WATERAGRI

D4.6 Development of Microfluidics for Water Reuse at Farm-scale

04/2023

WP 4 Nutrient Recovery from Streams

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Abstract:	This deliverable focuses on the qualitative and quantitative analysis of agricultural water to determine the concentrations of micronutrients and micropollutants, along with the design and development of microfluidic systems to recover micronutrients. Microfluidic systems for nutrient recovery offer an innovative approach to recovering the lost nutrients from the agricultural runoff and help in closing the nutrient loop back to the farmland. These innovative systems can be seamlessly incorporated into existing water treatment infrastructure and have the potential to efficiently process large water volumes, offering a continuous and effective approach for micronutrient recovery through process intensification. However, it is important to note that further technical advancements and improvements are needed to ensure the successful implementation of these systems in agricultural settings. The deliverable also identifies ideal deployment strategies, which include mapping the overland flow pathways.

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MCPA	2-methyl-4-chlorophenoxyacetic acid
MCPB	4-(4-chloro-o-tolyloxy)butyric acid
MCPP	methylchlorophenoxypropionic acid
PAH	Polyaromatic hydrocarbons
MV	Manual valves
NO	Normally open
NC	Normally closed
CAPEX	Capital expenditure
OPEX	Operational expenditure
DEM	Digital elevation model
ALS	Aerial laser scanning

List of definitions	
Agricultural wastewater	wastewater from agricultural operations, typically nutrient rich wastewater from livestock management etc
Drainage water	Excess water removed from poorly drained lands
Agricultural runoff	Agricultural Runoff is water from farm fields due to irrigation, rain, or melted snow that flows over the earth that can absorb into the ground, enter bodies of water, or evaporate

1. Introduction

In recent years, the use of chemical fertilizers containing nitrogen and phosphorus has become more prevalent as a means of enhancing crop yields. However, the improper and excessive application of such fertilizers poses significant risks to soil health and the quality of surface and ground waters due to pollution and eutrophication. To address this issue, the European Commission has set an ambitious target to reduce nutrient losses by a minimum of 50% by 2030 while also preventing any decline in soil fertility through its Farm to Fork strategy, a crucial component of the European Green Deal. The implementation of this strategy is expected to lead to a reduction in fertilizer use by approximately 20%. In response to this pressing issue, researchers have focused on the development of innovative solutions and technologies that promote nutrient recovery and reuse. One such approach developed within WATERAGRI involves the use of microfluidics technology to integrate into agricultural wastewater treatment systems and recover valuable nutrients from wastewater within the operational context.

Microfluidics is a rapidly developing field that deals with the precise control and manipulation of fluids through micron-scaled channels or pipes. It involves the development of microminiaturized devices that can confine fluid networks within them. Recent breakthroughs in the field of microfluidics have resulted in the use of continuous flow technology with exceptional accuracy, paving the way for numerous applications across a wide range of industries, such as biological analysis, chemical synthesis, optics, and information technology. Over the past two decades, microreactors employing microfluidic technology have made significant advancements as a process intensification technique. The unique characteristics of microreactors result from their small dimensions, in which chemical reactions take place. These reactors exhibit exceptional properties, including high surface-to-volume ratios, which facilitate superior heat and mass transfer kinetics, short molecular diffusion distances, laminar flow, and excellent spatial illumination homogeneity, surpassing those of traditional reactors. The use of microfluidic technology in microreactors has transformed chemical synthesis, leading to improved yields, reduced reaction times, and increased selectivity. In addition, microreactors allow for precise control over reaction conditions, including temperature, pressure, and mixing, resulting in the synthesis of complex molecules that would be difficult to achieve using traditional reactors. The advantages arising from the microfluidic dimensions might serve as an ideal basis for the development of a nutrient recovery system by performing the adsorption reaction in the micro-confinement, enhancing the adsorption kinetics of the reaction.

This report focuses on analysing the agricultural water from various sites to determine the amount of micronutrients that are leached out of agricultural fields and into the agricultural runoff. It also investigates the presence of emerging pollutants resulting from conventional agricultural practices. Furthermore, this report presents a proposal for designing and developing a microfluidic system that can effectively recover nutrients from agricultural wastewater streams and identify ideal deployment strategies by mapping the overland flow pathways. The ultimate goal is to establish a sustainable approach that addresses the issue of nutrient loss while promoting the reuse of wastewater in agricultural settings.

2. Wastewater analysis

Wastewater analysis involves a comprehensive examination of various types of wastewater with the aim of establishing a comprehensive database on the presence of both micronutrients and micropollutants. The technical recommendations for the microfluidic nutrient recovery systems were established by analysing the agricultural water to better understand the water quality of irrigation systems and the potential of wastewater reuse. Additionally, such analysis can offer valuable insights into the selection of suitable adsorbents for the selective removal of nutrients. This analysis was performed using wastewater samples provided by UNIDEB, UNIBO and UPWr. These analyses helped in the identification of the nutrient status and composition. Water sampling from the sampling sites was done in four phases, with consideration of climate and geography. Moreover, the waters were analysed for the pesticides and polyaromatic hydrocarbons as it is critical information for the reusability of wastewater. In addition to the technical recommendations for the system, these analyses of different agricultural waters from various locations across different countries enable to address the possible challenges and evaluate the viability of implementing the microfluidic technology in different geo-platforms.

A list of ten important micronutrients for analysis was first established, see Table 1:

Table 1. *List of micronutrients identified for analysis.*

Micronutrients	
Copper (Cu)	Phosphorous (P)
Zinc (Zn)	Calcium (Ca)
Boron (B)	Magnesium (Mg)
Manganese (Mn)	Potassium (K)
Iron (Fe)	Sulphur (S)

The list of analysed pesticides and polyaromatic hydrocarbons (PAH) is based on the most common pesticides used across the EU, see Table 2:

Table 2. *List of pesticides for analysis.*

Pesticides		
Benzo(a)anthracene	Terbutylazine	Atrazine
Acenapthylene	Desethyl terbutylazine	Cyanazine
Acenaphtene	Chlorotoluron	Desethyl atrazine
Fluorene	Diuron	Desisopropyl atrazine
Benzo(a)pyrene	Isoproturon	Hexazinone
Anthracene	Linuron	Prometryn
Benzo(ghi)perylene	Metabenzthiazuron	Propazine
Pyrene	Metobromuron	Sebutylazine
Benzo(b)fluoranthene	Metazachlor	Simazine
Benzo(k)fluoranthene	Metolachlor	Terbutryn
Chrysene	Propachlor	2,4-dichlorophenoxy (Butyric Acid)
Phenanthrene	Metoxuron	2,4,5-trichlorophenoxyacetic acid
Fluranthene	Monolinuron	Dichlorprop
Indeno(1,2,3, c,d)pyrene	Alachlor	Dicamba
Dibenz(a,h)anthracene	Chloridazon	Bentazon
Naphthalene	Metamitron	Fenoprop
Sum of PAHs	Bromacil	Carbendazim

2,6-Dichlorobenzamid	Propanil	Ethofumesate
Metribuzin	MCPB	Carbetamide
MCPA	MCPP	Chlorpropham
Fluroxypyr	2,4-dichlorophenoxyacetic acid	

The sources of agricultural wastewater are from UNIDEB (Hungary; fermented sludge wastewater and irrigation channel wastewater), UNIBO (Italy; surface irrigation water and agricultural drainage water) and UPWr (Poland; agricultural runoff and ditch).

Figure 1. *Sampling sites in Hungary (left), Italy (middle) and Poland (right).*

The sampling of wastewater took place in the fourth quarter (Q4) of 2021, the first and fourth quarters (Q1 & Q4) of 2022, and the first quarter (Q1) of 2023. Briefly, the wastewater sampling process can be defined as follows: first, samples were collected in the field and stored in plastic bottles. Then, in the laboratory, each water sample (150 ml) was microfiltered (0.22 µm) to remove all live cells and preserved with HNO_3 65% (2% HNO_3 in the sample) to maintain the micronutrient concentration steady. The temperature at which the samples were taken was also recorded. The analyses were performed according to validated methods. A thorough system of first, second, and third-line quality controls was used for each outcome. The water analysis was performed by a highly trained team with the most modern characterization techniques like atomic absorption spectroscopy (AAS), Inductively Coupled Plasma (ICP), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), High-performance liquid chromatography (HPLC), Gas chromatography–mass spectrometry (GC-MS), Liquid Chromatography Mass Spectrometry (LC-MS), etc. The detailed tabulated results of all the water analyses are provided in Annex.

2.1. Remarks and recommendations

The results of a comprehensive analysis of various case studies conducted across different countries have demonstrated that agricultural wastewaters contain a plethora of micronutrients in varying quantities. UNIDEB's fermented sludge samples were found to be abundant in potassium; potassium is an essential nutrient that plays a crucial role in several physiological and biochemical processes in food crops, including photosynthesis, water uptake, and transportation, activation of enzymes involved in the production of starch and sugars, and promoting root growth. Additionally, the wastewater displayed a complete absence of any micropollutants, indicating that it could be safely repurposed for irrigation purposes, particularly for growing food crops. The drainage water and surface water from the ditch at UPWr contained high levels of calcium and sulphur, two essential nutrients that are beneficial for the growth and development of food crops. Calcium is involved in regulating nutrient uptake and transportation, strengthening cell walls, and influencing plant growth, while sulphur plays a critical role in protein synthesis and enzyme activation in crops. In addition to calcium and sulphur, the samples from UNIBO also contained a significant amount of manganese, which is beneficial for food crops. Manganese aids in various physiological processes, including photosynthesis, nitrogen metabolism, and enzyme activation, and helps to improve the plants' ability to resist environmental stresses. Thus, to ensure a sustainable agricultural system, it is imperative to recover these valuable micronutrients and reintroduce them back into the farmlands. By doing so, we can efficiently close the nutrient loop and reduce our dependence on synthetic fertilizers. To achieve this, microfluidic systems can be employed to enhance the adsorption kinetics of micronutrients from agricultural wastewater via process intensification. Although microfluidic process intensification has been established as a viable concept for the adsorption of nutrients, its scalability remains a significant concern[1,2]. Nevertheless, EDEN's expertise in high-throughput microfluidics offers a promising solution to this issue by enabling the development of a cutting-edge microfluidic system that can efficiently process large volumes of water. The use of such systems can provide an efficient way to recover the micronutrients and simultaneously address the issue of nutrient recovery. This innovative approach can significantly contribute to the conservation of natural resources and create a more sustainable agricultural system.

