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GROUNDWATER CONTAMINATION RISK ASSESSMENT IN THE FIRST EXPLOITABLE AQUIFER STRATUM WITHIN BODZENTYN MUNICIPALITY, ŚWIĘTOKRZYSKIE VOIVODESHIP

OCENA RYZYKA ZANIECZYSZCZENIA WÓD PODZIEMNYCH W PIERWSZEJ EKSPLOATOWANEJ WARSTWIE WODONOŚNEJ NA TERENIE GMINY BODZENTYN, WOJEWÓDZTWO ŚWIĘTOKRZYSKIE

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Abstract

The objective of this study is to assess the threat of contaminating groundwater originating from the first exploitative aquifer level in the municipality of Bodzentyn within the Świętokrzyskie Voivodship. The analysis included 23 representative groundwater intakes from MHP 816 Bodzentyn sheet. The various potential sources of groundwater contamination were identified. The intrinsic vulnerability of the first aquifer to contamination and the water recharge area were determined. In the results intakes potentially threatened by anthropogenic pollution were indicated. Providing information on the potential risks of groundwater contamination will help better plan environmental and decision-making activities in this area. The results can serve as a basis for policy development, land use and sustainable resource management in the municipality of Bodzentyn.

Keywords: groundwater intake, well, first aquifer, pollution, hazard, MHP-816

Streszczenie

Celem niniejszego opracowania jest ocena zagrożenia zanieczyszczeniem wód podziemnych pochodzących z pierwszego eksploatowanego poziomu wodonośnego w gminie Bodzentyn na terenie województwa świętokrzyskiego. Analizą objęto 23 reprezentatywne ujęcia wód podziemnych z arkusza MHP 816 Bodzentyn. Zidentyfikowano różne potencjalne źródła zanieczyszczenia wód podziemnych. Określono wewnętrzną podatność pierwszego poziomu wodonośnego na zanieczyszczenie oraz obszar zasilania. W wynikach wskazano ujęcia potencjalnie zagrożone zanieczyszczeniami antropogenicznymi. Dostarczenie informacji na temat potencjalnego ryzyka zanieczyszczenia wód podziemnych pomoże lepiej zaplanować działania środowiskowe i decyzyjne na tym obszarze. Wyniki mogą służyć jako podstawa do rozwoju polityki, zagospodarowania przestrzennego i zrównoważonego zarządzania zasobami w gminie Bodzentyn.

Słowa kluczowe: ujęcie wód podziemnych, studnia, pierwsza warstwa wodonośna, zanieczyszczenie, zagrożenie, MHP-816

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1. INTRODUCTION

Groundwater serves as a crucial source of drinking water, irrigation, and industrial processes, playing a decisive role in maintaining the balance of various ecosystems. The chemical composition of water is closely related to the lithology of rocks and sediments covering mountain slopes [1, 2]. The preservation and quality of groundwater resources are essential to ensure the sustainable development of communities and ecosystems. Geological and hydrogeological conditions play a significant role in assessing the threat to groundwater quality. Giao et al. [2] confirmed that the quality of groundwater is associated with its geological location and potential sources of pollution. The increasing anthropogenic activities and urbanization have made the vulnerability of groundwater to contamination a matter of significant concern [3-6]. In Poland, the Water Law Act [7] imposes on owners, among other things, the obligation to carry out a risk analysis for groundwater intakes. The risk analysis is meant to justify the potential need for establishing an intermediate protection zone, the extent of which is determined based on hydrogeological conditions and prevailing circumstances within the area of groundwater inflow to the intakes.

An essential element of the risk analysis involves understanding the intrinsic vulnerability of groundwater to contamination, which is closely connected to the geological and hydrogeological conditions of the area, as well as the type of aquifer recharge [8]. The intrinsic vulnerability determines the potential for conservative pollutants (migrating according to the actual speed of groundwater flow) to migrate from the Earth's surface to the initial aquifer layer. Based on the seepage time of conservative contaminants into the first aquifer, it is possible to assess the risk of danger to the groundwater intake [9, 10]. In Poland, based on the data regarding the intrinsic vulnerability of groundwater, a Map of Groundwater Vulnerability to Contamination has been developed. However, due to the broad scale of 1:500,000, this document represents only the initial stage of groundwater threat recognition [9]. It's important to note that a 1 mm thick line on the map corresponds to a 500 m wide strip in actual terrain. Therefore, capturing the local variations in the susceptibility of shallow groundwater to contamination can be challenging, and undertaking actions toward detailed analyses appears justified.

