

Article

Risk Assessment of Water Intakes in South-Eastern Poland in Relation to the WHO Requirements for Water Safety Plans

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Abstract: Since 2017, risk assessments for water intakes in Poland have provided the basis for decisions to establish indirect water protection zones. The preventive, risk-based approach and the related risk minimization measures are required under the provisions of the Drinking Water Directive (DWD) of the European Parliament and of the Council of 16 December 2000 on the quality of water intended for human consumption. This approach is in line with the World Health Organization (WHO) recommendations for water safety plans. The aim of this study was to present a methodology and to carry out a risk assessment of the threats to surface water intakes, which in Poland, should be completed by the end of 2022. Risk assessments were performed for four onshore-type surface water intakes located in south-eastern Poland. The results were presented in aggregate form, which enabled clear presentation and conclusions. It was found that the greatest risks are associated with seasonal changes in water quality (mainly high turbidity and water blooms), unregulated sewage management, the occurrence of floodwater flows and catastrophic events caused by the potential failure of wastewater treatment plants. Based on the results of the risk assessment, the need to establish new, or to adjust the existing, protection zones for the analyzed water intakes was identified.

Keywords: threat identification; risk assessment; water intake protection zones



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1. Introduction

Access to safe drinking water is essential to health, a basic human right, and is a component of an effective health protection policy. Water supply systems (WSS) are critical infrastructure [1]. A definition of “critical infrastructure” includes the following: systems and functionally interconnected objects that are part of these systems, including building objects, units, installations and services that are key to state and public safety and that also ensure the efficient functioning of state administrative bodies, as well as institutions and business enterprises [2]. The main task of a WSS is to provide consumers with drinking water in adequate quantity, with the required quality and pressure corresponding to current standards. Due to the large spatial extent of water supplies and the diversity and age of the materials used, WSSs are difficult to operate effectively [3–6].

The water-pipe network is an expanded technical system, and its reliable operation depends on many internal factors (structure, material, conditions of hydraulic flow) (United States Environmental Protection Agency, 2006) as well as external factors (ground and climatic conditions, outside human activities). Consequences resulting from the impact of these factors are failure events causing unreliability of the WSS in its entirety or in part, which in turn may lead to losses of water consumer safety that should be considered in two respects [7]:

- Threats resulting from a lack of water or an interruption in the supply of water;

- Threats resulting from the possibility of consuming contaminated water (which may cause a loss of life or impact the health of consumers).

The sources that supply residents with drinking water are groundwater and surface water intakes. Water intended for human consumption should meet certain requirements. This is achieved by capturing good quality groundwater that requires little or no treatment, and surface water that may require treatment depending on its quality category and the appropriate treatment processes. The quality of the abstracted water depends mainly on the following [8]:

- in the case of groundwater intakes, the amounts and types of pollutants introduced into the ground or migrating from the ground surface to the aquifer supplying the intake;
- in the case of surface water intakes, the amounts and types of pollutants introduced into these waters above the intake.

The key task for public authorities in ensuring the appropriate quality of water intended for human consumption is to maintain the quality of the abstracted water and, where necessary, to improve water quality. This is realized, inter alia, by specifying, as part of water permits for water abstraction, the conditions under which these water sources can be extracted, and establishing protective zones for water intakes. Due to the fact that contamination of groundwater intended for human consumption may appear many years after the proper establishment of protection zones for intakes and compliance with conditions related to their establishment and issued water permits, the quality of drinking water depends on whether the protection efforts have been effective.

In Poland, the amended *Water Law Act* [8] specifies the rules for establishing protective zones for water intakes. A protection zone is an area where the orders, prohibitions and restrictions on the use of land and water are in force. A protection zone includes the area of direct protection only, or the area of direct protection together with an area of indirect protection. A protection zone covering only the area of direct protection is established for each water intake. The area of indirect protection of the groundwater intake covers the water intake area. The area of indirect protection of the groundwater intake is determined on the basis of the findings contained in the hydrogeological documentation for this intake. If the time required for water to flow from the border of the supply area to the intake is longer than 25 years, the area of indirect protection of the groundwater intake is determined by taking into account the area designated by the 25-year time period for water exchange in the aquifer. The protection zone of a mountain stream or upper stream water intake may cover the entire watercourse catchment area above the water intake.

In the area of direct protection, it is necessary to:

- Drain rainwater or snowmelt in a way that prevents it from reaching the devices used for water intake;
- Develop the area with greenery;
- Discharge sewage from sanitary facilities intended for use by persons employed in the operation of water abstraction devices beyond the border of the area of direct protection;
- Limit the presence of persons not employed in the operation of water abstraction devices to essential personnel only.

In the area of indirect protection, operations or activities that reduce the usefulness of the water intake or the intake efficiency may be prohibited or limited: for example, discharging sewage into waters or into the ground; the agricultural use of wastewater; storage or disposal of radioactive waste; the use of fertilizers and plant protection products; construction of new roads, railways, airports, or landing sites; construction of water melioration devices and earth excavations; operating industrial plants and animal breeding farms; and operating warehouses of petroleum products and other substances, as well as pipelines for their transport.

A protection zone covering only the area of direct protection is established ex officio.