However, the analysis of contaminants from the case studies in Poland and Italy has indicated the presence of certain micropollutants like chlorotoluron, metazachlor-oxalamic acid (OA), metazachlor-ethane sulfonic acid (ESA), Metolachlor and PAHs such as Fluorene, Phenanthrenein in the agricultural wastewater. These micropollutants can cause severe harm to the environment and must be treated before releasing the water back into the ecosystem. The treatment of these contaminants is crucial to safeguard the environment and ensure that agricultural practices do not contribute to its degradation.

3. Microfluidic nutrient recovery system

3.1. Prototype 1

Prototype 1 of the microfluidic nutrient recovery system was designed based on Eden Tech's AKVO compact water treatment system. This system is inspired by nature and is designed to remediate polluted waters by mimicking the systemic fluidic networks found in nature: the vascular systems of humans and plants. The AKVO prototype, patented by Eden, has a unique architecture that allows for the parallelization of thousands of microchannels, resulting in high flow rates at low pump pressure. This innovative design allows for the treatment of large volumes of water with minimal energy consumption. AKVO is made up of filtrating discs, which are similar in size to a CD and can be stacked in groups of 10s and 100s, depending on the client's needs. The discs are engraved with networks of microchannels, which are arranged into smart energy microfluidic grids, as shown in Figure 2. The high flow rates and low energy consumption of this system make it an attractive option for agricultural and municipal applications, and the ability to customize the system by stacking discs in groups of 10s and 100s adds to its versatility.

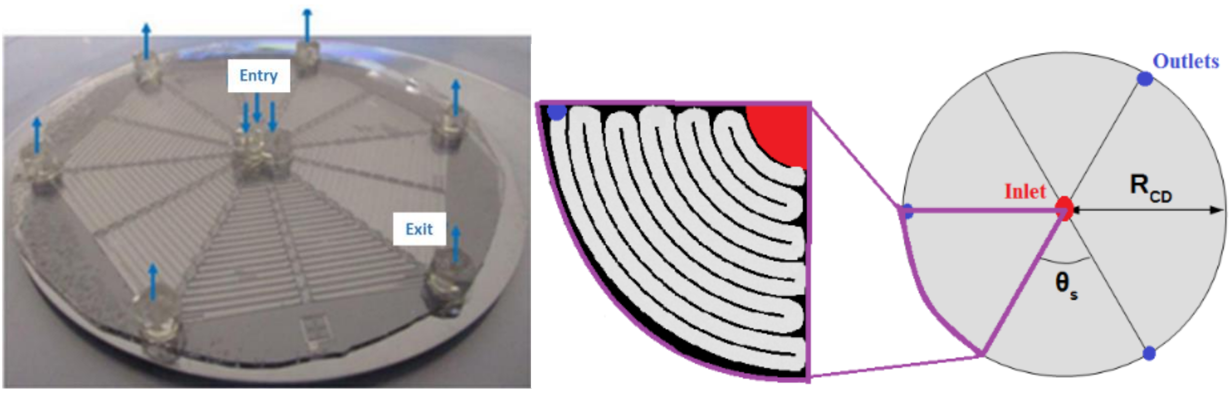


Figure 2. *Image of the first AKVO prototype and its schematic representation*

The first iteration of the prototype design features a central inlet structure with three inlets and six peripheral outlets. The fluid passes through a grid of 12 structures that purify the fluid before it reaches the outlet. The purification process is facilitated by a network of 392 parallelized microchannels that connect the main entry and exit channels of each of the 12 structures. These microchannels are designed to integrate adsorbing agents on one or more walls, which are capable of collecting micronutrients. This feature allows for efficient nutrient recovery from wastewater. The dimensions of the prototype are specified in Table 3, providing precise details on the size and shape of the system.

Table 3. *Dimensions of the first prototype 1's design*

H	W	L	Main channel's H
10 µm	400 µm	1 mm	200 µm
Main channel's W	**Main channel L**	**Number of structures per CD**	**Number of microchannels per CD**
200 µm	~13 cm	12	4704

The EU Nitrates Directive is a crucial instrument for safeguarding water against agricultural pressures and complements the Water Framework Directive. The directive's first step is to identify waters that are polluted or at risk of becoming so if no action is taken. These waters are characterized by having nitrate concentrations exceeding 50 mg L^{-1} or having the potential to exceed this level if no intervention occurs. Additionally, the directive considers waters that are eutrophic or susceptible to eutrophication without proper management practices. Keeping this in mind, a simulation was designed for the first prototype on COMSOL. This simulation takes into account the requirements of the EU Nitrates Directive and considers the potential for eutrophication. By doing so, the simulation provides a comprehensive understanding of how the prototype will perform in real-world applications, ensuring that it meets regulatory standards.

For the adsorption of nitrates, an anion exchange resin Indion NSSR was considered as the adsorbent with an adsorption rate constant k_{ads}= 0.06 min^{-1} and desorption rate constant k_{des}= 0.006 min^{-1} [3]. To simulate the performance of this resin in a real-world setting, COMSOL Multiphysics software was used to model the AKVO prototype simulations with microchannel dimensions L=1 mm, W=400 µm, and H=10 µm. The coefficient of diffusion of nitrates in water, which was found to be $D=1.7\times10^{-9}$ m^2 s^{-1} (M=62 g mol^{-1}), was used in the simulations. The initial nitrate concentration was set to C_0=10 mg L^{-1}. It was found that at the Péclet number[1] 0.9, the prototype achieved a 90% purification rate for nitrates. The prototype could process a flow rate of 67 L day^{-1} in the CD, indicating that it had a promising capacity for removing nitrates from water. However, it was noted that the prototype's adsorption capacity was limited by its fast saturation rate. The device reached its maximum capacity within just one second (t_{sat}=1s). Therefore, while the prototype showed potential for removing nitrates from the water, it may not be the best option for removing micronutrients from water due to its limited adsorption capacity.

[1] The Peclet number determines whether mass transport is dominated by either diffusion or convection, which is greater than 1 for convection and less than 1 for diffusion. The values of the Peclet number can be calculated by the equation Pe = vl/D where v is the velocity of the fluid, l is the characteristic length of the fluid, and D is the diffusion coefficient.

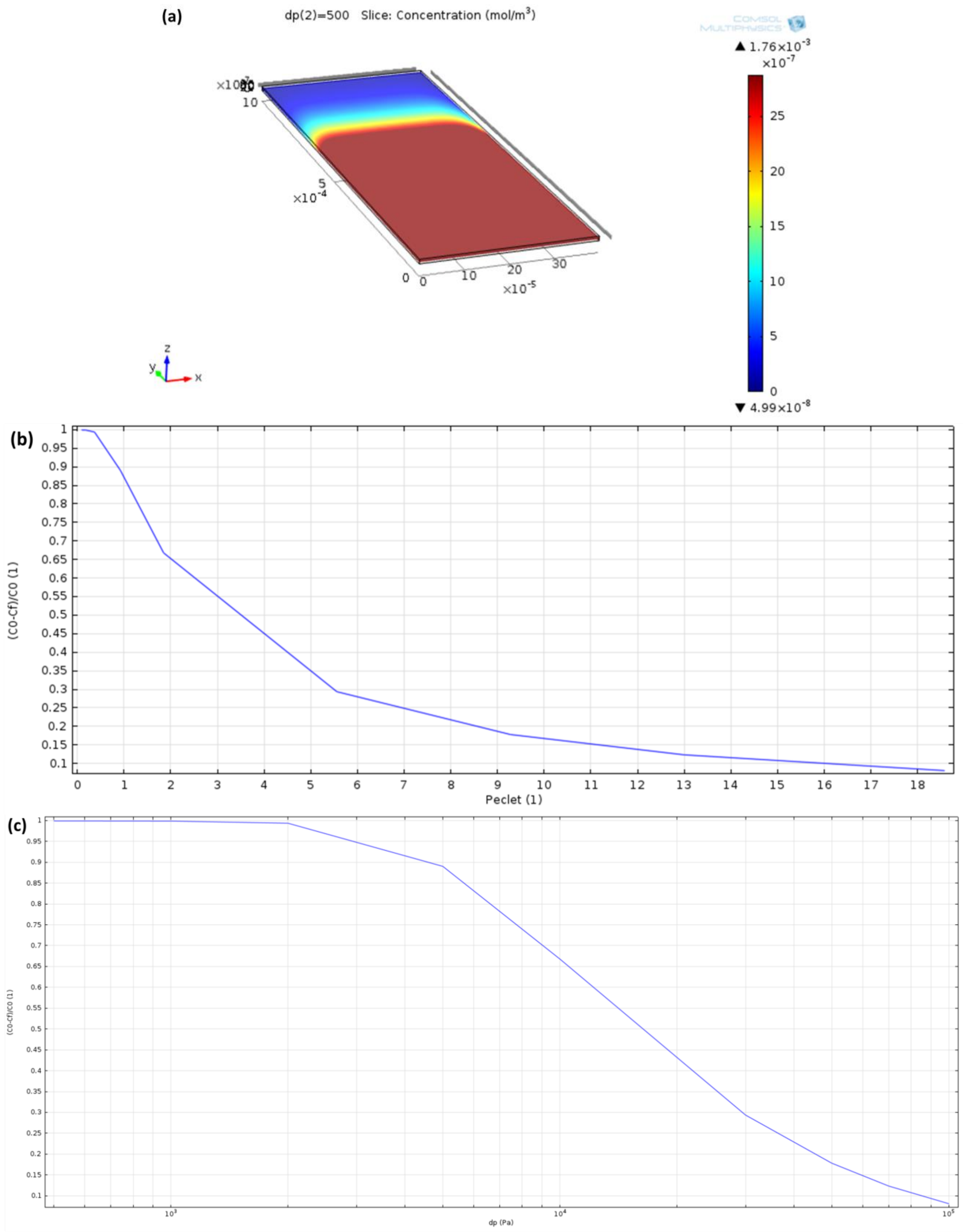

(a)
dp(2)=500 Slice: Concentration (mol/m³)
▲ 1.76×10⁻³
×10⁻⁷
25
20
15
10
5
0
▼ 4.99×10⁻⁸
×10⁻⁴
×10⁻⁵
(b)
(C0-Cf)/C0 (1)
Peclet (1)
(c)
(C0-Cf)/C0 (1)
dp (Pa)

