et al., 2011).

$$t_a = \sum_1^n \frac{m_{ai} \cdot w_{0i}}{R}, \tag{1}$$

where:

$m_{ai}$ – thickness of the vadose zone calculated for each layer of soil ($i$) [m],

$w_{0i}$ – average volumetric water content of the strata in the vadose zone calculated for each layer of soil ($i$) [-],

$R$ – mean annual recharge [mm] expressed as

$$R = P \cdot \omega_i, \tag{2}$$

where:

$P$ – mean annual precipitation (700 mm in 1991––2020 was assumed) [mm],

$\omega_i$ – effective infiltration coefficient [-].

According to Macioszczyk (1999), the method proposed by Witczak and Żurek (1994) probably gives overestimated values for vertical seepage time. The reason may be that the formulas were verified by observations of the rate of transfer of chemical indicators, and this process is inherently slower due to the known phenomenon of 'lag'. However, the same author points out that the results were discussed in the Hydrogeology Committee of the Committee of Geological Sciences of the Polish Academy of Sciences, which appreciated the validity and the need to use the Witczak and Żurek (1994) formula for estimating the seepage time of conservative substances. The commission concluded that using the formula is useful, and sometimes even necessary, when organising the development of protective areas.

To assess the risk of threats from existing sources of pollution, the radius of the water runoff (abbreviation in Polish OSW) was calculated for each groundwater intake. The Sauta formula was used, which assumes radial inflow (Łońska, 2012):

$$r = 2.764 \cdot \sqrt{\frac{Q \cdot t}{m \cdot n_e}}, \tag{3}$$

where:

$Q$ – well capacity [$m^3 \cdot h^{-1}$],

$t$ – 9,130 [days] ≈ isochrone 25 [year],

$m$ – thickness of the aquifer [m],

$n_e$ – effective porosity (according to the graph of the relationship $k$ to $n_e$ in the publication by Pazdro, 2013, p. 110).

Identification of potential threats to groundwater intake was based on archival materials and the Central Geological Database (geolog.pgi.gov.pl), with its own verification. Agricultural land was also included in the study. The data on agricultural land was obtained from the land and building registry available in the Geoportal database (geoportal.gov.pl), curated by the Head Office of Geodesy and Cartography (Główny Urząd Geodezji i Kartografii [GUGiK], 2023).

## RESULTS AND DISCUSSION

Table 2 and Figure 4 summarise the results for 29 local deep wells. Table 2 shows, but is not limited to, the intrinsic susceptibility of the first aquifer to contamination, the susceptibility class rating, and the radius of the water runoff to each well intake. In Figure 5, map was created with the location of the intakes and the existing sources of contamination.

Based on the analysis of the results in Table 2, Figures 4 and 5, the current risks for each well intake are presented. The results were included in Table 2 ('hazard' column). The hazard assessment