A protection zone, including the area of direct protection and the area of indirect protection, is established on the basis of a risk analysis, including an assessment of health hazards taking into account the factors adversely affecting the quality of the abstracted water, carried out on the basis of hydrogeological or hydrological analyses and hydrogeological or hydrological documentation, an analysis of the identification of the sources of threats resulting from the method of land development, as well as the results of the study of the quality of abstracted water.

Risk analyses are carried out for: water intakes providing more than 10 m³ of water per day or serving water to more than 50 people; and individual water intakes supplying up to 10 m³ of water per day or serving water to 50 people, if the water is supplied as water intended for human consumption, or as part of commercial, service, industrial or public utility buildings.

Risk analyses are updated at least every 10 years, and in the case of water intakes delivering less than 1000 m³ of water per year, at least every 20 years. A protection zone is established at the expense of the owner of the water intake.

Risk analyses in water supply systems are widely known and used [4,9–13]. However, the *Water Law Act*, introduced in 2018, listed risk analyses as official for the first time.

The aim of this study was to present a risk assessment methodology for surface water intakes, and these assessments are to be carried out in Poland by the end of 2022. The hazard risk assessments were carried out for four surface water intakes located in south-eastern Poland.

2. Materials and Methods

2.1. Characteristics of the Research Object

A risk analysis was carried out on four water intakes located in the region of south-eastern Poland in the Podkarpackie Voivodeship. Their locations are shown in Figure 1. These are surface water intakes of the onshore type, with three of them taking water from rivers, and one taking water from a dam reservoir. Table 1 presents the basic information regarding the analyzed water intakes.

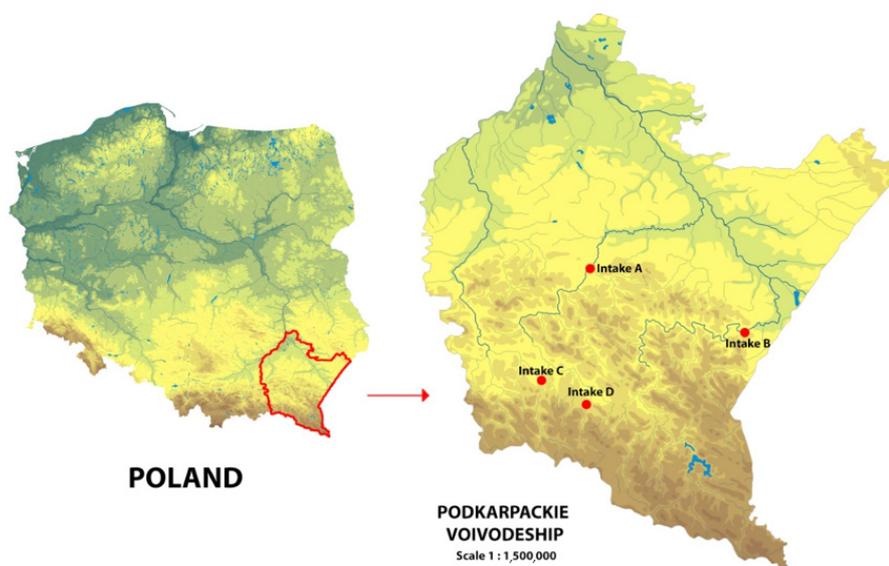


Figure 1. Locality of research objects.

Table 1. Basic information regarding the analyzed water intakes.

Water Intake	Source of Water	Water Production Amount (m ³ /day)	Water Treatment Technology
Intake A	Wisłok River	84,000	pre-ozonation, coagulation, filtration (anthracite-sand bed), secondary ozonation, filtration (carbon bed), disinfection with Cl ₂ , ClO ₂ , UV disinfection
Intake B	San River	21,600	initial ozonation, coagulation, filtration (sand bed), disinfection with Cl ₂
Intake C	Jasiołka River	7000	pre-oxidation, coagulation, filtration (sand-gravel bed), disinfection with ClO ₂ , UV disinfection
Intake D	Besko dam reservoir	17,000	pre-oxidation, coagulation, filtration (anthracite-sand bed) disinfection with ClO ₂ , UV disinfection

2.2. Identification of Threats

One of the first stages of a risk assessment is the detailed identification of any threats to the water intakes, and includes an assessment of the health hazards for the water, which is required by the provisions of the *Water Law Act* of 20 July 2017 [8] and by the Drinking Water Directive, adopted by the European Parliament and the Council on the quality of water intended for human consumption [14]. This approach is in line with the World Health Organization (WHO) recommendations on water safety plans, including a risk assessment and management method covering all stages of water supply from intake to the consumer's tap. A risk assessment in catchment areas for water intakes intended for human consumption should be carried out by 12 July 2027 in accordance with the Drinking Water Directive, while Polish legislation set this deadline for the end of December 2022. A detailed identification of the threats to the quality of the taken water was carried out in the catchment area covering the area of 12-h water inflow for four analyzed water intakes. A register of the emergency events that took place in the previous years in the area covered by the analysis was also analyzed.

Water pollution is a common phenomenon, conditioned by physical–geographical, climatic and anthropogenic factors in a given catchment area [15,16]. It results from the presence of various types of substances in the water, which may come from natural or artificial sources. Nitrogen and phosphorus compounds are especially dangerous to water environments [17,18]. These compounds make the water environment rich in the nutrients responsible for the eutrophication of water, causing the development of algae and cyanobacteria, which in turn increases water turbidity and reduces the diversity of ichthyofauna. Among the sources of threats, we can distinguish three main groups: point sources, line sources and area sources.