According to the review of documents from the Polish Geological Institute, it is evident that groundwater in the Bodzentyn municipality area may be susceptible to contamination due to the weak substrate isolation and the porous nature of carbonate rocks [11]. As per authors [12, 13], carbonate rocks exhibit significant variability in pore/crack dimensions, which affects the dynamics of groundwater. Considering the fractured rock nature of the local underground water reservoir 816 in Bodzentyn, characterized by spatial and temporal variability [14], there is a need to determine the intrinsic vulnerability of groundwater around the groundwater intakes. Subsequently, by identifying the area of water inflow to the intake and the existing sources of pollution within its vicinity, it is possible to assess the risk of endangerment to the intake [15]. This necessity is reinforced by the fact that the Bodzentyn municipality lies within the scope of protected areas, thereby industrial activities must not disrupt sustainable development.

The objective of this study is to comprehensively assess the threat of contaminating groundwater originating from the first aquifer level in the municipalities of Bodzentyn, Świętokrzyskie Voivodship. Through a detailed investigation of geological and hydrogeological conditions, land use practices, and potential sources of contamination, this research aims to achieve the following goals:

- To determine the intrinsic vulnerability of the first aquifer to contamination for 23 local deep wells.
- Identify and categorize the various potential sources of groundwater contamination within the study area.
- To calculate the radius of the water recharge area to the groundwater intake.

This study is likely the first research focusing on individual well intakes, considering local variations and taking existing sources of pollution into account. Studying the impact of anthropogenic activities on groundwater quality using the developed methodology allows for analyses under various geological and hydrogeological conditions. Therefore, it is not limited to regional actions but can be effectively applied in different geographic areas.

2. METHODS AND MATERIALS

2.1. Research methodology

The depth to the groundwater table and the physical properties of the overlying layer are crucial parameters that significantly influence the vulnerability of groundwater to contamination [16].

The intrinsic vulnerability of the first aquifer to contamination was calculated for 23 local deep

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wells in the municipality of Bodzentyn. Each well was then categorized into classes of vulnerability to contamination depending on the expanding seepage duration (t_a) in years [10]:

- A1 – Signifying an aquifer with an exceptionally high risk where $t_a < 2$ years. Soil-water system susceptible to most pollutants.
- A2 – Representing an aquifer with a high risk where $2 \leq t_a < 5$ years. Soil-water system is susceptible to many types of pollutants, in addition to those highly sorptive (e.g., heavy metals).
- B – Designating an aquifer with a moderate risk where $5 \leq t_a < 25$ years. Soil-water system susceptible to some types of pollution, but only if introduced or washed out continuously.
- C – Denoting an aquifer with a low risk where $25 \leq t_a < 100$ years. Soil-water system is susceptible only to conservative pollution introduced or washed out continuously and over a large area.
- D – Indicating an aquifer that is virtually devoid of risk where $t_a > 100$ years. Isolation layers with minimal infiltration are present or a permanent natural hydraulic barrier exists.

The water exchange time (t_a) was calculated using the following equation (1) [9, 17]:

$$t_a = \sum_{1}^{n} \frac{m_{ai} \cdot w_{0i}}{P \cdot \omega_i} \tag{1}$$

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) [−]; P – mean annual precipitation [mm/a], 700 mm (1991-2020) was assumed; ω_i – effective infiltration coefficient [-].

This formula, despite the fact that it may overestimate the values of vertical seepage [18] can be a useful tool for determining protection zones of groundwater intakes.

Identification of potential sources of contamination for existing groundwater intakes was based on the Geolog database [19] and current (2023) Google Street View maps. Then, based on the hydrogeological map (MHP-816) [20], the direction of groundwater flow was determined. Finally, the radius of the area of water runoff to each intake was calculated to check the risk of the groundwater intake being threatened by a specific pollution source.

The radius of the water runoff for each groundwater intake was calculated using formula (2):

$$r = 2.764 \cdot \sqrt{\frac{Q \cdot t}{m \cdot n_e}} \tag{2}$$

where: Q – well capacity [m^3/h]; t – 9130 days ≈ isochrone 25 years; m – thickness of the aquifer [m]; n_e − effective porosity (according to the graph of the relationship k to n_e, on page 110 – "General Hydrogeology") [10].

The filtration coefficient was obtained from well cards provided by the National Geological Institute.