**Table 2.** Hydrogeological characteristics and assessment of hazards to groundwater intakes

| No[1] | SHEET MHP-814 PIEKOSZÓW | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | No of well[2] | Location | PPW[3] [m] | $t_a$[4] [year] | Calculated risk class[5] | $Q$[6] [$m^3 \cdot h^{-1}$] | osw[7] [m] | Hazards[8] |
| 1 | 8140002 | Promnik | 11.5 | 1.72 | A1 | 8 | 185.8 | petrol station |
| 2 | 8140003 | Oblęgorek | 23.2 | 4.76 | A2 | 16 | 370.9 | |
| 3 | 8140004 | Łopuszno | 7.8 | 1.72 | A1 | 0.1 | 42.7 | petrol station, sewage plant |
| 4 | 8140005 | Oblęgorek | 11.7 | 2.65 | A2 | 2.4 | 151.3 | |
| 5 | 8140010 | Piekoszów | 46 | 0.08 | A1 | 96.6 | 801.1 | industry: meat |
| 6 | 8140011 | Jaworznia | 36.4 | 0.42 | A1 | 5.4 | 197.3 | industry: limestone powder |
| 7 | 8140020 | Gnieździska | 6 | 1.51 | A1 | 0.1 | 65.3 | farmland! |
| 8 | 8140023 | Snochowice | 13 | 0.11 | A1 | 0.1 | 36.8 | |
| 9 | 8140027 | Cierchy | 47 | 1 | A1 | 96.6 | 763.8 | |
| 10 | 8140028 | Strawczyn | 19.3 | 3.31 | A2 | 2.2 | 131.9 | |
| 11 | 8140036 | Piekoszów | 15.6 | 7.98 | B | 181.5 | 676.1 | garden farm ‘Zajączków’! |
| 12 | 8140038 | Strawczyn | 9.6 | 2.85 | A2 | 83.7 | 567.2 | |
| 13 | 8140040 | Gnieździska | 25 | 0.98 | A1 | 2.4 | 191.8 | farmland! |
| 14 | 8140041 | Piekoszów | 86 | 120.9 | D | 153 | 1 111.4 | |
| 15 | 8140042 | Micigózd | 22.3 | 0.23 | A1 | 3.1 | 301 | industry: meat |
| 16 | 8140044 | Oblęgorek | 31.5 | 37.28 | C | 1.2 | 181.7 | |
| 17 | 8140046 | Skoki | 42 | 12.52 | B | 5.1 | 321.6 | |
| 18 | 8140050 | Wesoła | 7 | 1.9 | A1 | 6 | 239.3 | farmland! |
| 19 | 8140051 | Jaworznia | 29.5 | 6.45 | B | 3 | 183.7 | |
| 20 | 8140052 | Piaski | 56 | 75.66 | C | 5.4 | 256.2 | |
| 21 | 8140053 | Gnieździska | 10.5 | 0.34 | A1 | 54.7 | 327.1 | |
| 22 | 8140056 | Rykoszyn | 0.9 | 0.16 | A1 | 4.7 | 242.2 | |
| 23 | 8140057 | Gnieździska | 17.2 | 0.93 | A1 | 234.4 | 1 308.6 | |
| 24 | 8140059 | Rykoszyn | 22 | 21.02 | B | 2 | 217.1 | |
| 25 | 8140064 | Wielebnów | 29.2 | 1.61 | A1 | 33.8 | 496.9 | |
| 26 | 8140066 | Laskowa | 0.4 | 1.59 | A1 | 2.3 | 207 | industry: meat, petrol station |
| 27 | 8140067 | Ruda Str. | 45 | 5.33 | B | 26.3 | 204 | |
| 28 | 8140069 | Laskowa | 71.5 | 0.07 | A1 | 73.3 | 422.3 | industry: meat, petrol station |
| 29 | 8140071 | Zawada | 28 | 9.13 | B | 12.5 | 183 | |

[1]Cardinal numbers.

[2]Number according to the database of the Polish Geological Institute – National Research Institute (geolog.pgi.gov.pl).

[3]Depth to the first aquifer (abbreviation in Polish PPW).

[4]Average water migration time from the ground surface to the first aquifer in years according to Eq. (1).

[5]A1 – $t_a < 2$; A2 – $t_a$ < 2–5 >; B – $t_a$ < 5–25 >; C – $t_a$ < 25–100 >; D – $t_a > 100$ years (Duda et al., 2011).

[6]Capacity of wells.

[7]Radius of the water runoff area according to Eq. (3).

[8]Potential hazards to groundwater intakes.

Source: own work.