Point sources of pollution include, in particular, municipal wastewater treatment plants, industrial wastewater treatment plants, industrial plants, petrol stations and warehouses of hazardous substances. The greatest pressure on the condition of surface waters in south-eastern Poland is exerted by the emission of municipal wastewater to soil and water. When identifying threats in catchment areas above a water intake, all municipal and industrial wastewater outlets (treated and untreated), industrial plants and other point facilities that may pose a threat to water intakes should be located. In the case of introducing pollutants from point sources to surface waters, the condition of the water may deteriorate due to an increase in suspended solids, an increase in the concentration of nitrogen and phosphorus compounds, chlorides, dissolved organic substances, BOD₅, a reduction in dissolved oxygen and biological contamination.

The line sources of pollution are car and rail transport. The following types of linear pollution are distinguished:

- Solid pollutants related to the use of communication routes (fuel leaks, surface erosion);
- Periodic contamination caused by routine works (use of fluxes, insecticides);
- Accidental pollution caused by random events (failures).

Pollution from linear sources runs off to nearby areas from roads or track structures during rain or thaw. The impact of the threat is greater when the communication route runs close to a river and the terrain makes runoff easier. The indicators that characterize the quality of water runoff are: suspended solids, petroleum substances, general coal, chlorides, sulphates and other indicators resulting from the type of catchment management. The identification of linear sources of pollution should include all elements of road and rail infrastructure in catchment areas covering the area of 12-h water inflow to the analyzed water intake. These elements should have appropriate protection against the release of pollutants into water or soil. Bridges located on main roads in an analyzed area require protection against the inlet of pollutants to surface waters. Road bridges with a monolithic structure should have a drainage system equipped with highly efficient separators. Rainwater and snowmelt from local roads should be discharged to, e.g., rain sewage systems or tight ditches, and in the case of significant contamination, it should be pretreated before being discharged into waters or into the ground. It is necessary to completely exclude the discharge of rainwater from polluted surfaces to the ground or water in the entire area of the water intake protection zone.

The main factor causing the migration of area pollutants is soil erosion [19,20]. During heavy rains and thaws, nutrients not taken up by plants migrate from agricultural areas by surface runoff. As a result of the use of pesticides and herbicides with a high degree of toxicity, burying the packaging of these products and disposing of slurry sewage to farmlands, surface waters may be contaminated [18,21].

On the basis of the maps, the percentage share of agricultural land for a given area was estimated, on the basis of which the weights were assumed and the value of risk was determined, in consultation with the local administration related to agriculture. In surface waters, an increase in P_{og} , $N-NH_4$, $N-NO_3$ and K, as well as heavy metals and pesticides is observed. In the case of heavy rainfall, the use of artificial fertilization and chemical pesticides can lead to pollutants reaching surface waters by washing away from the soil. Another source of pollution is the discharge of untreated sewage into soil or water with use of roadside ditches, leaks from septic tanks and the transport of sewage to farmlands (lack of a collective sewage disposal system). When untreated sanitary sewage is introduced into surface waters, there is an increase in suspended solids, nitrogen and phosphorus compounds, chlorides, dissolved organic substances, BOD_5 , a reduction in dissolved oxygen and significant biological contamination. Wild landfills in water intake protection zones are another threat to the quality of surface waters. They can contribute to the growth of mineralization, oxidability, organoleptic changes, BOD_5 , COD and specific pollutants with varying degrees of toxicity (heavy metals) in surface waters. Cemeteries located near areas of water intake are also a potential threat to the quality of surface waters.

A risk assessment for water intakes should also be based on an analysis of the quality tests results of the taken water [22,23]. Data on water quality and the hydrological characteristics of a river that is the water source supplying a population with water constitute valuable information supplementing the process of risk analysis for water intakes. Raw water taken at A, B, C and D intakes is subject to constant water quality monitoring, including the physico-chemical and microbiological parameters of the water, such as: temperature, turbidity, color, odor, pH, UV absorbance, electrical conductivity, ammonium ion, nitrite ion, nitrate ion, phosphates, oxygen, iron, manganese, alkalinity, chlorides, sulphates, COD, BOD_5 , TOC, *coliform bacteria*, *Escherichia coli*, *streptococcus* and *clostridium*. Water quality tests are performed in an accredited laboratory. Based on the results of observations from several years, it is possible to determine the relationship characteristics for a given river,

which may differentiate the impact of particular types of threats on the risk level. Despite sudden changes in the quality of the water characteristics of mountain rivers (turbidity at the level of several thousand NTU), the water treatment technology in the analyzed cities is carefully selected, and the treated water that is pumped into the water supply system meets the quality requirements for water intended for human consumption, in accordance with the applicable Polish regulation from the Minister of Health on 7 December 7 2017 [24]. In addition, on the basis of the available hydrological documentation, the so-called characteristic flows in the river were determined for quantitative evaluation of the water intake amount, and in order to assess the potential boundary for the amount of water intake impacting the city development. The analysis showed that no shortcomings were found in this respect.