2.2. Characteristics of the study area

Bodzentyn Municipality is located in the Świętokrzyskie Voivodeship in southeastern Poland. Bodzentyn town is located about 30 kilometers from Kielce (Fig. 1a). It is situated within the Świętokrzyskie Mountains. There are nature reserves, national parks and protected areas in the municipality to protect local flora and fauna. These areas have restrictions on human activities to minimize disturbance to the ecosystem (Fig. 1b). The area is characterized by rolling hills, forests, and numerous streams and rivers. The city of Bodzentyn is surrounded on all sides by agricultural land. Their area in the municipality is 8185 hectares [21] (Fig. 1c).

2.2.1. Geological and hydrogeological conditions

Figure 2 depicts the geological diversity of Bodzentyn municipality.

The water management of Bodzentyn municipality relies on groundwater originating from the Middle and Upper Devonian limestone formations (Fig. 3). Their water-bearing capacity varies greatly, depending on the degree of fracturing, karstification, and the occurrence of local lenses of sandstone and shale. The capacity can vary for individual wells from 0.5 m^3/h to 119 m^3/h [23]. The primary significance lies in the local underground water reservoir 816 in Bodzentyn. It is situated within the confines of groundwater body No. 102. According to the assessment for the period 2022-2027, the reservoir was deemed to be not at risk. In 2019, both the quantitative and qualitative statuses were appraised as good [11]. However, the same document notes a potential local hazard to groundwater intakes stemming from anthropogenic pollution of unknown origin. Rzonca [14] points out that the underground water reservoir is virtually inseparable from the surface terrain, thereby posing a substantial risk of groundwater contamination.