Figure 3. *(a) Concentration at the center of the channel for ΔP=500Pa, (b) Purification rate as a function of Péclet number and (c) Purification rates obtained for several pressure differences applied to the µchannel (logarithmic (ΔP) scale)*

3.2. Prototype 2

To circumvent the saturation problem encountered in the first prototype, the second prototype underwent a modification where the microfluidic channel dimensions were increased. This crucial adjustment facilitates the use of readily available ion exchange resin beads for efficient absorption of nutrients present in agricultural wastewaters. Furthermore, it enables the isolation and concentration of these adsorbent particles, which can enhance the overall effectiveness of the system. Several microbeads capable of adsorbing nutrients are commercially available, such as Lewatit from Lanxess[4,5], Puralite[6,7], Amberlite from Dupont[8,9], Dowex from Dow[10], Diaion from Mitsubishi[11] etc.

The absorption of nutrients using ion exchange resin beads occurs through a mechanism where the nutrient ions in water are replaced by ions present in the resin phase. These resin beads have been extensively studied for their potential in the recovery of nutrients such as phosphates and nitrates from various sources of wastewater. Synthetic organic resins made of polymers are used for most ion exchange applications in water treatment because of their relatively high ion exchange capacities and ease of regeneration. Similar to the first prototype, the second prototype also employs microfluidic networks, but in this case, they serve two purposes. Firstly, they are used for process intensification, and secondly, they facilitate the isolation of adsorbent microbeads. This prototype capitalizes on the absence of turbulence at the microscale to achieve precise control over the position and movement of suspended particles. Through the application of established microfluidic techniques, adsorbent particles can be separated while still in suspension and concentrated hundreds to thousands of times over. This intricate particle positioning mechanism enables the nutrient-adsorbent microbeads to be guided into a separate chamber for recovery and regeneration. Once regenerated, the microbeads can be reintroduced into the system for recirculation.

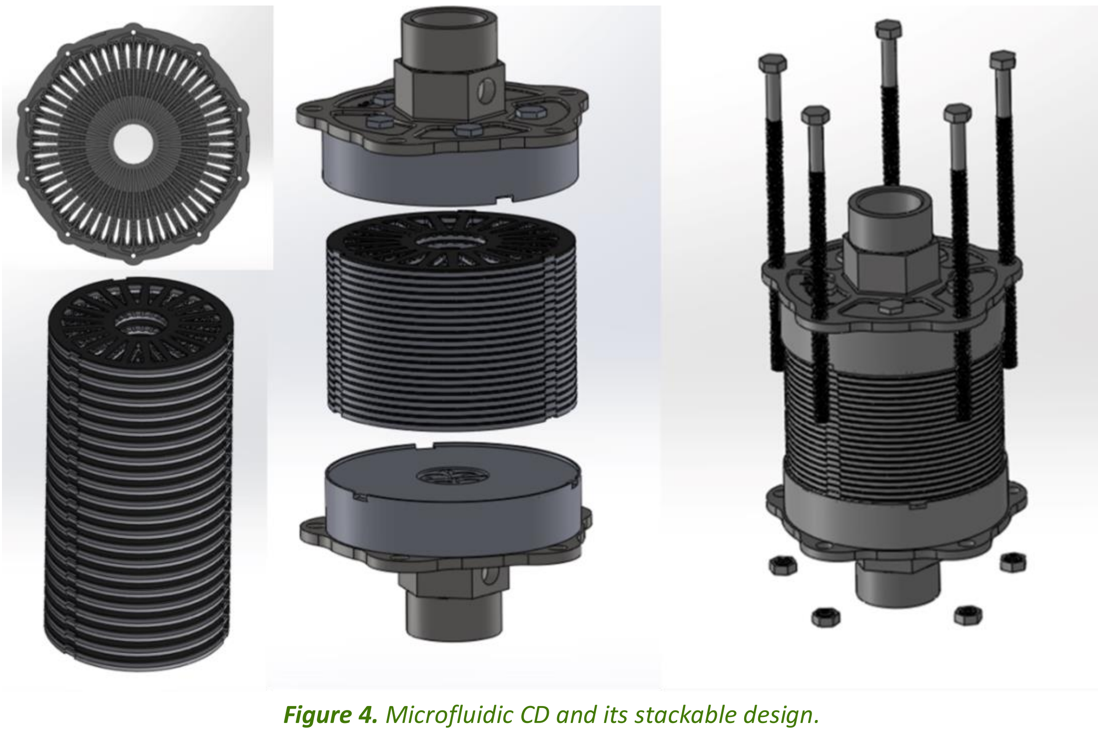


Figure 4. *Microfluidic CD and its stackable design.*

The microfluidic network employed in this prototype utilizes a combination of two techniques - inertial microfluidics and obstacles - to isolate the adsorbent microbeads with high precision. Inertial microfluidics, one of the isolation techniques used, leverages inertial forces to align the initially dispersed particles into precise positions within the microfluidic channels. Although several factors influence this phenomenon, the velocity profile inside the microchannel plays a major role. This phenomenon, commonly found in nature, is biomimetic in its approach, with manta rays being an excellent example of its application in separating and concentrating microplankton in their oesophagus via a series of microstructures in their mouth that create local vortices. The second technique, obstacle-based filtration, employs meticulously designed geometric obstacles like pillars to reinforce the filtration process. The system ensures that no particles larger than the gap between pillars can escape the filtration process. The parallelized nature of the system minimizes the impact on overall performance if particles get trapped in the pillar structure. Furthermore, a purge system is in place to periodically clean the system of any aggregated particles, creating a failsafe mechanism. Thus, even if the inertial focusing technique fails locally, the obstacle filtration technique takes precedence, ensuring the system's continued functionality. By utilizing both of these techniques, this microfluidic network achieves exceptional precision and efficiency in isolating the adsorbent microbeads, allowing for their subsequent recovery and regeneration.

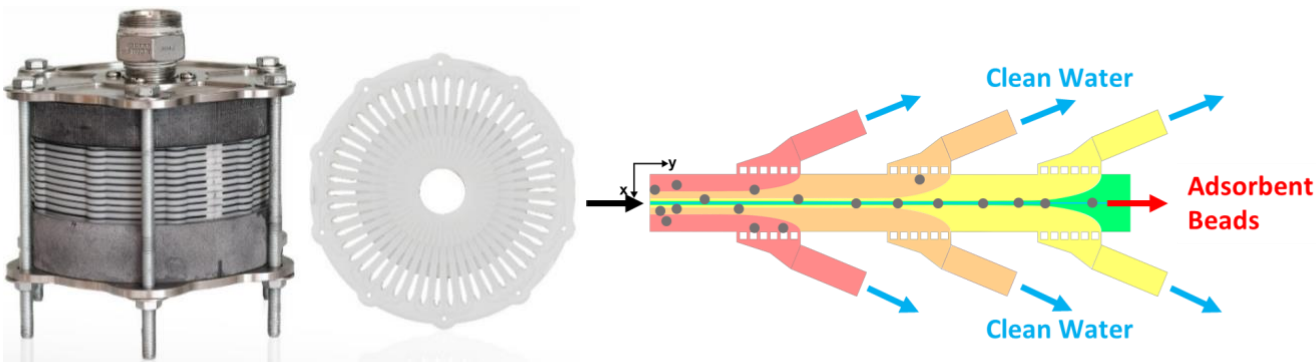


Figure 5. *Microfluidic nutrient recovery system with stacked prototype 2 CDs, and a schematic representation of the mechanism behind the Microfluidic nutrient recovery system prototype 2.*

This technology's biomimetic design, which has been incorporated into 2D CD structures, is its fundamental component. It enables precise control over suspended particles, making the process highly efficient. Each CD has multiple copies of a filtration unit (as illustrated in Figure 5: 50 microfluidic channels on a 15 cm diameter CD), and when stacked together, they form a 3D network, creating a miniature factory with a high throughput capacity. The system's processing capacity is directly proportional to the number of CDs stacked, allowing for increased water volume treatment. Notably, the entire process is built upon a microfluidic design that isolates and concentrates adsorbent beads, eliminating the need for any chemical agents. Furthermore, its low-pressure operation requires minimal energy input.