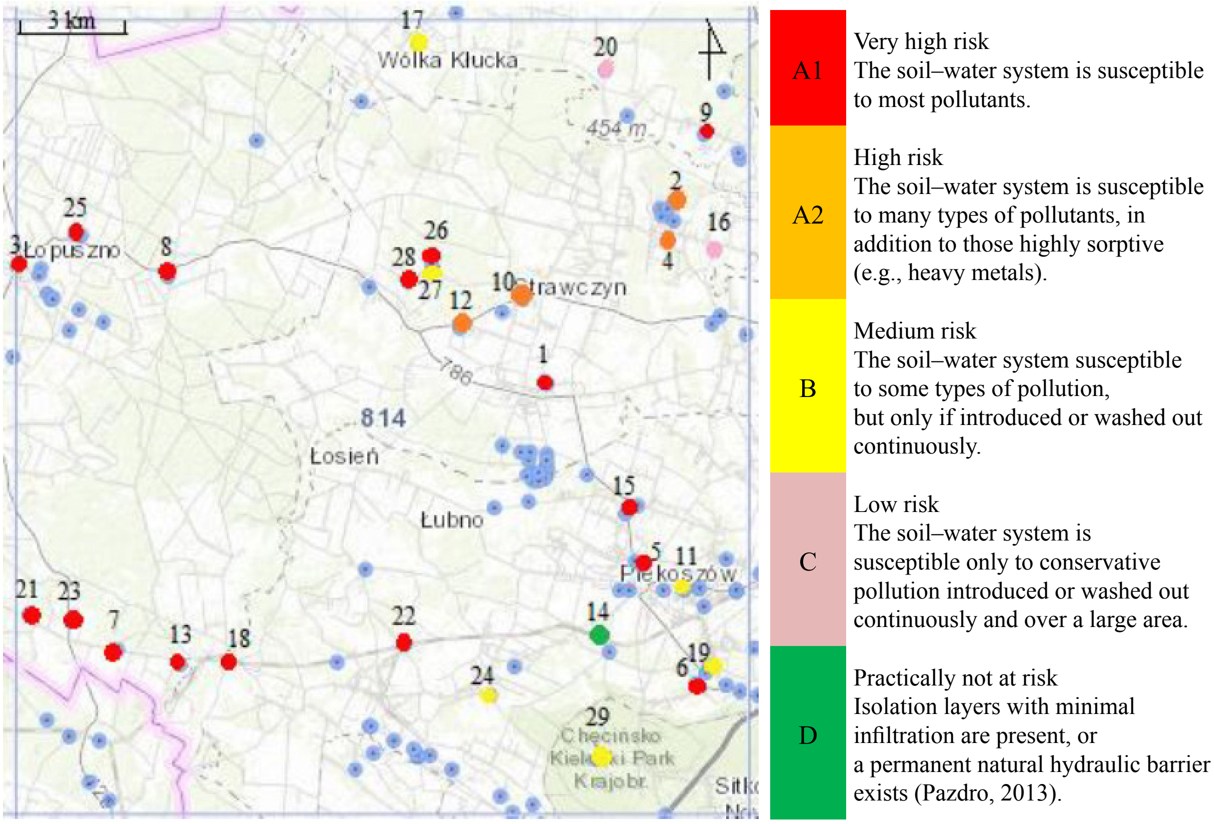



**Fig. 4.** Location of groundwater intakes with assigned vulnerability class. Nos 1–29 are consistent with the intake numbers in Table 2

Source: own elaboration based on PIG-PIB (2023a).

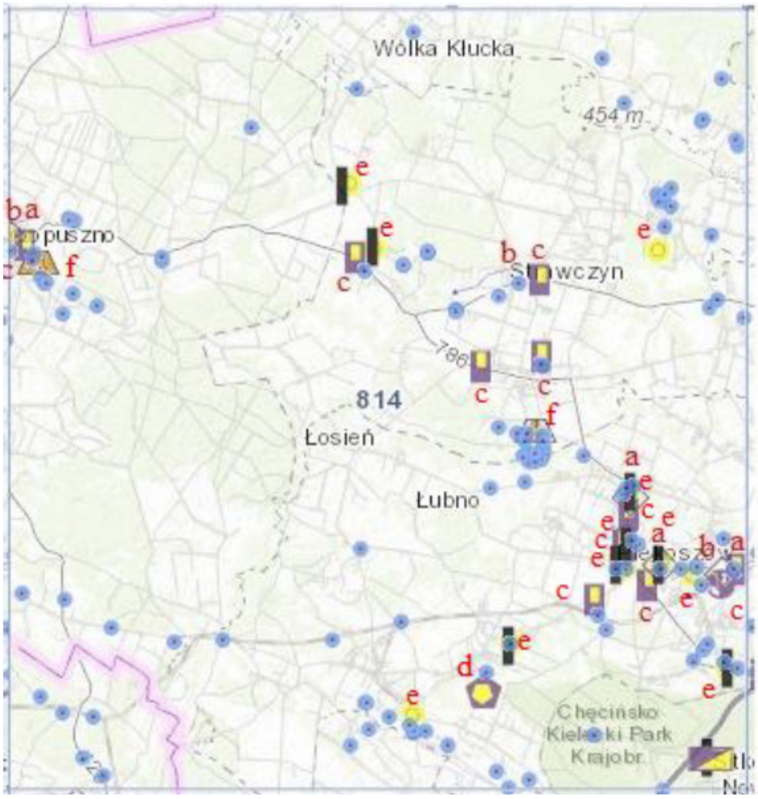
considered the class of vulnerability of the aquifer to contamination, the radius of the water runoff area to the intake and the distance from potential pollution sources.