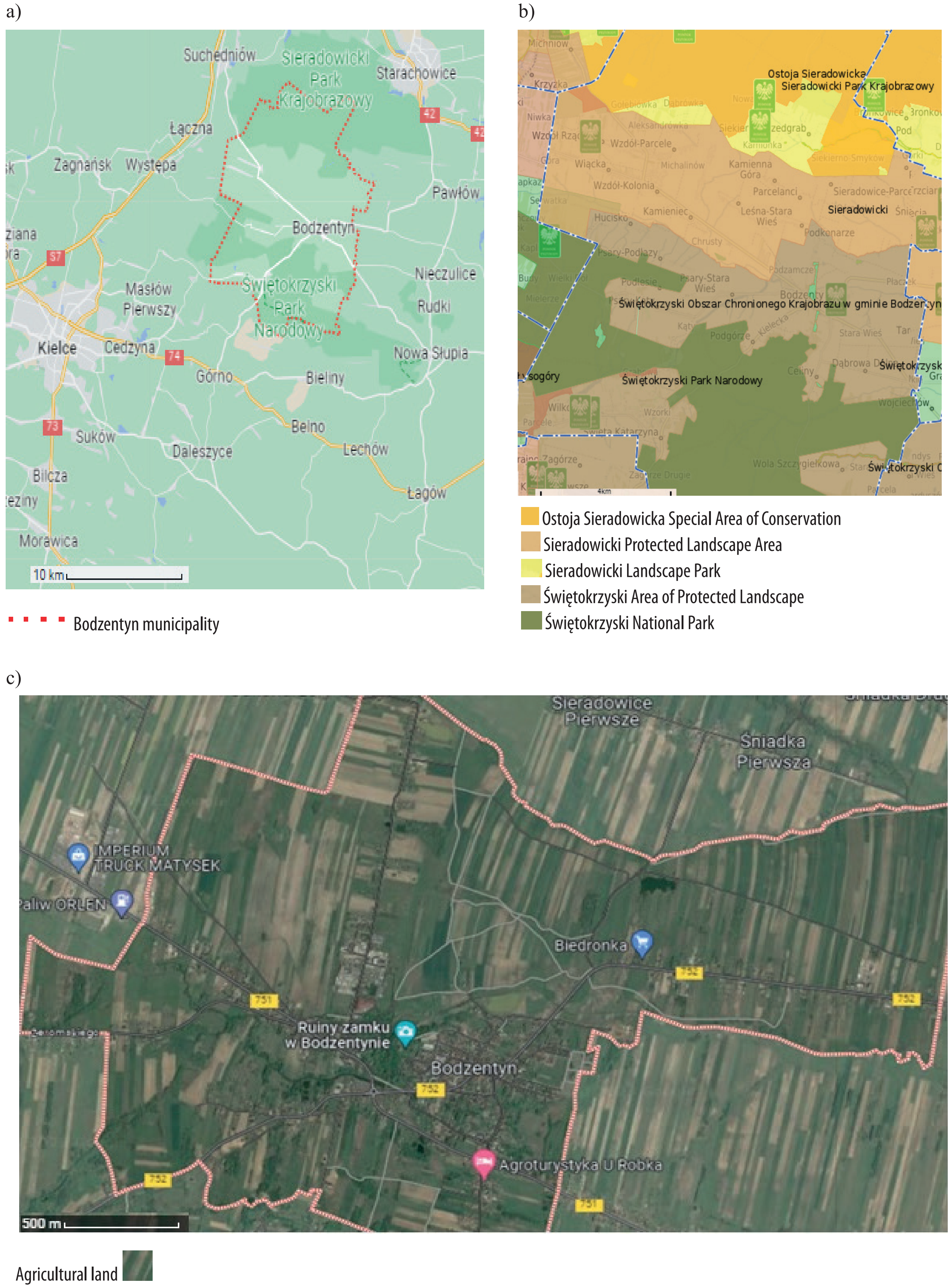

Fig. 1. Bodzentyn municipality: a) against the background of the city of Kielce, Poland; b) on the background of protected areas; c) against the background of agricultural land [22]

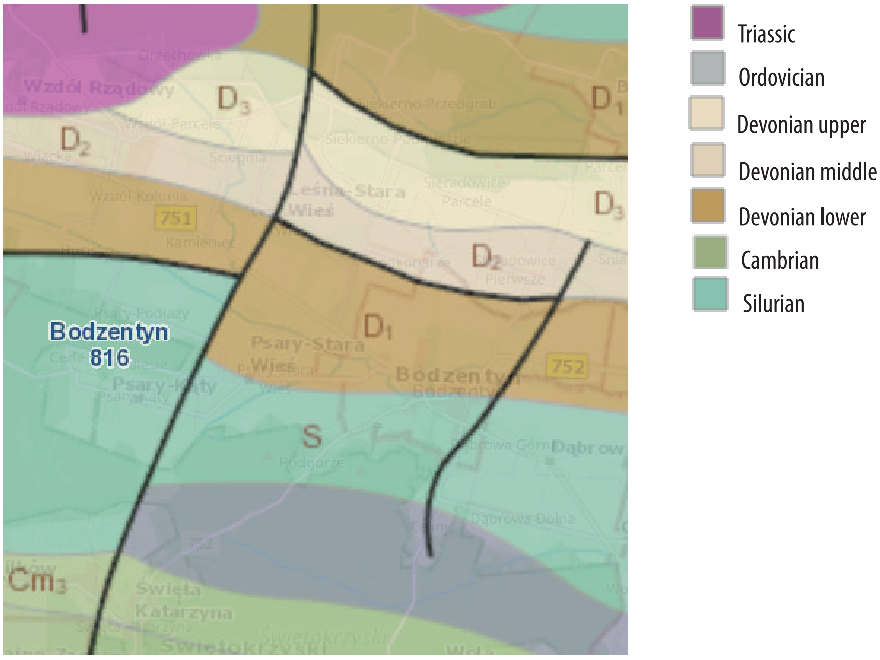

Fig. 2. Cartography of the depth of the study area (Bodzentyn municipality) [19]

Fig. 3. The Underground Water Reservoirs for the municipality of Bodzentyn [11, 19]

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3. RESULTS AND DISCUSSION

Table 1 provides a comprehensive overview of the outcomes associated with 23 local deep wells in Bodzentyn municipality. The groundwater intakes show different levels of vulnerability to contamination, ranging from exceptionally high risk to moderate risk.

In Figure 4, a geographical map has been constructed illustrating the precise positions of the well intakes along with the pre-existing contamination sources.

Figure 5 illustrates the results concerning the natural vulnerability of groundwater to contamination in relation to groundwater intakes within the reach of pollution sources.

In the catchment area of wells no. 816013, no. 8160067, no. 8160068, no. 8160069, no. 8160076, and 816108, agricultural fields are present (Fig. 1c). Due to the elevated risk of groundwater contamination at these extraction points, further risk analyses in this area are required, taking into account the pollutant load

Table 1. Hydrogeological characteristics and assessment of the class of intrinsic vulnerability of groundwater intakes to contamination in the municipality of Bodzentyn