Table 4. *Dimensions of prototype 2's design*

Main channel's H	Main channel's W	Main channel's L	Number of structures per CD	Pillar Gap
450 µm	1600 µm	1.7 cm	50	85 µm

3.2.1. Lab scale experiments using prototype 2.

A lab-scale experimental set-up was developed to analyse the adsorption bead isolation of the microfluidic nutrient recovery system. The experimental setup is shown in Figure 6. It consists of a reservoir of 300 L capacity from which water is pumped through the circuit using a high-capacity pump. Prior to testing with the adsorbent beads, a series of experiments were carried out to ensure the setup had no leakage and had the capacity to operate at high flow rates. The system operates in 2 modes, namely collection mode and purge mode. During the collection mode, the water is pumped from the reservoir and follows the path indicated in Figure 6 (blue arrows). The adsorbent microbeads are injected into the water in the vicinity of MV2. At a flow rate of 100 L min^{-1}, the adsorbent-bead-containing water is pumped through the microfluidic system, where the microbeads are separated into a small volume of water, and the rest of the clean water is returned to the reservoir.

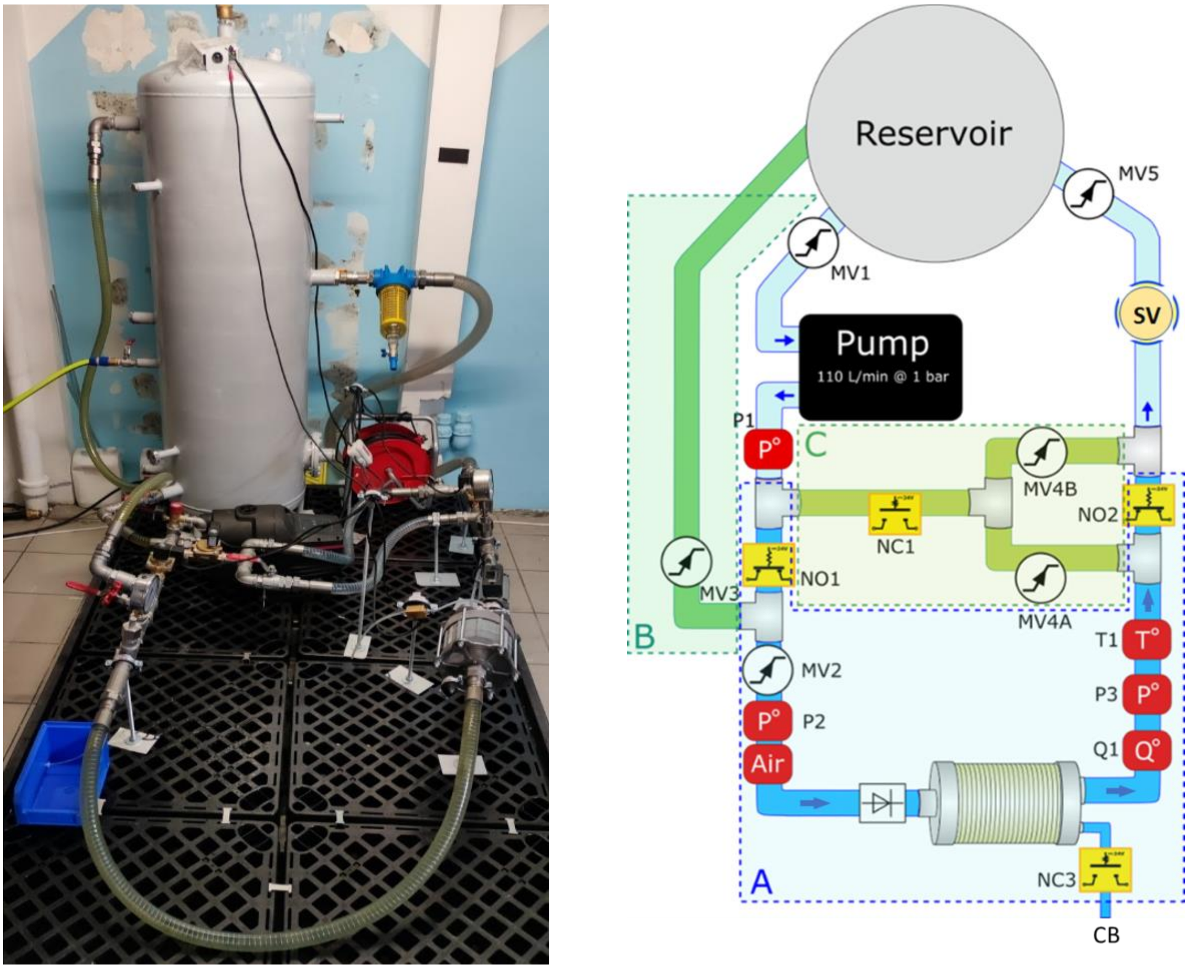


Figure 6. *The lab scale experimental setup and the flow chart of the microfluidic nutrient recovery system; MV1, MV2, MV3, MV4A, MV4B, MV5: Manual valves; P1: safety relieve valve (3 bar); P2, P3: Manometer; NO1, NO2: normally open valves; NC1, NC3: normally closed valve; Q1: Flowmeter; Air: air bubble purge; CB: concentrated beads; SV: safety filter.*

The purge mode mechanism is set up to allow the clearance of any microbeads lodged in the obstacles. The NO1 and NO2 are closed during purge mode, while the NC1 and NC3 are opened. The water is then pumped through the microfluidic system in the other direction to dislodge the microbeads, which are later collected at CB. The frequency of purging determines the concentration power of the system. The concentrating power represents the ability of the system to concentrate suspended particles in a given volume of water. It is defined by the ratio of the volume of water treated in the collection and the volume recovered during the purge.

The experimental setup's design ensures that the microfluidic nutrient recovery system's performance can be evaluated accurately. The high-capacity pump and 300 L reservoir enable the system to operate continuously, replicating real-world conditions. The setup's ability to operate at high flow rates and the absence of leakages ensures that it can handle the expected volume of water effectively.

The experiments were carried out using circular beads of 250-350 µm diameter, corresponding to the particle size of Lewatit® FO 36 (~350 µm) microporous polystyrene-based resin with a phosphate adsorption capacity (Qe) of 90 mg g^{-1} [12]. During the course of the 7 h experiment, the flow rate was held constant at 100 L min^{-1}. The system was purged every hour for 5 seconds at a pressure of 1 bar. Despite the system's impressive isolation rate[2] of over 98%, the experiment showed that only 88.30 ± 2.05 % of the injected particles were recovered (Figure 7). This result indicates that some particles may still be trapped inside the system even with an efficient purging mechanism.

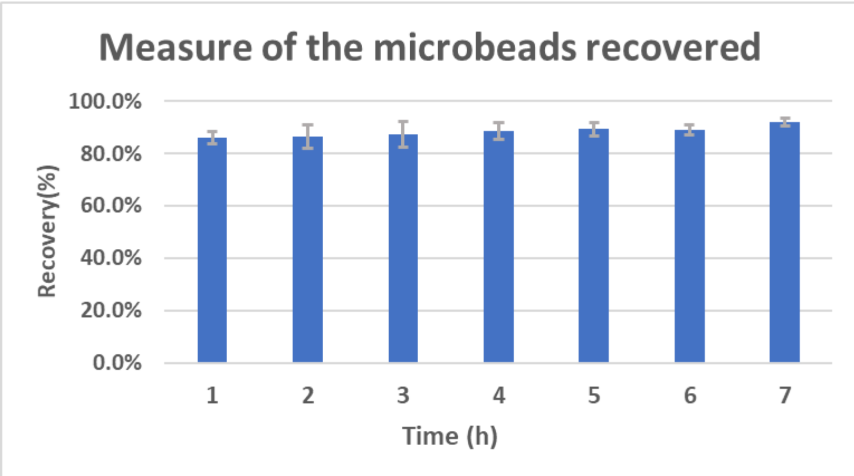


Figure 7. The recovery of the microbeads over a period of 7h.

4. Deployment path for the microfluidic nutrient recovery system

Although the microfluidic nutrient recovery system has shown great promise as a novel technology for recovering nutrients, various technical recommendations must be taken into account to ensure the efficient deployment of this system in agricultural settings.

4.1. Strategize on the wastewater streams for recovery

Developing an effective strategy for nutrient recovery from wastewater is a critical step towards the successful implementation of a microfluidic nutrient recovery system in agricultural settings. This involves identifying the most nutrient-rich agricultural wastewater streams and adapting the recovery solution to meet specific needs. Through a careful analysis of wastewater streams, it becomes possible to determine which nutrients are most abundant and which adsorbent resin beads would be most effective in targeting them. By employing a targeted approach, the efficiency and effectiveness of the microfluidic nutrient recovery system can be improved, enhancing its overall implementation potential

[2] The ratio between the concentration of injected particles and the concentration of particles in the outlet.

in agricultural settings. Additionally, this strategic approach can help optimize the use of resources and reduce waste in agricultural operations. By recovering and reusing valuable nutrients from wastewater, agricultural producers can improve their sustainability and reduce their environmental impact. This not only benefits the environment but also provides a cost-effective alternative to traditional nutrient sources, ultimately increasing profitability in the long term. With a well-planned nutrient recovery strategy, the microfluidic nutrient recovery system can be optimized for maximum efficiency and effectiveness in agricultural applications.

4.2. Design a compatible adsorbent bead regeneration step.

To achieve a closed circulation loop in the microfluidic nutrient recovery system, it is crucial to design a regeneration step that is compatible with the adsorbent bead used and the targeted nutrient. This step is essential for recovering the adsorbent beads' functionality after their circulation in the microfluidic network. The design of a feasible regeneration step is dependent on the specific ion exchange resin and the target nutrient. It is imperative to consider factors such as regeneration time, temperature, and the regeneration solution's composition. The regeneration solution should effectively desorb the targeted nutrient from the adsorbent beads without causing damage to the beads or any other system components. By integrating an efficient and compatible regeneration step into the microfluidic nutrient recovery system, we can ensure that the adsorbent beads' functionality is maintained and the system operates optimally. This will contribute to the overall sustainability and economic viability of the system, making it a more attractive option for agricultural wastewater treatment and nutrient recovery. Furthermore, the practical implementation of microfluidic systems for nutrient recovery requires efficient and cost-effective separation and recovery of the captured nutrients. The development of innovative recovery and recycling methods will be necessary to ensure that the captured nutrients can be effectively and sustainably returned to the farmland.