2.3. Risk Matrix

Risk management is the systematic implementation of a management policy with an implementation of procedures and practical actions aimed at reducing the risk of threats to a rational level. It includes the risk assessment phase, i.e., defining the area of analysis, hazard identification, hazard risk assessment and risk evaluation, as well as the risk response phase, which includes management of the hazard risk, monitoring of the hazard risk and communication of the hazard risk. The Polish Water Law [10] requires water companies to conduct a risk analysis by the end of 2022, therefore the work focuses on this aspect of the analysis. Finding solutions to diagnosed problems, calculating the cost of their removal and determining the time period is beyond the scope of this work. However, we consider these problems if they relate to potentially limiting access to water.

Environmental engineering (as in most engineering applications) applies the basic definition of risk, which presents risk as the product of the probability of the occurrence of undesirable events and losses resulting from their occurrence. This definition is a starting point and can be extended with additional variables, primarily taking into account the degree of protection of water consumers against the consequences of undesirable events. In this paper, the risk of a hazard is determined according to the formula:

$$r = \frac{P \cdot C}{O} \quad (1)$$

where P = the probability of the occurrence of the i -th threat; C = the consequences for water consumers as a result of the occurrence of the i -th threat; and O = the level of trust in the effectiveness of safety system components, which are to ensure the water supply is of appropriate quality to consumers after the occurrence of the i -th threat.

For the variables P , C and O , the size level is assumed each time by means of a point scale from 1 to 5, using a three-stage matrix method. The risk ranges from 0.20 to 25. Table 1 proposes a method of adopting weights for risk variables. Tables 2–4 propose adopting a scale and point weights for individual parameters.

Table 2. Criteria and point weights for the parameter P .

Probability	Parameter Description	Point Weight
very low	every 10 years or less	1
low	once in 5–10 years	2
average	once in 1–5 years	3
high	1–12 times a year	4
very high	more than once a month	5

Table 3. Criteria and point weights for the parameter C.

Consequences	Parameter Description	Point Weight
very low	possible short-term deterioration of water quality, no health risk for consumers	1
low	noticeable organoleptic changes in water (smell, changed color and turbidity)	2
average	significant organoleptic nuisance (odor, changed color and turbidity)	3
high	exposure of a significant group of consumers to the consumption of low-quality water, a risk to human health	4
very high	exposing a large group of consumers to the consumption of microbiologically contaminated water or finding a high level of harmful substances, a serious threat to human health	5

Table 4. Criteria and point weights for the parameter O.

Protection	Parameter Description	Point Weight
very low	monitoring of the quality of raw and treated water only in case of hazard; treatment technology cannot be corrected to remove harmful substances; no alternative water sources and reservoirs; no designated water intake protection zones	1
low	periodic water quality monitoring system (e.g., once a month); the ability to react to changing water quality parameters during the treatment process to a small extent; no alternative water sources; no tanks	2
average	raw and treated water quality monitoring system (water sampling at least once a day); determination of coagulant doses based on the current results of the water quality analysis; alternative water source, clean water tank or network tank; the intake area is fenced	3
high	electronic raw and treated water quality monitoring system with alarm function (on-line measurement); the possibility of using alternative treatment technology or water collected in network water tanks; reserving strategic facilities at the intake and the water treatment plant (cold and hot reserve)	4
very high	electronic raw and treated water quality monitoring system with alarm function (on-line measurement); a modern and effective water treatment system that allows the removal of high concentrations of pollutants from the water; the possibility of using alternative treatment technology, alternative sources of water or water collected in network water reservoirs; use of the early warning system: biomonitoring, early warning station; reservation of strategic facilities at the intake and the water treatment plant (cold and hot reserve)	5

The parameters were defined by the authors together with representatives from the water supply companies with which the authors have been cooperating for over 20 years. The authors were responsible for the work of developing enterprises in the field of implementing risk analysis in water supply.

The criteria for assessing the risk are listed below:

- Tolerated risk: $0.20 \leq r < 5.0$;
- Controlled risk: $5.0 \leq r < 9.0$;
- Unacceptable risk: $9.0 \leq r \leq 25.0$.

It is impossible to completely eliminate all risks. However, various actions can be taken in order to obtain a risk level that is “as low as reasonably practicable” (ALARP).

3. Results

In accordance with the Water Law [8], which regulates the intake protection zones in Poland, a protection zone that includes an area of direct protection and an area of indirect protection is based on a risk analysis that includes an assessment of the health hazards resulting from the way the land is developed, hydrological documentation analysis and the results of water quality analysis. This approach is in line with the requirements of Drinking Water Directive 2020/2184 [14] and the requirements of the WHO [25] on risk assessment in water supply systems.

A risk analysis was performed for four water intakes in selected cities located in south-eastern Poland. After a detailed identification of the risks to the water quality of the rivers, the existing safety measures that protect consumers from consuming water of inadequate quality were identified. The existing safety measures were also validated. The purpose was to confirm the effectiveness of these measures in normal and crisis conditions. The effectiveness of the safety measures reduces the risk value. Missing safety measures were also indicated, i.e., safety measures that should function in the system but had not been implemented so far.

