Risk and Hazard Analysis of Riverbank Filtration Water Intakes for Water Safety Planning

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Abstract — **Water Safety Plans (WSPs) are a proactive framework recommended by the World Health Organization to ensure the safety of drinking water through risk assessment and risk management along the entire supply chain – from catchment to consumer. This study presents a methodology for identifying and assessing hazards and hazardous events in riverbank filtration (RBF) water supply systems at the initial WSP development stage. A pilot investigation was conducted for a small urban settlement in the Ivano-Frankivsk region, Ukraine, where groundwater abstraction is performed from two rivers, including the Dniester. Bibliometric analysis of 3,879 publications in Scopus (as of 2025) identified key approaches and gaps in WSP-based risk assessment. Field investigations under the project Climate-Resilient Management for Safe Disinfected and Non-Disinfected Water Supply Systems - 101081980 - SafeCREW - Horizon-cl6-2022-zeropollution-01 included 2,956 measurements of physicochemical and microbiological indicators. Main hazards identified were microbial contamination during warm seasons and clogging of infiltration zones due to increased turbidity in the Dniester River. Risk assessment demonstrated medium to high levels of vulnerability associated with reservoir maintenance and seasonal water quality fluctuations. The results provide a structured basis for WSP implementation and adaptation of EN 15975-2:2022 and ISO 31000:2018 principles in small-scale water systems using riverbank filtration.**

Keywords — Water Safety Plan; Risk Assessment; Risk Management; Hazard Analysis; Water Supply; Environmental Monitoring, Sensor-based Monitoring

I. INTRODUCTION

A. *Justification of Research Relevance*

In the 21st century, there has been a significant reduction in the availability of acceptable-quality water worldwide, particularly in Ukraine. This is due to excessive consumption, the pollution of watercourses and groundwater aquifers, intensive agriculture, climate change, and the financial and personnel-related inability to implement modern water treatment, disinfection, distribution and selection technologies., among other reasons, [1].

An important mechanism for addressing water resource challenges is Hydroinformatics, which, through the integration of data, digital modelling, and decision support systems [1], and with the application of Artificial Intelligence (AI) [2], has evolved into a socio-technical dimension. This transformation enables a shift from reactive to interactive decision-making processes that engage all stakeholders [3], [4], [5].

This approach is also realized through the procedures of Water Safety Plan (WSP) formulation procedures. The systematic approach recommended by the World Health Organization (WHO) [6], aims to reduce risks in drinking water supply systems, from the catchment area to the end user.

B. *Problem Statement*

The purpose of this study is to identify hazards and hazardous events, conduct their analysis, and validate existing control measures at the initial stage of Water Safety Plan (WSP) development for water supply systems, focusing on Modules 1 – 4 [6].

C. *Review of the Current State of Research*

An analysis of existing methodologies for risk assessment of drinking water catchments, their strengths, and weaknesses is presented in [7]. The following risk assessment methods were considered: Hazard Analysis and Critical Control Points (HACCP) developed by the U.S. Food and Drug Administration (FDA), [8], and its application to drinking water supply systems [9]; World Health Organisation Water Safety Plans (WSP), [6];

Australian Standard AS/NZS 4360:2004: Risk management, [10]; and The Australian Drinking Water Guidelines (the Guidelines) [11]. The study emphasizes the importance of initial water quality verification, which is valuable for identifying key quality issues, guiding risk assessment, and developing a comprehensive understanding of the catchment and water source conditions. To identify causes and consequences of hazardous events and to prioritize risk management, [12] proposes the Failure Experience Improvement System (FEIS), which maintains a continuously updated database of failures, their causes, and consequences – including data from social media analysis.

More recent studies present WSP implementation results for the drinking water system of Mortara (Pavia, Italy) [13] where risk assessment was performed using a semi-quantitative approach. Another relevant example comes from Serbia [14], where a Field Guide to Improving Small Drinking-Water Supplies: Water Safety Planning for Rural Communities [15] was developed and applied to rural small-scale systems. The integrated Water and Sanitation Safety Planning (iWSSP) approach, implemented at pilot sites, essentially mirrors WSP methodology while combining several modules (3-4, 6-8, and 9-10), omitting some direct impact assessments and management procedures [14].