4.3. Perform techno-economic analysis.

To assess the viability and feasibility of the microfluidic nutrient recovery system for agricultural wastewater treatment to recover nutrients, it is essential to conduct a comprehensive techno-economic analysis. The analysis should evaluate the system's suitability based on the wastewater treatment capacity and nutrient availability. A key aspect of the analysis would be to determine the capital expenditure (CAPEX) and operational expenditures (OPEX) associated with the system's deployment and operation. This analysis would help to identify and highlight any areas for optimization. In addition to financial considerations, it's important to evaluate the environmental and social costs associated with nutrient releases. This analysis can provide insights into the system's sustainability and societal impact, allowing for the development of effective strategies for minimizing these costs. This would provide valuable information to stakeholders, including investors and policymakers, and enable them to make informed decisions regarding the adoption and implementation of the microfluidic nutrient recovery system.

4.4. Partner with adsorbent bead manufacturers

To further enhance the efficiency and effectiveness of the microfluidic nutrient recovery system, it's important to collaborate with manufacturers who specialize in the production of ion exchange resin beads. These manufacturers can provide valuable expertise in designing beads that specifically target multiple nutrients with greater efficiency. Collaborating with such manufacturers can also help to optimize the manufacturing process of the beads, ensuring consistent quality and performance. This partnership can facilitate the development of customized bead solutions that are tailored to meet the specific needs of the agricultural wastewater treatment industry. Furthermore, by partnering with bead manufacturers, it may be possible to reduce the costs associated with the production and distribution of the beads, thereby making the system more economically viable.

5. Mapping overland flow pathways

The catchment of the Ślęganina watercourse, Lower Silesia in southwestern Poland

All the fields belonging to the farm in the Polish case study are shown in Figure 8. However, not all of them have been investigated. The fields where the UPWr carried out experiments as part of the project are located in the catchment of the Ślęganina watercourse. To establish the areal extent of the catchment of the Ślęganina watercourse, a digital elevation model (bare-earth DEM) was used. It was created with LiDAR data from aerial laser scanning (ALS) in the form of a point cloud with a density of 4 points/m^2. At the pre-processing stage, special attention was paid to selecting the optimal resolution and hydrological correction of the DEM. Grid format DEM of spatial resolution 0.5 m, generated from the point cloud, was used for analyses in ArcGIS with ArcHydro module and functions in the Spatial Analyst extension. ArcGIS (software created by ESRI Environmental Systems Research Institute) is one of the most popular commercial mapping products. However, the analysis and establishment of surface runoff pathways can be performed with most available GIS applications, including freeware. All the analyses and resulting maps were created on the basis of spatial data in the coordinate system PL-92 EPSG:2180.

The creation of maps of flow direction and flow accumulation can be performed on the hydrologically conditioned (hydrologically correct) DEM. The model was corrected with the *fill sink* function (ArcGIS geoprocessing tool that removes erroneous sinks and peaks in an elevation surface raster) – as in most depression filling algorithms. The calculations were based on the 1-D single flow direction. Sink filling (or peaks removing) maintains the continuity of flow pathways, but apart from vertical error,s it may also remove real microtopographic features. Therefore it is important to control the created DEM in order to avoid excessive generalisation. The disruption and impediment of overland flow by sinks (pits and depressions), hummocks and hedgerow banks were analysed. Catchments that are mostly flat (low slope values) also need additional “breaching” or “burning” DEM with place line bridges, culverts, and other DEM errors. Finding that places require some additional documentation and/or point cloud and orthophoto analysing and/or field visits. There are tools for “breaching” in proprietary software (i.e. ArcGIS-TopoToRaster-ANUDEM, Arc Hydro-Conditioning) and free software (i.e. QGIS, GRASS-r.carve). We used orthophoto, field visits and documentation (Database of Records of Waters and Water Facilities) for identifying these places. The results are presented in Figure 8.

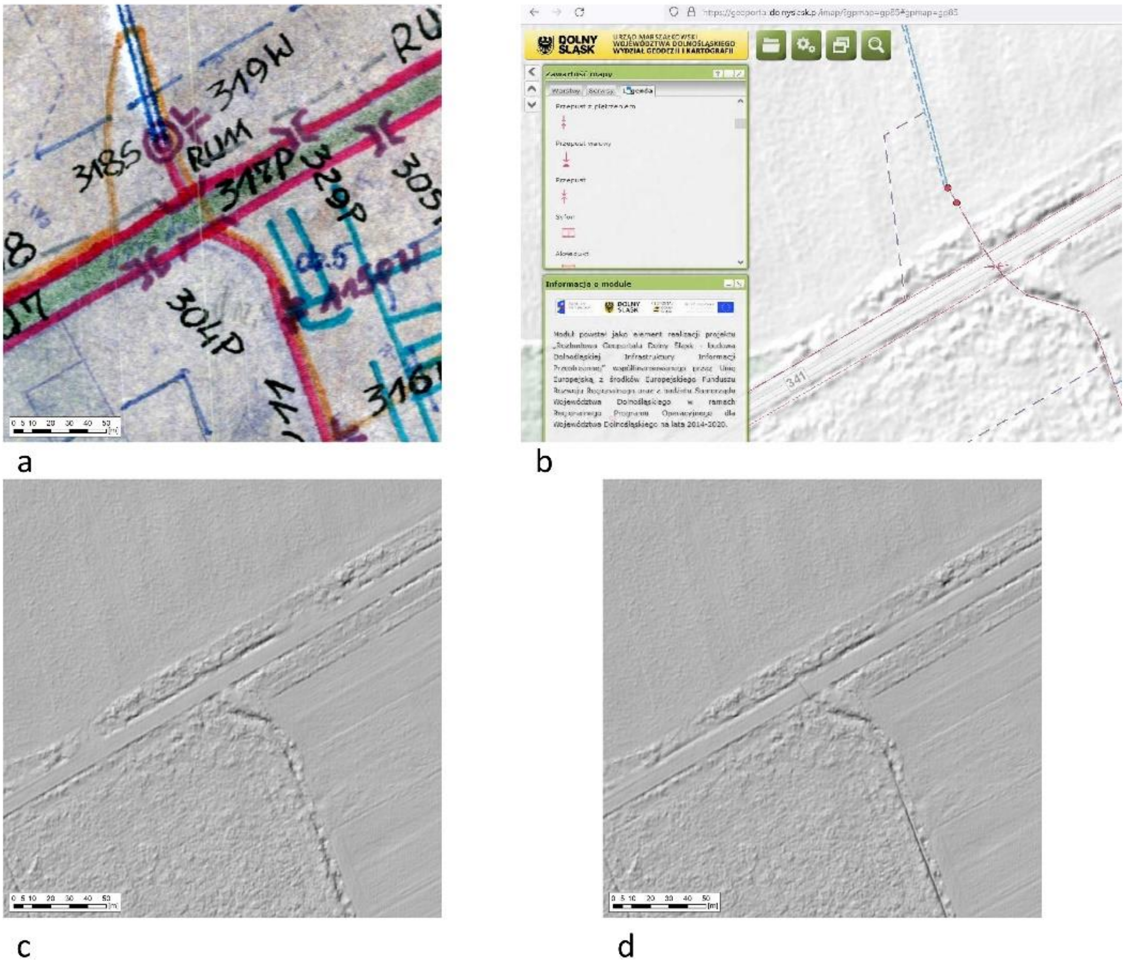


Figure 8. *Example of identification of culvert location: a, b source data (Database of Records of Waters and Water Facilities, Lower Silesia Geoportal), c DEM before conditioning, d DEM after conditioning.*

Flow direction raster and flow accumulation raster were generated using the deterministic eight-node algorithm (D8), which allowed us to determine the areal extent of the catchment of the Ślęganina watercourse. On the basis of the conditioned DEM a slope map and a hillshade map of the surface were also created.

According to the DEM, the surface area of the catchment was calculated - 1702 ha (terrestrial and aquatic part). The areal extent of the catchment established on the basis of the DEM from high-resolution LiDAR differs from the one determined in the MHDP (the Map of Hydrological Division of Poland), which was created on the basis of DEM of much lower resolution and topographic maps. The differences between catchment boundaries exceed 500 m and result from taking into account microtopographic features such as rills, field boundaries, small ditches, culverts and roads (Figure 9). The usage of high-resolution DEM for small areas makes it possible to consider microtopographic features and to precisely determine the boundaries of sub-basins (topographic water divides).