Table 1 shows the results of the risk analysis performed. The obtained results are from studies prepared by the authors. They were commissioned by the water companies managing intakes A, B, C and D. Each event is described by three parameters: “probability”, “consequences” and “protection”, and based on determined parameters of the risk. Figure 2 and Table 5 show the obtained risk values broken down by the type of undesirable event. The method of determining the risk value is presented in the examples below.

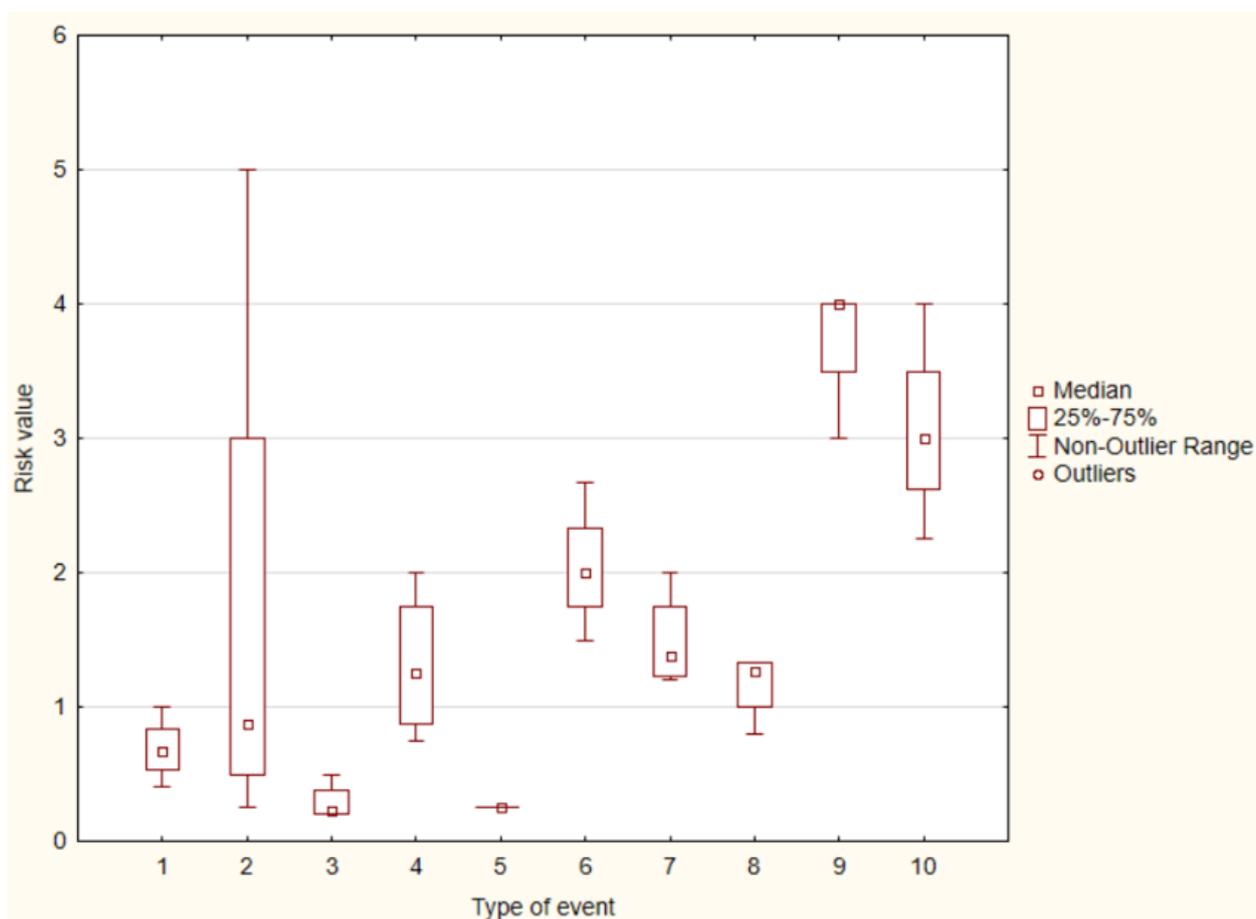


Figure 2. Risk values for adverse events 1–10 (numbering of undesirable events according to Table 5).

Table 5. The results of the risk analysis for selected surface water intakes in south-eastern Poland.