Accurate risk assessment also requires expert surveys following WSP stages. Such questionnaires [16] include inquiries on control measures implemented across system zones:

- Groundwater protection area,
- Treatment and distribution,
- Consumers.
- Risk Assessment and Risk Management (RA/RM) are also evaluated through organizational practices such as:
- Communication with consumers (websites, surveys, social media, information sessions, etc.);
- Staff and subcontractor training;
- Engagement and communication with stakeholders, including municipalities, water resource authorities, health departments, emergency services, and environmental organizations.

A significant example of RA/RM application is the Netherlands' national practice of cyclic WSP-based risk analysis and management, as described in RIVM Report 2017-0036 [17], which ensures continuous improvement and feedback integration.

An important study on the application of risk analysis and risk management (RA/RM – risicoanalyses en risicomanagement) in the Netherlands, which covers all steps of the WSP and is implemented as a cyclical process with room for improvement, is the Risk Analysis and Risk Management of Drinking Water Production in the Netherlands, RIVM Rapport 2017-0036, H.H.J.L. van den Berg et al. [16].

II. METHODS

A bibliometric analysis of the literature was carried out in two stages: a systematic search and a snowball search [18]. The systematic search followed the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [19].

The search query "*water* AND *safety* AND *plan*" was applied on Scopus (www.scopus.com) as of October 1, 2025. The database contained 3,879 documents (up to 01.10.2025), among which the most cited works were [20] (1,091 citations in Scopus – 98th percentile), [21] (622 citations), and [22] (182 citations). To refine the dataset, relevant keywords such as "*Water Safety Plans*" and "*Water Safety Plan*" were applied, reducing the sample to 293 documents.

Fig. 1 shows the co-occurrence network and relative frequency of key terms found in document keywords, titles, and abstracts. The proportional node size reflects the relative number of publications and their citation rates, while the link thickness indicates the frequency of co-occurrence.

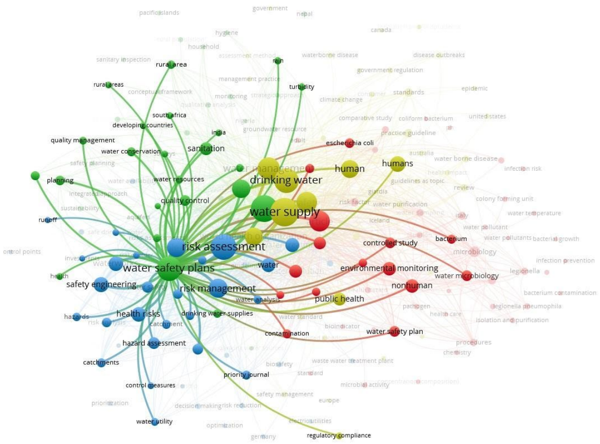


Fig. 1. Search results in the Scopus abstract scientometric database for search terms «*water* AND *safety* AND *plan*»

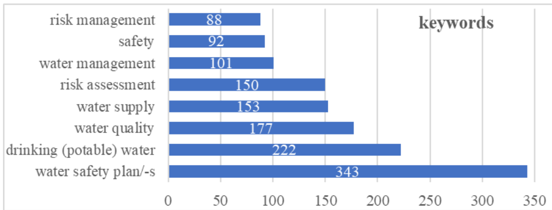


Fig. 2. Number of publications with corresponding keywords

When performing risk assessment, it is essential to follow the principles of risk management outlined in DSTU ISO 31000:2018 – Risk Management: Principles and Guidelines [23]. As one of the core principles, inclusiveness ensures stakeholder engagement, enhances awareness among the WSP team and the population [24], and increases the justification of proposed control measures.