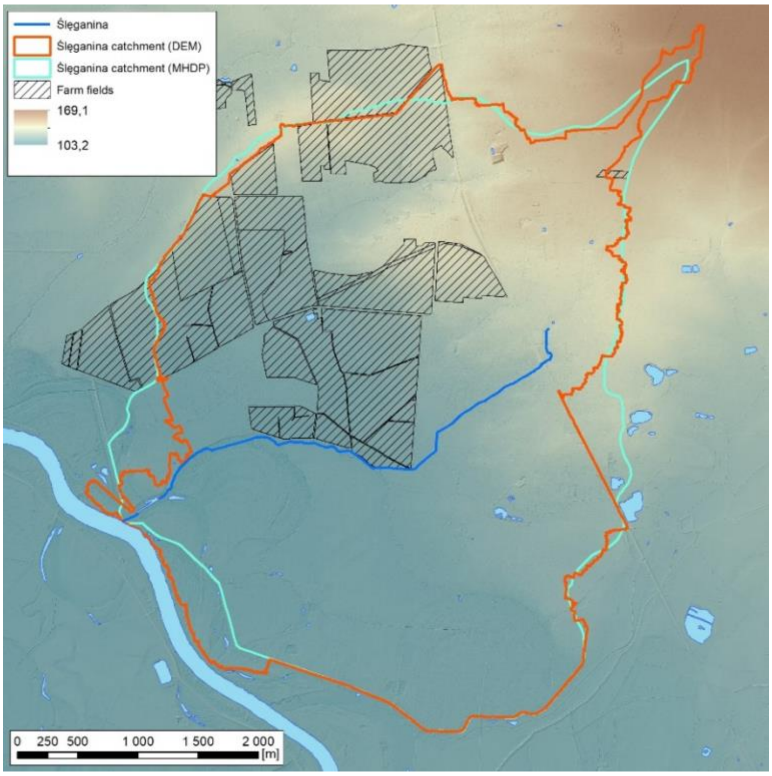


Figure 9. *The catchment of the Ślęganina watercourse.*

In the majority of the studied lands, terrain slopes do not exceed 3°, and in several locations, exceed 15 degrees (Figure 10). With the use of data from Urban Atlas 2018 (Copernicus Land Monitoring Service), the management pattern of the catchment was presented. The catchment is intensively used for agriculture, with a predominance of arable lands, pastures, and rural settlements (Figure 11).

According to the size of the analysed area, classes for the accumulation of surface runoff were established. Figure 12 presents an exact flow accumulation map (flow accumulation counted from junction to junction). The obtained layout of the surface transport pathways was verified with cartographic material (orthophoto maps and the Map of Hydrological Division of Poland). It is compatible with the hydrological network (according to the MHDP). The pathways are a development of a network of small (temporary and perennial) streams and ditches. We obtained a very detailed image also showing the temporary pathways by which water flows only during heavy rainfall and the concentration of runoff.

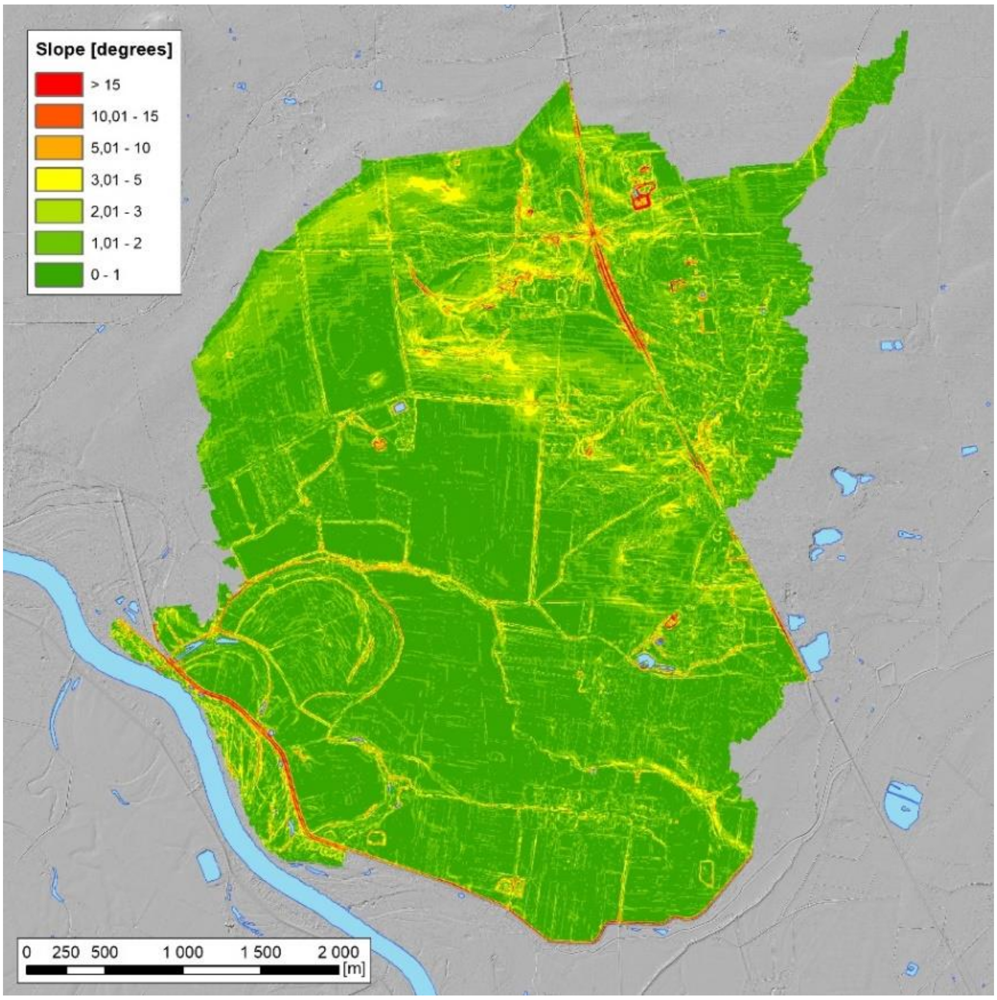


Figure 10. *Slope map of the catchment of the Ślęganina watercourse*

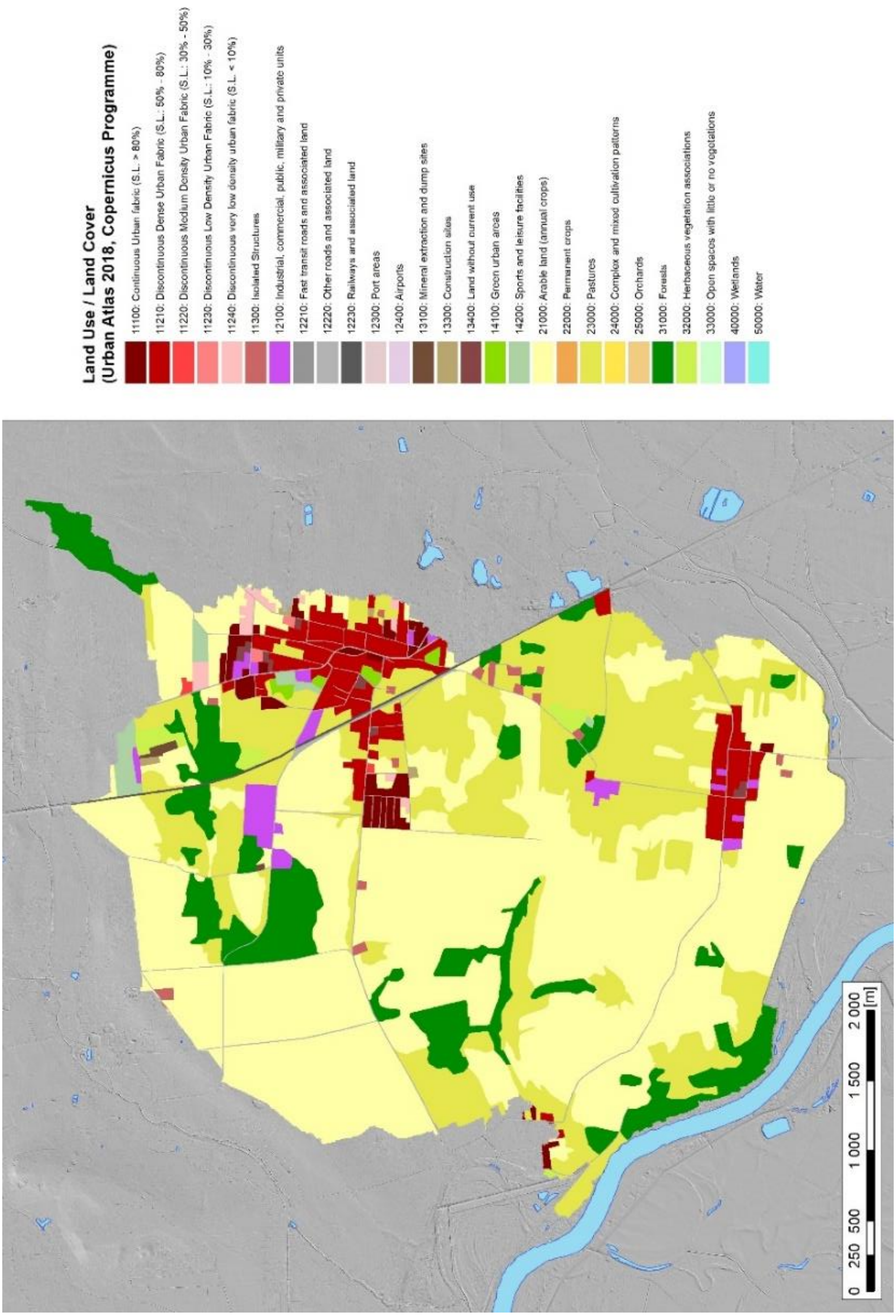
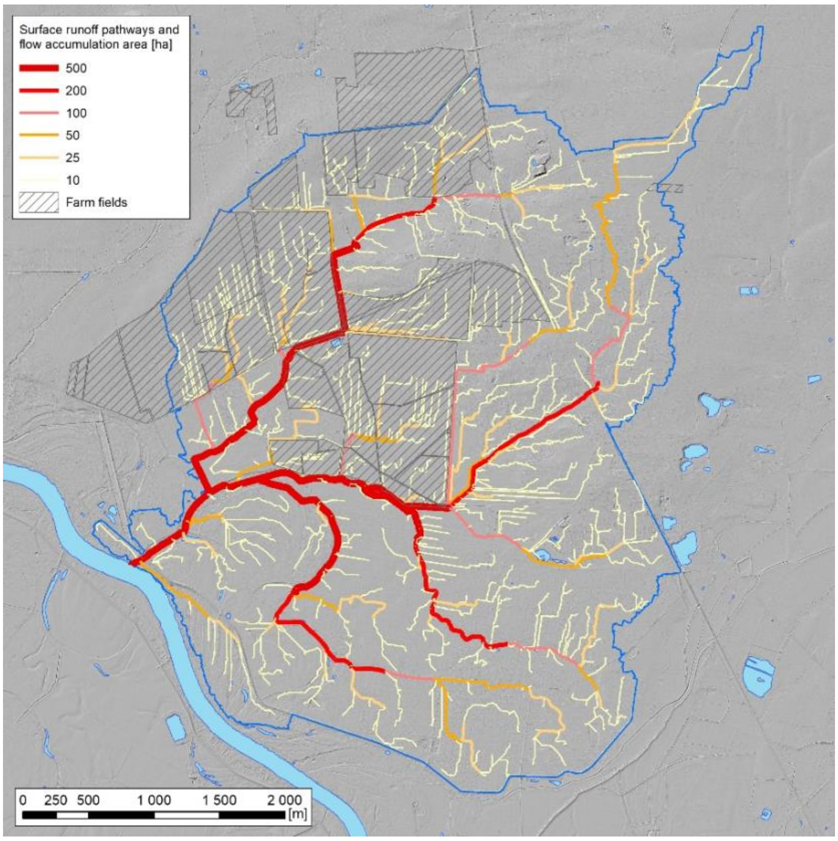
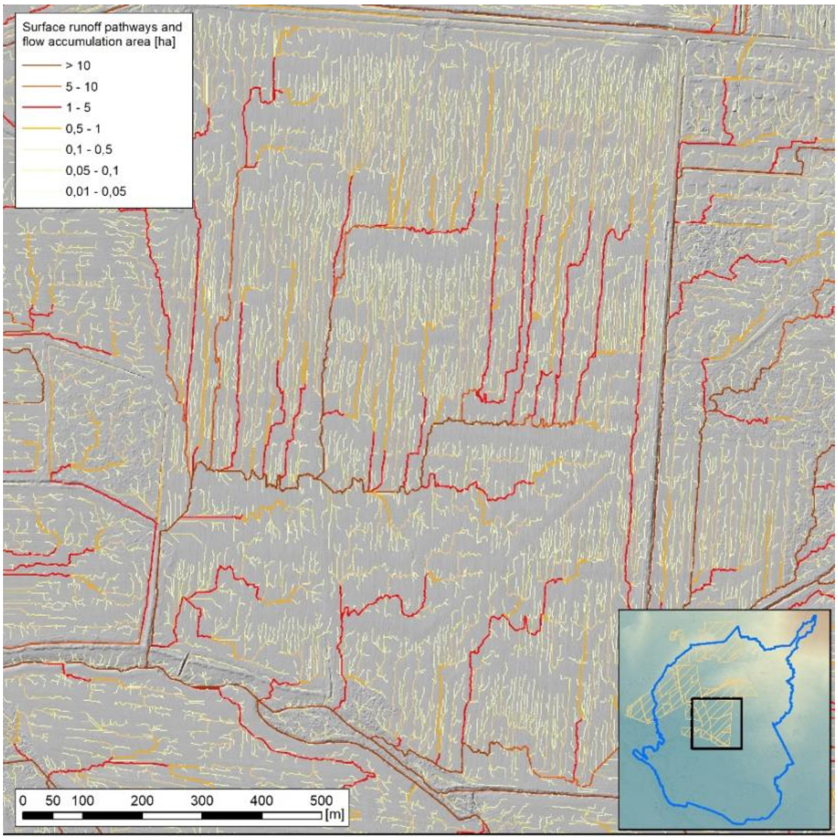