No.	Type of Event	Characteristics of the Undesirable Event	RISK				Median	Minimum	Maximum	Standard Deviation	Lower Quartile (25%)	Upper Quartile (75%)
			Intake A	Intake B	Intake C	Intake D						
1	A road or rail accident	River water pollution caused by a road or rail accident (oils, gasoline, PAHs, chemicals)	0.40	1.00	0.67	0.67	0.67	0.40	1.00	0.21	0.47	0.75
2	Municipal or industrial Wastewater treatment plant	Incidental contamination of river water caused by a failure of municipal or industrial wastewater treatment plants (above the water intake), which results in the discharge of untreated municipal sewage (bacteria, viruses, nutrients) or industrial sewage (harmful substances, heavy metals) into the river	1.00	0.75	5.00	0.25	0.88	0.25	5.00	1.90	0.38	2.00
3	Industrial factories	River water pollution caused by plants with a high risk of a major industrial accident	0.25	0.50	0.20	0.20	0.23	0.20	0.50	0.12	0.20	0.31
4	Agricultural activity	River water pollution caused by inadequate agricultural activity (pesticides, nutrients)	1.50	0.75	1.00	2.00	1.31	1.25	0.75	2.00	0.48	0.81
5	Other area sources	River water pollution caused by other area sources, i.e., wild landfills, petrol stations, cemeteries	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.00	0.25	0.25
6	Unregulated sewage management	Contamination of river water by leaky septic tanks and discharge of untreated sewage into the ground or water (no collective sewage disposal system)	2.00	1.50	2.67	2.00	2.00	1.50	2.67	0.42	1.63	2.17
7	Flood	River water pollution caused by flood or heavy rainfall (increased turbidity and biological contamination of the water)	1.20	1.50	2.00	1.25	1.38	1.20	2.00	0.32	1.21	1.63
8	Action by other people	River water pollution caused by harmful effects of third parties (vandalism, sabotage)	0.80	1.20	1.33	1.33	1.17	1.27	0.80	1.33	0.22	0.90
9	Seasonal changes in water quality: summer	Seasonal changes in water quality in summer (increase in the concentration of nutrients causing eutrophication)	4.00	3.00	4.00	4.00	4.00	3.00	4.00	0.43	3.25	4.00
10	Seasonal changes in water quality: winter	Seasonal changes in water quality in winter (deoxidation of water, increase in NH ₄)	4.00	2.25	3.00	3.00	3.00	2.25	4.00	0.62	2.44	3.25

Failure of the planned wastewater treatment plant, which is located approximately 7 km from Intake C:

- Probability of the event: “average” $P = 4$.

It is estimated that, as a result of the wastewater treatment plant failure, serious water pollution will be noted by the water company no more than once a year:

- Consequences for water consumers: “very high” $C = 5$.

The water treatment technology used at the water treatment plant in Intake C will not allow water to be treated to an appropriate quality in the event of a failure of the planned wastewater treatment plant. As a result, a large number of consumers will be exposed to the consumption of water of inadequate quality (microbial contamination):

- Protection of water consumers: “average” $O = 3$.

The water treatment technology does not include a high-efficiency coagulation system, making the water treatment plant very susceptible to changes in water quality. On the other hand, the system has a second water intake and a network water tank.

Based on the above information, the risk value $r = 5$, which corresponds to the controlled level of risk. In order to protect Intake C, sewage transfer should be considered from towns with new sewage facilities located close to Intake C to outside the indirect water intake protection zone, e.g., to an existing wastewater treatment plant in a city below a water intake. Risk mitigation, i.e., taking preventive actions related to risk reduction, is the most effective risk response strategy.

Flood in the basin of river, which is a source of water for Intake C:

- Probability of the event: “low” $P = 2$.

Assumptions were made on the basis of flood risk maps, which are provided in Poland by the government agency “Wody Polskie” (whose task it is to protect against floods and droughts, manage water services and manage the water environment in Poland). These maps, among others, are designated for the Upper Vistula basin area, which is covered by the study (the maps are available online). In Poland, flood risk maps show areas with a certain probability of flood occurrence: once in 500 years, once in 100 years and once in 10 years. The area located in the direct neighborhood of the water intake is the area where the probability of flooding is 10% (once in 10 years). The map shows that in the indirect protection zone area of Intake C, with a probability of flood once every 10 years, mostly farmlands and single-family housing are flooded (Figure 3):

- Consequences for water consumers: “average” $C = 3$.

Extensive flooding causes a decrease in water quality, mainly an increase in turbidity and biological contamination of the water—washing out fertilizers from farmlands and pathogenic microorganisms from sewage systems and septic tanks. The map of flood risk shows that there will be no physical flooding of the water treatment plant (WTP) and the water treatment process will not be interrupted (Figure 3). A long-lasting flood can cause noticeable organoleptic changes in water smell and changes in color and turbidity due to the insufficient effectiveness of the treatment process:

- Protection of water consumers: “average” $O = 3$.

The water treatment technology used at the WTP of Intake C (based on slow sand filters) does not include a high-efficiency coagulation process, which means that, in order to meet the quality requirements for water intended for human consumption (in Poland, defined by the regulation from the Minister of Health, 2017), water taken from the river must be of high quality. During flooding, the water in the river does not meet this condition and the intake may be turned off in the period of deteriorated water quality in the river. According to Table 4, a point weighting of $O = 3$ was adopted. The most important barrier to eliminating the threat to water quality in every water company is the water treatment technology used and its effectiveness, which should determine the value of the parameter O .

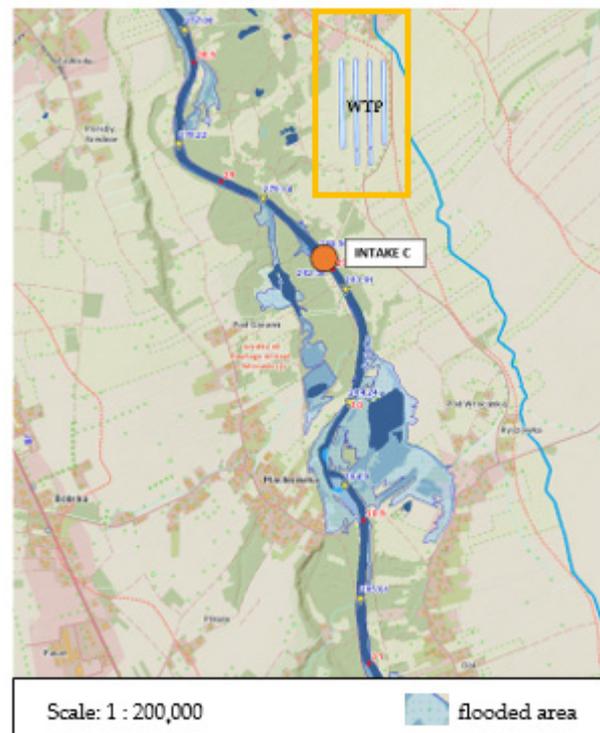


Figure 3. The flood risk map for a fragment of the indirect protection zone of Intake C.