Because WSP guidelines provide limited direction on incorporating various risk assessment methods and prioritization, it is appropriate to apply the European Standard EN 15975–2, which defines fundamental RA/RM elements and is implemented in Ukrainian legislation as DSTU EN 15975-2:2022 "Safety of Drinking Water Supply – Guidelines for Risk and Crisis Management – Part 2: Risk Management" [25].

Additionally, for the consideration of "crisis" scenarios, DSTU EN 15975-1:2022 (EN 15975-1:2011+A1:2015, IDT) [26] should be applied. These standards are thoroughly analyzed in [27].

III. OBJECT OF STUDY

The object of this study is a small town in the Ivano-Frankivsk region, Ukraine, with a daily water supply production of up to 1,000 m³/day and a population of up to about 5,000 inhabitants. Water abstraction is based on the principle of riverbank filtration, where filtrate is drawn into wells from two rivers, one of which is the Dniester. The catchment area of the smaller, cleaner tributary (let's call it Basic River) is less than 1,500 km², while the Dniester River basin area is approximately 14,700 km².

IV. RESULTS:

The introduction of Water Safety Plans (WSPs) decreases the risk of a reduction or interruption to the water supply, as well as the spread of contamination, in urban drinking water supply systems. This risk can arise anywhere from the catchment basin to the end user [6]. Drinking water safety planning is carried out in four stages: development, implementation, verification and review. During the development stage of the WSP, ten main stages (modules) are formed [6]. The first step (module 1) is to establish a multidisciplinary WSP team with a collective understanding of all components of the water supply system, from the catchment basin to the consumer. This team will then lead the development and implementation of the WSP. Module 2 involves the WSP team describing the water supply system from the catchment to the consumer. Our research considers the centralised water supply scheme of the facility shown in Fig. 3.

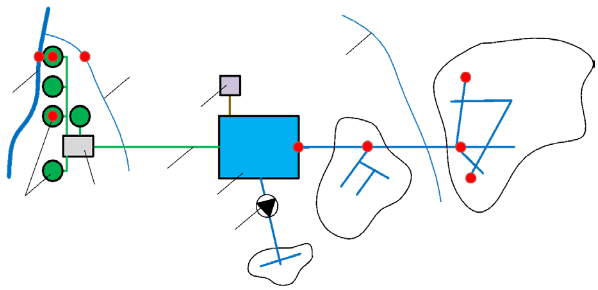


Fig. 3. Water supply scheme: 1 – Dniester River; 2, 3 – tributaries of the Dniester River; 4 – water intake wells; 5 – switching chamber and water metering unit; 6 – collecting water pipe; 7 – clean water reservoirs; 8 – disinfectant dosing unit; 9 – booster pump; 10, 11, 12 – settlements with a centralized water supply network

The main stakeholders, are identified in Module 3, along with the hazards and hazardous events, with the involvement of their representatives. At this stage, the knowledge base required for all subsequent risk management steps is formed. Clear identification of hazards and events is necessary for risk ranking, selecting control measures, and monitoring. The specific features of a water supply system must be taken into account, such as hazards related to the amount of water available to users (Q); microbiological hazards (M); acceptability of water in terms of taste, colour and odor (A); and contamination with radionuclides (R) and chemically hazardous substances (C). Hazard identification establishes a link between system description and risk assessment.

Fig. 4 summarises the hazards and hazardous events of the research object, as identified by the WSP group.

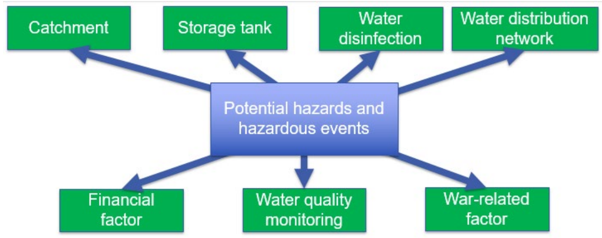


Fig. 4. Potential hazards and hazardous events at the research site

Below, we consider two examples of water-related hazards: 1) Intensive microbial growth in river water during the warm season and subsequent migration into intake wells; 2) Clogging (colmatation) of well infiltration zones, leading to increased hydraulic resistance. (See Table 1, which shows a sample from the set of indicators).