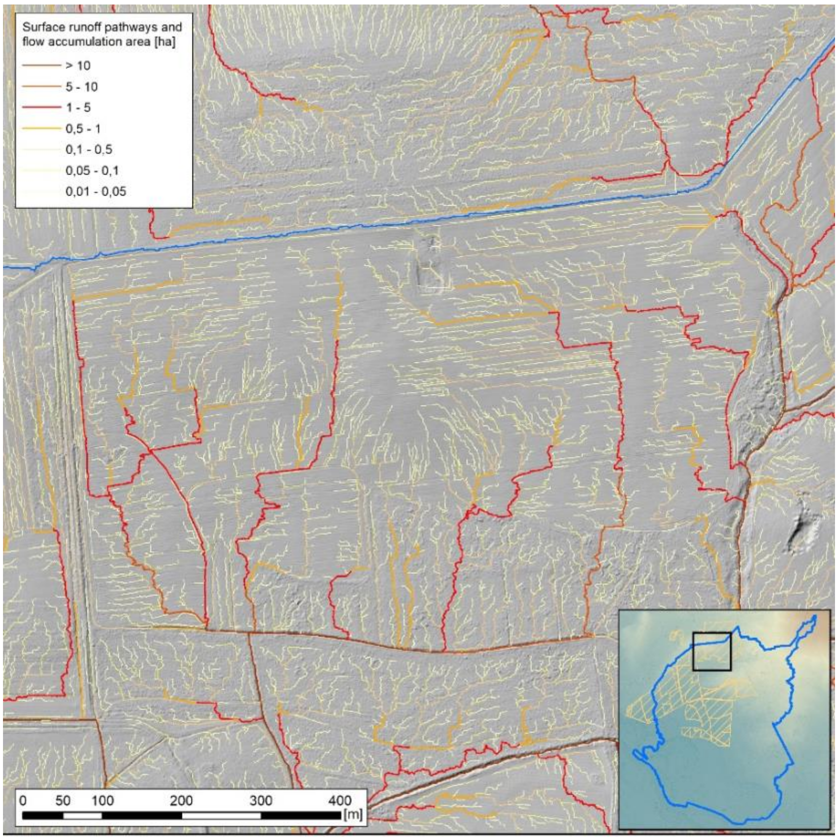
Figure 11. *Land use pattern of the catchment of the Ślęganina watercourse*


Surface runoff pathways and flow accumulation area [ha]
500
200
100
50
25
10
Farm fields
0 250 500 1 000 1 500 2 000 [m]

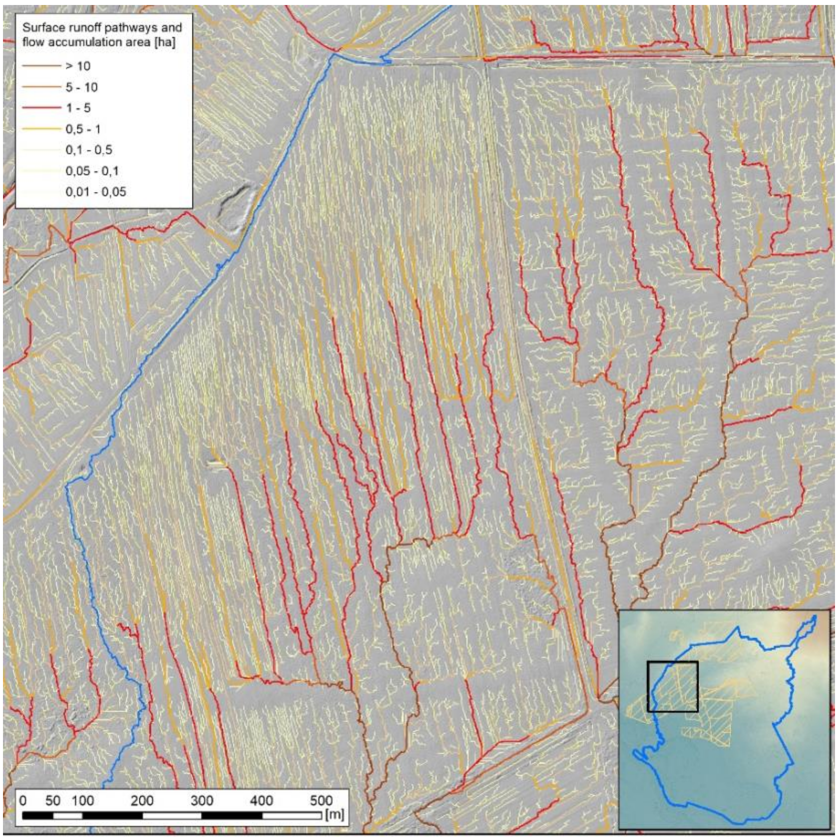
a


Surface runoff pathways and flow accumulation area [ha]
> 10
5 - 10
1 - 5
0,5 - 1
0,1 - 0,5
0,05 - 0,1
0,01 - 0,05
0 50 100 200 300 400 500 [m]

b



c



d

Figure 12. *Surface runoff transport pathways and flow accumulation areas a. at the catchment scale, b-d. at the field scale*