Based on the performed analysis for the water in Intake C, it can be concluded that flooding does not cause a significant threat to the analysed intake. However, the operator of the water supply system should have a response plan in the event of flooding and the related water quality deterioration, which causes a threat to the continuity of the water treatment process. The analyzed system has another two independent water intakes, so in the case of flooding, they can compensate for the water production of Intake C. Another option to ensure the supply of water is to determine the possibility of water supply from outside sources (water intake from public wells, water trade with neighboring municipalities).

4. Discussion of Results and Assessment of the Need to Establish or Adapt Water Protection Zones

The water quality of rivers, which are the source of water supply, is threatened by adverse events related to the discharge of untreated municipal wastewater (Event 6) and, to a lesser extent, by agriculture (Event 4). This is due to the fact that some of the areas located in the catchment area of these rivers still do not have sewage systems (sewage systems in communes is at the level of approximately 70%), which, in the absence of the control of invoices for waste disposal, means that residents often discharge sewage into the ground or a ditch. According to administrative units, eutrophication caused by pollution from municipal sources is the most significant threat to a high-quality water status in the Podkarpackie Province in Poland. For this reason, the ammonium nitrogen content is a very important indicator of water quality. The content of individual nitrogen ionic forms present in the water (ammonium NH_4^+ , nitrate NO_3^- and nitrite NO_2^-) and the assessment of their variability over time, along with correlation with the data on land use in the vicinity of the intake, allows for an approximate assessment of the time and possible origin of the pollutants. The ammonium ion found in water intended for human consumption may come from anthropogenic pollutants entering the intake (mainly surface intakes). The source of threats may be a situation where water pollution (sewage, natural and artificial fertilizers, rainwater runoff and leachate from landfills) causes microbiological contamination of the water or penetration of the water by toxic chemicals. The ammonium

ion is not the cause of the danger here, but it does signal risk. In the winter season, when both vegetation and nitrification are inhibited, the values of ammonium ion concentrations show an upward trend (Event 10).

The greatest threats are periodic increases in turbidity and water blooms causing, among others, the necessity for the frequent rinsing of filters (Event 9). Very high turbidity (even 3000 NTU) is often associated with the occurrence of flood water flows (Event 7). In the analyzed time period (10 years), water intake was continuous, and the water treatment plant worked continuously, pumping water to the water supply network in compliance with the regulation from the Polish Minister of Health on 7 December 2017 on the quality of water intended for human consumption. Maintaining the suitability of the water treatment plant, however, required heavy involvement from the operators and a strict control of the treatment process (mainly filter rinsing). The analysis of the current crisis situations and the method of dealing with them prove that the technology of the water treatment process in the analyzed systems meets the criteria set for them, and is matched to the changing hydrological conditions of the river and a wide range of raw water parameters.

When it comes to catastrophic events caused by a potential failure of the sewage treatment plant (Event 2), the risk is very diverse, due to the fact that the efficiency of the sewage treatment plant and its distance from the water intake have a decisive influence on the level of risk. The greatest risk is caused by a failure of the wastewater treatment plant located within the indirect protection zone of the water intake, approximately 4.8 km from Intake A, and the failure of the planned wastewater treatment plant, which was to be located at a distance of approximately 7 km from Intake C. The probability of such an event occurring is small, but the potential consequences require the introduction of a tight security system in anticipation of it occurring. After the major failure of a collector sending sewage to the “Czajka” wastewater treatment plant in Warsaw in August 2019, the General Inspectorate for Environmental Protection in Poland called on municipalities to check their procedures in the event of a serious accident in wastewater treatment plants. It should be noted that the water supply companies are not responsible for the technical condition of the installations in external sewage treatment plants, however their improper functioning (inconsistent with the water permit) or failure significantly impedes the maintenance of the appropriate quality of water supplied to consumers. The harmful effects of third parties (Event 8) can potentially cause many diseases, but it should be emphasized that the poisonous substance is significantly diluted in raw water.

The results of the risk analysis are the presentation of proposals for remedial measures and proposals for the extent of the indirect protection zones for water intakes A–D. The proposed extent of the indirect protection zones for Intake A, Intake B and Intake C is shown on the map in Figure 4. This is the area for which the risk analysis was carried out, i.e., the water intake catchment area covering an area of 12-h water inflow. However, the conducted risk analysis did not show any significant threats to the water intake for Intake B. In connection with the above, combined with the fact that the entire area covered by the study includes a specially protected natural area (i.e., Landscape Park) and that there is a lack of large sanitary wastewater treatment plants and industrial plants posing potential threats, there is no need to establish an indirect protection zone for the water intake. The analyzed water supply systems are equipped with the necessary security measures related to the intake of surface water. The risk assessment of threats to the water intakes did not reveal any significant threat to water consumers.