No.of well[1]	Location	PPW[2] [m]	t_a[3] [y]	Calc. risk class[4]	Q[5] [m³/h]	OSW[6] [m]
8160001	Bodzentyn	55	5.3	B	8	N. D
8160002	Bodzentyn	5.8	0.9	A1	40	345
8160007	Sieradowice	32	2.8	A2	58	2021
8160008	Wilków	No aquifer was detected to a depth of 698 m				
8160009	Bodzentyn	9.8	0.8	A1	1.1	N. D
8160011	Bodzentyn	7	0.4	A1	63.8	475
8160013	Wzdół Rządowy	15.1	8.7	B	2.5	171
8160014	Leśna-Stara Wieś	27	5.9	B	4.2	157
8160028	Bodzentyn	32	17.9	B	1.2	78
8160054	Bodzentyn	23	13.9	B	2.8	N. D
8160056	Psary Kąty	5.4	1.6	A1	0.8	N. D
8160058	Bodzentyn	3	0.9	A1	26.2	199
8160067	Bodzentyn	6.2	1.0	A1	37.7	214
8160068	Psary-Stara Wieś	20.5	6.4	B	1.0	131
8160069	Wzdół Rządowy	13	4.0	A2	80	521
8160070	Bodzentyn	23.5	0.9	A1	64.6	391
8160073	Bodzentyn	31	2.8	A2	9	145
8160076	Wzdół Rządowy	21.5	4.1	A2	0.5	98
8160080	Bodzentyn	21	12.3	B	15	1054
8160092	Orzechówka	67	3.5	A2	1.3	171
8160103	Leśna-Stara Wieś	10	2.3	A2	7.4	254
8160108	Wzdół-Parcele	16	1.1	A1	60	377
8160157	Bodzentyn	6.5	0.4	A1	63.8	349

[1] Number according to the database of the National Geological Institute (geolog.pgi.gov.pl); [2] Depth to the first exploitable aquifer (abbreviations in Polish 'PPW'); [3] Average water migration time from the ground surface to the first aquifer in years according to Eq. 1; [4] A1 – $t_a < 2$; A2 – t_a <2-5>; B – t_a (5,25>; C – t_a (25,100>; D – t_a >100 [year] [6]; [5] Exploitable capacity of wells; [6] Radius of the water runoff area acc. to Eq. 2; n.d. not available – no filtration coefficient

Source: own elaboration.

f. ex. nitrates. In the catchment area of water intake no. 8160028, which is characterized by a moderate pollution risk, there is a wastewater treatment plant. The gas station is located near the area of runoff to well nos. 8160058, 8160070 with high vulnerability to contamination. Within the range of influence of groundwater intakes number 816001, 816002, 8160073, there is a truck and tractor repair station and a building materials warehouse. The company has a hazardous waste permit of 13.29 Mg/year. The listed groundwater intakes have a very high vulnerability to contamination, so it is recommended that the quality of these aquifers be monitored or protective steps be taken. Particular attention should also be given to well number 8160028, which is located near the wastewater treatment plant area. The other groundwater intakes no anthropogenic hazards have been identified within them.

The results are difficult to compare because the map 'first aquifer sensitivity and quality' at a scale of 1:50,000 for MHP-816 sheet has not been developed for the area [19]. In addition, the development of these maps operated on other assumptions [8]. Presented study is probably the first study for individual well intakes that shows local variation and takes into account existing sources of pollution.

Studies by other researchers confirm that groundwater management can be effectively carried out based on the assessment of groundwater vulnerability to contamination [24, 25]. Krogulec et al. [24] suggest considering various susceptibility assessment scenarios (variants dependent on average, maximum, and minimum groundwater levels). Reshma and Sidhu [25] also emphasize the importance of conducting comparative studies. Therefore, the presented results can serve as a basis for such analyses. In the future, this data could also be utilized as a significant component of a dataset for machine learning in predicting the degree of groundwater contamination risk. Similar analyses have been successfully conducted by Soriano et al. [26].