To assess microbial contamination likelihood, under the Horizon Europe project Climate-Resilient Management for Safe Disinfected and Non-Disinfected Water Supply Systems - SafeCREW during 2024–2025 774 measurements of ten microbiological indicators were performed (including Total coliforms, E. coli, Enterococci, Coliphages, Salmonella, Pseudomonas aeruginosa, helminth eggs and larvae, protozoan oocysts and cysts, total microbial count at 37 °C).

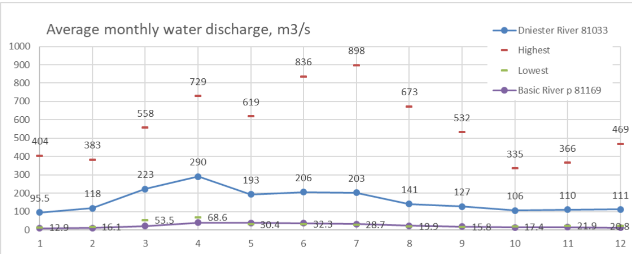
Physicochemical parameters such as conductivity, temperature, pH, and free/total chlorine were determined on-site using portable meters (GMH3410, Ezodo 8200M, Ezodo 7200, Milwaukee MI404 Photometer), while other indicators were analyzed in laboratories, in particular in the Hydrochemical Laboratory of NUWEE (Certificate PT-046/025). In total, 2,956 measurements across 28 indicators were conducted.

Clogging risk (colmatation of well infiltration zones) increase with turbidity in river water; therefore, turbidity analysis was performed for both rivers (Fig. 5). The average annual turbidity in the Basic River was 81 g/m³, whereas in the Dniester River it reached 180 g/m³. The maximum turbidity was 8,100 g/m³ for the Dniester compared to 3,300 g/m³ for the Basic River. The duration of high-sediment exposure (>100 g/m³) was about 55 days per year for the Dniester River and only 13 days per year for the Basic River, indicating a higher risk of well clogging and filtration efficiency loss when operating wells with water infiltrating from the Dniester River.

TABLE I. RISK ASSESSMENT (SAMPLING)

Hazardous event	Type of hazards	Like–lihood	Severity	Risk assessment	Level of risk
Intensive development pf microbial contamination in the river (X) during the warm season and its subsequent entry into the catchment wells (Y).	M	2	4	8	M
Clogging (Colmatation) of the well's filter zones (X), which causes an increase in hydraulic resistance (Y).	Q, R	2	3	6	M
Failure in the pump unit (X), which will lead to the stoppage of water supply to the storage tank (Y).	Q, C, M, R	2	1	2	L
Failure of catchment pumps (X) due to a power grid malfunction caused by flooding of the switchboard during the flood (Y).	Q	1	4	4	L
Freezing of the main water pipeline (X) supplying water to the storage tank, which may lead to the emptying of the storage tanks (Y).	Q	2	3	6	M
Poor maintenance of storage tanks (ultimately cleaning and disinfection) (X) increases the risk of microbial contamination of the water in the storage tank and the subsequent spread of contaminants in the water supply network (Y).	M, C	5	3	15	H

Risk levels were classified as Low (≤5), Medium (6–14), and High (≥ 15).



The developed hazard identification framework allows systematic evaluation of events affecting RBF systems, particularly microbial contamination and clogging of infiltration zones.

Field data showed higher turbidity and suspended sediment loads in the Dniester River, increasing the risk of well clogging and reduced filtration capacity compared to the smaller tributary.

Microbiological monitoring identified a medium-to-high risk of contamination in periods of elevated water temperature and inadequate reservoir maintenance.

The obtained results enable prioritization of control measures at critical points and support the development of site-specific Water Safety Plans for small municipal systems relying on riverbank filtration.

Future research should focus on the integration of sensor-based monitoring and AI-driven data interpretation to improve early warning and adaptive management within WSP frameworks.

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