Within MHP-814 Piekoszów map sheet, the occurrence of agricultural land was identified within the runoff of water to intakes Nos 8140057, 8140020 and 8140050. The well intakes are very highly at risk ($A_1$). In these areas, more detailed studies are required to establish or change the extent of protection zones.

The threatened area also includes intake No 8140036, and the radius of water runoff to the intake includes the nearby horticultural farm ‘Zajączków’. The intake is classified as moderately at risk. The need to control the quality of the water in this intake for possible contamination, such as fertilisers, is indicated. Due to the very high intrinsic vulnerability of the aquifer to contamination, the presence of industrial plants or petrol stations within the runoff of water to the intake Nos 8140002, 8140004, 8140010, 8140011, 8140042, 8140066 and 8140069, it is recommended that the quality of these aquifers be monitored or protective steps be taken.

The other groundwater intakes do not have a very high vulnerability class, or no anthropogenic hazards have been identified within them.

The results are difficult to compare because this is probably the first study for individual intakes that shows local variation and takes into account existing sources of pollution. Considering only the degree of vulnerability of aquifers to contamination, a high




a – waste recycling and disposal plants
b – municipal wastewater treatment plants
c – petrol stations
d – hazardous (explosive) materials storage
e – industrial plants (meat, greenhouse farming, mine vehicle repairs, boiler production)
f – landfills for non-hazardous and non-inert waste

**Fig. 5.** Location of potential pollution sources for groundwater intakes

Source: own elaboration based on PIG-PIB (2023a).

degree of convergence with the map 'first aquifer sensitivity and quality' at a scale of 1:50 000 is visible. This is unexpected, as the creation of this map was based on different methodological concepts (Duda et al., 2011).

## CONCLUSIONS

This study identifies risks to the quality of the first aquifer of groundwater intakes from the MHP-814 Piekoszów map sheet. In the assessment of the risk of contamination, the following were taken into account: the natural vulnerability of water to contamination, the radius of the runoff area to the intake and existing sources of pollution.

Based on the above factors, intakes particularly at risk were selected – which require concrete actions toward their protection: monitoring, modification of protection zones, elimination of pollution sources or, at least, further research.

The following hazards were selected for the study area for specific numbers of water intakes: agricultural lands (Nos 8140057, 8140020 and 8140050), horticultural farm 'Zajączków' (No 8140036) and industrial plants or petrol stations (Nos 8140002, 8140004, 8140010, 8140011, 8140042, 8140066 and 8140069).

The study is informative for the local community and local governments. The scale of groundwater contamination in Poland should contribute to increasing public attention to its protection and the consequences that our passivity and ignorance can cause. Today, educating and encouraging the cooperation of all stakeholders and the local community is important so that the state of the waters improves, guaranteeing adequate quantity and quality for future generations.

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## RYZYKO ZANIECZYSZCZENIA PIERWSZEJ WARSTWY WODONOŚNEJ W CENTRALNEJ CZĘŚCI WOJEWÓDZTWA ŚWIĘTOKRZYSKIEGO (ARKUSZ MHP-814 PIEKOSZÓW)

### STRESZCZENIE

Celem badań jest ocena lokalnego zróżnicowania podatności właściwej płytkich wód podziemnych na zanieczyszczenia oraz wskazanie potencjalnych źródeł zanieczyszczeń, które mogą wpłynąć na jakość wód podziemnych. Analizie poddano 29 reprezentatywnych ujęć wód podziemnych z arkusza MHP-814 Piekoszów, województwo świętokrzyskie. Stworzono mapę z zaznaczonymi ujęciami oraz stopniem ich podatności na zanieczyszczenia wraz z istniejącymi ogniskami zanieczyszczeń. Wskazano ujęcia potencjalnie zagrożone. Sporządzone opracowanie pełni funkcję informacyjną i może być wykorzystane w celu wykonania map zagospodarowania przestrzennego w gminach, projektowania stref ochronnych ujęć oraz tworzenia scenariuszy zagrożeń zanieczyszczeniami specyficznymi dla analizowanych ujęć wód podziemnych.

**Słowa kluczowe:** ujęcie wód podziemnych, studnia, pierwsza warstwa wodonośna, zanieczyszczenie, zagrożenie, MHP-814