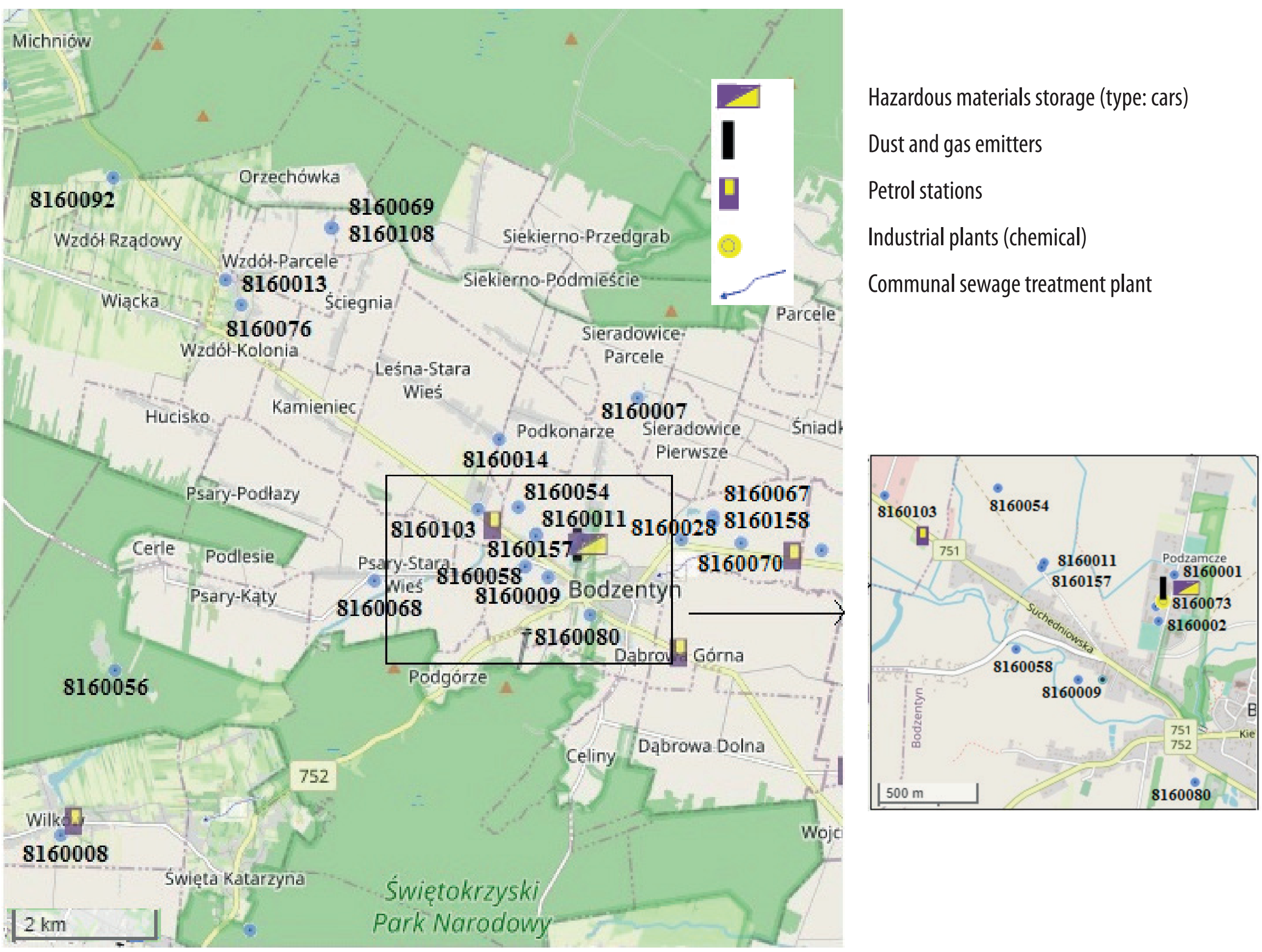

Fig. 4. Location of groundwater intakes with potential pollution sources for the municipality of Bodzentyn. Own elaboration based on [19]

a)