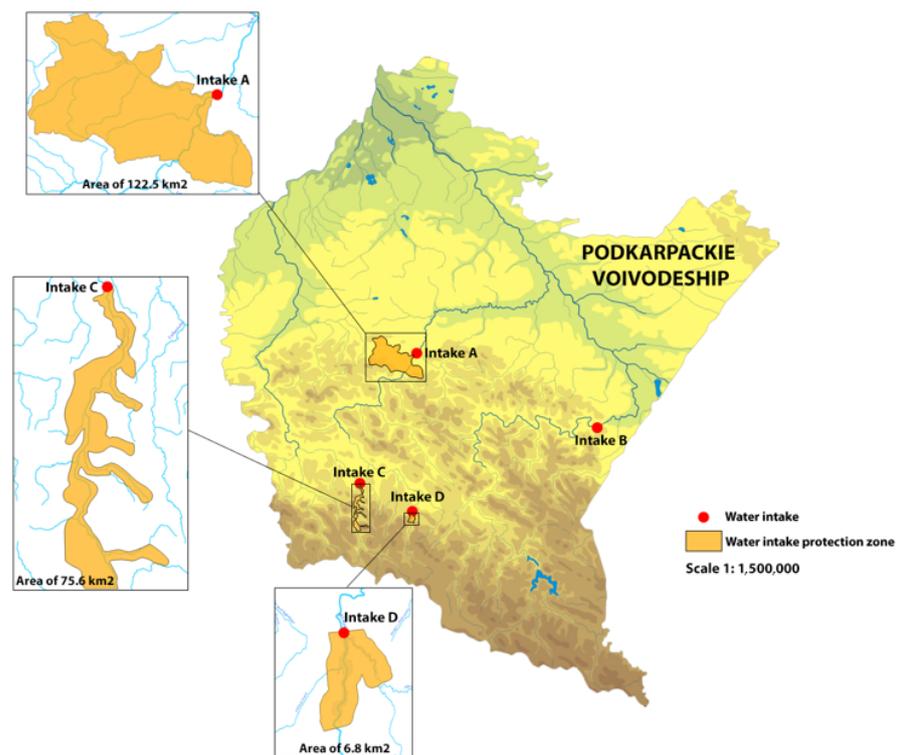


Figure 4. The scope of the designed indirect protection zone for Intake A, Intake C and Intake D.

Risk assessment is a continuous process, which is why, based on the performed risk analysis, a proposal of corrective or repair actions that the water supply company should take in order to constantly control and reduce the risk was presented. Corrective actions are presented as follows for the sources of threats that have the most significant impact on the risk levels for intakes A–D:

- Developing procedures for dealing with contaminants that conventional treatment will not be able to remove;
- Obtaining funds from local government units for the construction of sanitary sewage systems in the towns located in the catchment area of rivers from which the water is drawn, in particular, in the indirect protection zone of the water intake;
- Monitoring the usage of plant protection products in the indirect protection area and controlling their quality;
- Developing a plan for checking the technical condition of facilities and pipelines at wastewater treatment plants and procedures in case of a major failure in wastewater treatment plants;
- Banning new municipal and industrial wastewater treatment plants within the indirect protection zone of the water intake.

5. Conclusions and Perspectives

In accordance with the provisions of the Drinking Water Directive [14], risk assessments and risk management in the catchment areas of water intakes should be carried out in the EU by 12 July 2027. Poland meets this requirement—it is estimated that risk analyses will be carried out by the end of 2022 for water intakes producing more than 10 m³ of water per day or supplying water to more than 50 consumers. Some of the Polish water supply companies have already performed a risk analysis, submitted it to the relevant authorities (the voivode) and obtained a decision to establish a water intake protection zone. Actions aimed at minimizing the risk to water supply systems defined in Poland by the *Water Law Act* [10] are in line with the WHO recommendations.

The *Water Law Act* [8] requires water companies to carry out a risk analysis, but it does not indicate how. As a result, water supply companies have looked for substantive support in this regard. In cooperation with water supply companies, we carried out risk analyses for the water intakes presented in this work, and on this basis, the relevant authority established the required water intake protection zones. The methodology presented in this paper can be used by both Polish and European water supply companies to perform a risk analysis for water intakes and for the annual evaluation of threats to water intakes, which are necessary, as the risk factors cannot be completely eliminated.

The risk-based approach appears to be optimal for the safety of water consumers and for socio-economic development. The establishment of a water intake protection zone is always related to a limitation on economic activity in a given area, and it should be established only when it is necessary to ensure the appropriate quality of the taken water. Based on the results of the risk assessment carried out by the author's team for four surface water intakes located in south-eastern Poland, appropriate risk management measures were defined to prevent or control the identified threats and the need to establish new or adjust existing water intake protection zones for the analyzed intakes was assessed. The performed risk analysis did not reveal any significant threats to the water intake for Intake B, therefore there is no need to establish an indirect water intake protection zone. For intakes A, C and D, an indirect water intake protection zone was established, covering the area of 12-h water inflow.

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