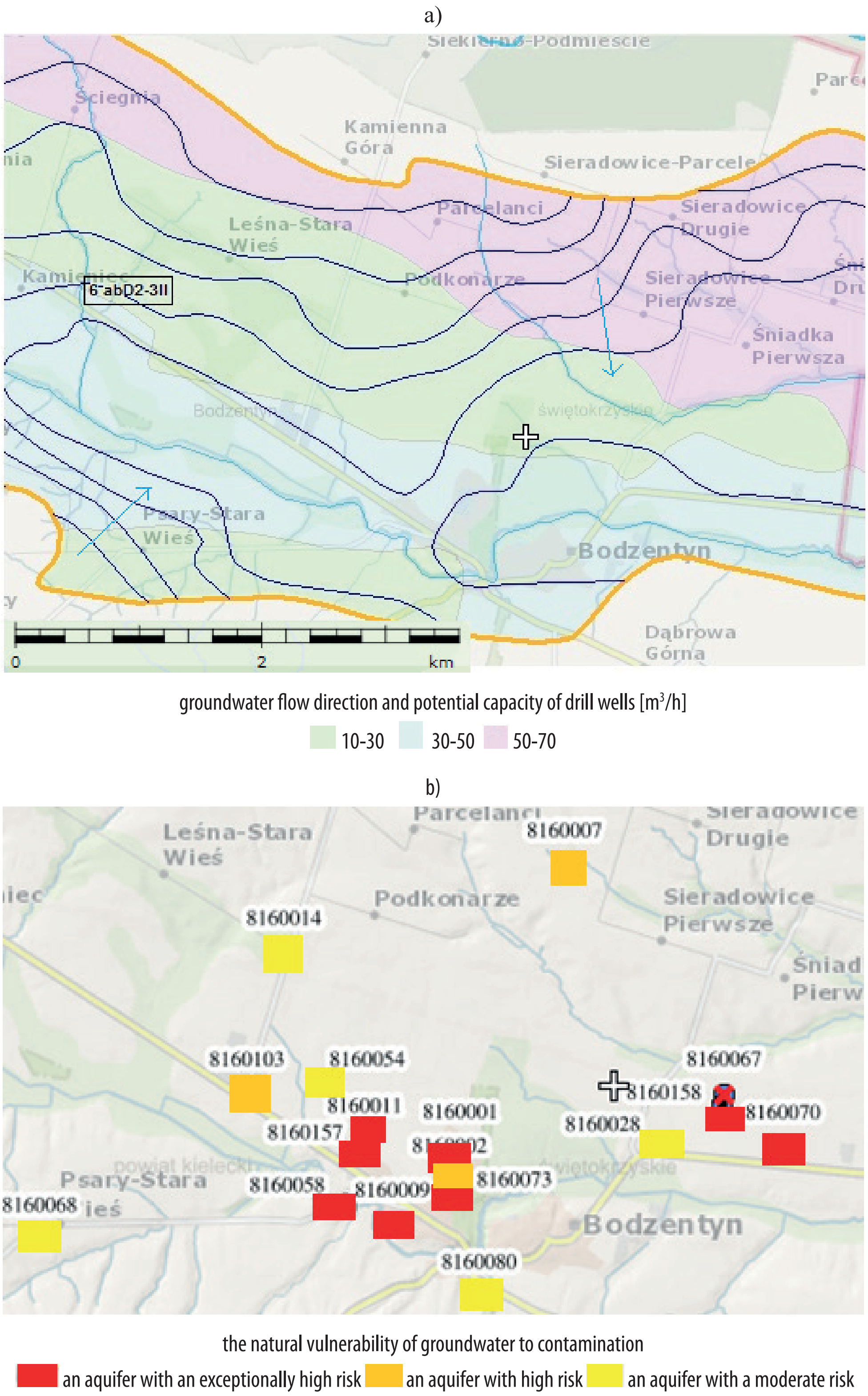

Fig. 5. The intrinsic vulnerability of groundwater to contamination in relation to groundwater intakes and the groundwater flow direction

4. CONCLUSIONS

The primary objective of this study was to evaluate the potential risk of groundwater contamination originating from the first exploitative aquifer level within the Bodzentyn municipality of the Świętokrzyskie Voivodship. Analysis of 23 representative groundwater intakes revealed potential contamination sources and assessed the aquifer's vulnerability. Specific wells near agricultural fields, gas stations, repair stations, and wastewater treatment plants are at risk. Comprehensive risk analyses, particularly for agricultural wells, considering contaminants like nitrates, are recommended. Ongoing monitoring or protective measures are crucial due to the vulnerability of these intakes. The presented results can serve as a basis for further comparative analyses in this region. Understanding contamination risks informs better environmental planning, decision-making, and policy formulation, benefiting sustainable resource management in Bodzentyn.

References

[1] Michalik A.: *The Use of Chemical and Cluster Analysis for Studying Spring Water Quality in Świętokrzyski National Park*. Polish J. of Environ. Stud., 17 (2008).

[2] Metryka-Telka M., Styś-Maniara M., Dołhańczuk-Śródka A.: *Activity of 222Rn in tap water in Kielce county*. Structure and Environment, 14 (2) (2022), el 007

[3] Giao N.T., Nhien H.T.H., Anh P.K. et al.: *Groundwater quality assessment for drinking purposes: a case study in the Mekong Delta, Vietnam*. Sci Rep., 13 (2023), 4380.

[4] Makanda K., Nzama S., Kanyerere T.: *Assessing the Role of Water Resources Protection Practice for Sustainable Water Resources Management: A Review*. Water, 14 (2022), 3153.

[5] Link A., El-Hokayem L., Usman M., Conrad C., Reinecke R., Berger M., Wada Y., Coroama V., Finkbeiner M.: *Groundwater-dependent ecosystems at risk – global hotspot analysis and implications.* Environ. Res. Lett., 18 (2023), 094026.

[6] Canora F., Sdao F.: *Groundwater Vulnerability to Pollution Assessment*. Water, 14 (2022), 2205.

[7] Chakraborty M., Tejankar A., Coppola G. et al.: *Assessment of groundwater quality using statistical methods: a case study*. Arab J Geosci., 15 (2022), 1136.

[8] Water Law Act of 20 July 2017, item 156. Published in the Polish Journal of Laws on 23 August 2017.

[9] Czop M., Herbich P., Janica R., Lidzbarski M., Mulik B., Nikiel G., Prażak J., Rodzoch A., Staśko S., Woźnicka M., Zimoch I.: *Protection zones of groundwater intakes- risk analysis and design Methodological guide* (in Polish), National Geological Institute, Warsaw 2022.

[10] Duda R., Witczak S., Żurek A.: *Map of Vulnerability of Poland's Groundwater to Pollution 1:50 000* (in Polish), AGH University of Science and Technology, Cracow 2011.

[11] Pazdro Z.: *General Hydrogeology – Third Edition Supplemented. Practical aspects of assessing the susceptibility of groundwater to contamination by the DRASTIC method* [in Polish], Białystok 2013.

[12] Documents of the National Geological Institute [online] 2023. Available from https://www.pgi.gov.pl/docman-tree/psh/zadania-psh/jcwpd/jcwpd-100-119/4535-karta-informacyjna-jcwpd-nr-102/file.htm.

[13] Skowera K.: *Fusion of differential analysis of volumetric strain method (dilatometric thermoporometry) and mercury intrusion porosimetry method for pore space characterization in carbonate rocks*. Structure and Environment, 15(2) (2023), el 009.

[14] Steiakakis E., Vavadakis D., Mourkakou O.: *Groundwater Vulnerability and Delineation of Protection Zones in the Discharge Area of a Karstic Aquifer – Application in Agyia's Karst System (Crete, Greece)*. Water, 15 (2023), 231.

[15] Rzonca B.: *The hydrogeological properties of the Devonian carbonate rocks in the Holy Cross Region.* Geologia, 32(3) (2006), 235-343.

[16] Nartowska E.: *The risk of contamination of the first aquifer in the central part of the Świętokrzyskie Voivodship (MHP-814 Piekoszów).* Acta Sci. Pol. Architectura, 22 (1) (2023), 61-70.

[17] Patel P., Mehta D., Sharma N.: *Assessment of groundwater vulnerability using the GIS approach-based GOD method in Surat district of Gujarat state, India*. Water Practice and Technology, 18 (2) (2023).

[18] Witczak S., Żurek A.: *Use of soil-agriculture maps in assessing the protective role of soils for groundwater (In Polish)*. [w:] Kleczkowski A.S. (Ed.): *Methodological basis of groundwater protection*, AGH University of Science and Technology, Cracow 1994, 155-180.

[19] Macioszczyk T.: *Vertical water seepage time as an indicator of the degree of aquifer shielding* (in Polish). Przegląd Geologiczny, 47(8) (1999).

[20] Database of National Geological Institute [online] 2023. Available from: https://geolog.pgi.gov.pl/.

environment

[21] Database of National Geological Institute [online] 2023. Available from: https://baza.pgi.gov.pl/resources.html?type=mhp&id=816.
[22] Podawca K., Pawłat-Zawrzykraj A.: *The Agriculture and Forestry Lands Level of Changes in Planning Process as a Sustainable Development Measure of Municipalities Located within National Parks Impact Areas.* J. Ecol. Eng., 20(8) (2019), 153-164.
[23] Spatial Information System City and Municipality Office of Bodzentyn [online] 2023. Available from: https://bodzentyn.e-mapa.net/
[24] Nartowska E., Budzianowski D., Styś-Maniara M.: *Assessment of the Thermal Power of Groundwater Intakes in the Kielce District*. Civil and Environmental Engineering Reports, 32(4) (2022), 3922.
[25] Krogulec E., Zabłocki S., Zadrożna D.: *Variability of Intrinsic Groundwater Vulnerability to Pollution in River Valley due to Groundwater Depth and Recharge Changes*. Appl. Sci., 9 (1133) (2019).
[26] Reshma R., Sindhu G.: *Assessment of groundwater vulnerability to contamination: a case study*. Environ Monit Assess., 191 (356) (2019).
[27] Soriano Jr. M. et al. *Assessment of groundwater well vulnerability to contamination through physics-informed machine learning.:* Environ. Res. Lett. 16 (2021), 084013.

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