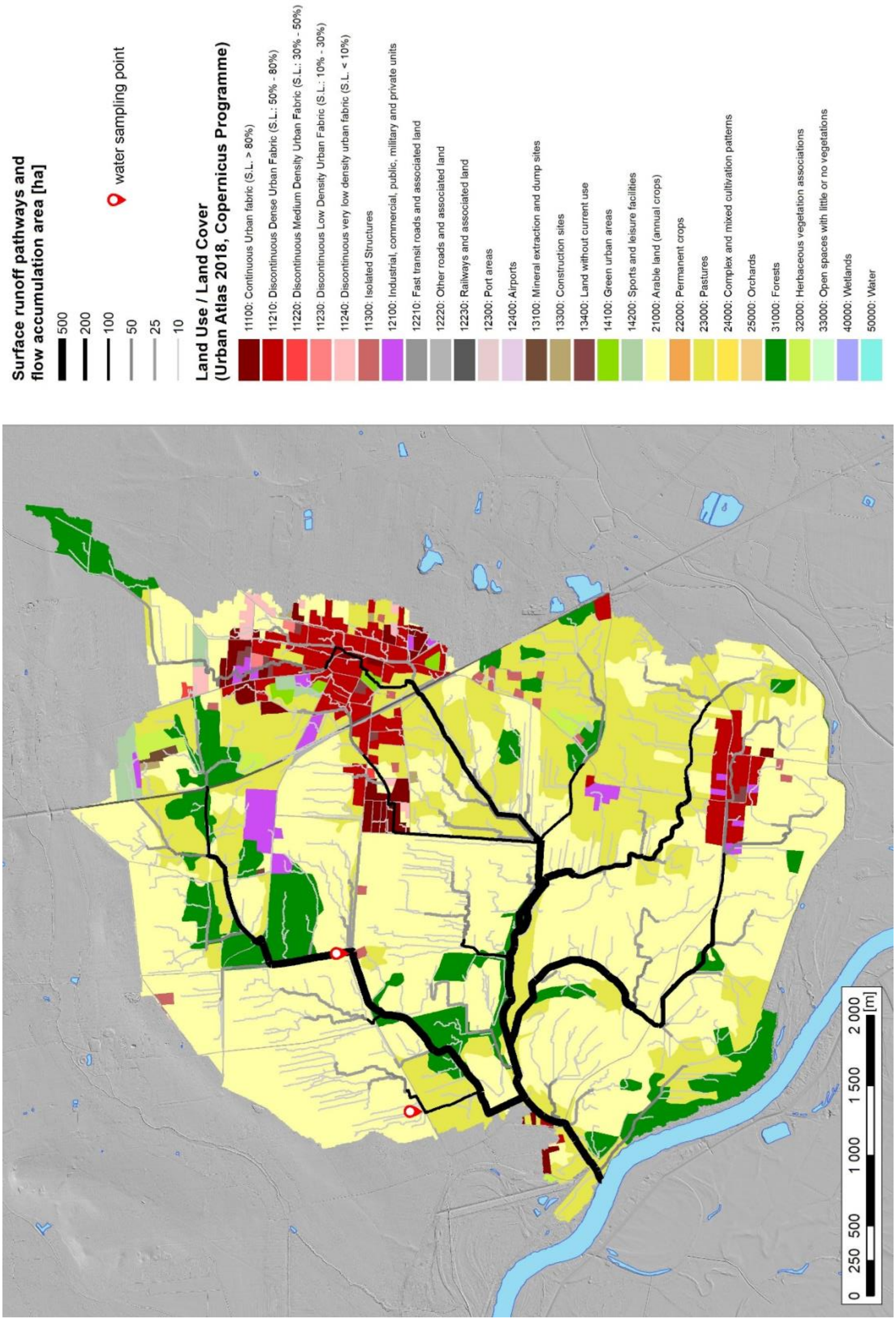

Surface runoff pathways and flow accumulation area [ha]
500
200
100
50
25
10
water sampling point
Land Use / Land Cover (Urban Atlas 2018, Copernicus Programme)
11100: Continuous Urban fabric (S.L. > 80%)
11210: Discontinuous Dense Urban Fabric (S.L.: 50% - 80%)
11220: Discontinuous Medium Density Urban Fabric (S.L.: 30% - 50%)
11230: Discontinuous Low Density Urban Fabric (S.L.: 10% - 30%)
11240: Discontinuous very low density urban fabric (S.L. < 10%)
11300: Isolated Structures
12100: Industrial, commercial, public, military and private units
12210: Fast transit roads and associated land
12220: Other roads and associated land
12230: Railways and associated land
12300: Port areas
12400: Airports
13100: Mineral extraction and dump sites
13300: Construction sites
13400: Land without current use
14100: Green urban areas
14200: Sports and leisure facilities
21000: Arable land (annual crops)
22000: Permanent crops
23000: Pastures
24000: Complex and mixed cultivation patterns
25000: Orchards
31000: Forests
32000: Herbaceous vegetation associations
33000: Open spaces with little or no vegetations
40000: Wetlands
50000: Water
0 250 500 1 000 1 500 2 000 [m]

Figure 13. Surface runoff transport pathways and accumulation areas against the land use pattern and the water sampling points

Within the study catchment, there is a high concentration of surface runoff from areas of over 500 ha. The catchment land cover with regard to surface water quality is unfavourable, agricultural land use is predominant. The existing forests do not provide buffer zones, forests are poorly linked to watercourse banks or main surface runoff transport pathways. Some fields are oriented and ploughed perpendicular to watercourse banks or main surface runoff transport pathways, locally more inclined slopes are present, and transfer of eroded material occurs along furrows, ditches and natural pathways (Figure 13).

With such unfavourable conditions in the catchment area, special emphasis should be placed on changing land use type for part of the area and creating riparian buffer zones, adjusting mitigation solutions to reduce the transport of pollutants and sediment from land to water in areas on locally more inclined slopes, introducing Agricultural Best Management Practices and Rural Sustainable Drainage Systems for sustainable stormwater management.

5.1. Remarks and recommendations

The fundamental objective of charting the surface flow pathways was to pinpoint strategic locations where future measures for recovering nutrients could be introduced, with a specific focus on addressing the issue of agricultural runoff. It should be emphasized that this analysis was not limited to Microfluidic systems, but instead, it could be extended to encompass other types of nutrient recovery solutions as well. Through a comprehensive study of surface flow pathways within a catchment area in Poland, this process enabled the identification of optimal sites for water sampling. This involved a painstaking selection of two sampling points, taking into account the intricate interplay of factors that contribute to agricultural runoff while being mindful of the potential for contamination from urban sources. By conducting such a meticulous analysis, this study provides invaluable insights into the potential for mitigating the harmful impacts of agricultural practices on the surrounding ecosystem. The findings could serve as a crucial reference point for future efforts to design effective nutrient management strategies that can help safeguard our natural resources.

6. Conclusion and outlook

Microfluidic nutrient recovery system utilizing adsorbent beads provides a novel approach for the recovery of nutrients from agricultural wastewater. This technique can provide a continuous method for the recovery of nutrients via recovery, regeneration, and reintroduction of the adsorbent beads. Despite the failure of prototype 1, prototype 2 proved to be quite effective at isolating the microbeads. The preliminary lab results suggest that the microfluidic system is highly effective in the recovery of the adsorbent microbeads while operating at high flow rates. Operating at a high flow rate of 100 L min^{-1} the system demonstrated an isolation rate of >98% for an extended period of time. Furthermore, these microfluidic systems can be connected in parallel to increase the volume of water treated while still operating at low pressure.

However, several factors must be considered before implementing this approach in real applications. For example, prefiltration and regeneration of the adsorbents must be addressed to ensure the system's effectiveness over time. Furthermore, as observed from the mapping of the overland pathways, several considerations need to be made so that the location of the microfluidic nutrient recovery device will be optimal. Despite these challenges, the microfluidic nutrient recovery system shows great promise in providing a continuous and efficient method for recovering nutrients from agricultural wastewater. In addition, it could also be possible to remove different pollutants from these water sources, whose presence was confirmed with the sample analysis from the three WATERAGRI case studies.

7. References

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Annexe: Agricultural water analysis

7.1. Hungarian Case Study

7.1.1. Sampling 1

Sampling Organization: UNIDEB
Type of Water: Fermented sludge
Source: Outlet point of the biogas fermentation plant
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581
Sampling date: 15.11.2021
Analysis date: 21.12.2021

Table 5. *Micronutrient concentrations in fermented sludge of Hungarian case study Sampling 1*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	0.057	Phosphorous (P)	3.9
Zinc (Zn)	0.20	Calcium (Ca)	5.34
Boron (B)	0.17	Magnesium (Mg)	0.906
Manganese (Mn)	0.034	Potassium (K)	174
Iron (Fe)	2.2	Sulphur (S)	7.2

Table 6. *Pesticide concentration in fermented sludge of Hungarian case study Sampling 1*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.010
Acenapthylene	<0.030	Desethyl terbutylazine	<0.010
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	<0.030	Metoxuron	<0.020

Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3, c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.010	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.010	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.010	Dichlorprop	<0.020
Desisopropyl atrazine	<0.010	Dicamba	<0.020
Hexazinone	<0.010	Bentazon	<0.020
Prometryn	<0.010	Fenoprop	<0.020
Propazine	<0.010	Carbendazim	<0.020
Sebutylazine	<0.010	Ethofumesate	<0.020
Simazine	<0.010	Carbetamide	<0.020
Terbutryn	<0.010	Chlorpropham	<0.020

7.1.2. Sampling 2

Sampling Organization: UNIDEB
Type of Water: Fermented sludge
Source: Outlet point of the biogas fermentation plant
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581
Sampling date: 15.11.2021
Analysis date: 07.01.2022

Table 7. *Micronutrient concentration in fermented sludge of Hungarian case study sampling 2*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	0.10	Phosphorous (P)	4.1
Zinc (Zn)	0.30	Calcium (Ca)	4.95
Boron (B)	0.15	Magnesium (Mg)	0.780
Manganese (Mn)	0.051	Potassium (K)	178
Iron (Fe)	2.6	Sulphur (S)	8.5

7.1.3. Sampling 3

Sampling Organization: UNIDEB
Type of Water: Irrigation water containing fermentation sludge (approx. 20%)
Source: irrigated field
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581
Sampling date: 15.11.2021
Analysis date: 28.12.2021

Table 8. *Micronutrient concentration in irrigated water containing fermented sludge of Hungarian case study sampling 3.*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	0.038	Phosphorous (P)	12
Zinc (Zn)	0.085	Calcium (Ca)	41.6
Boron (B)	0.13	Magnesium (Mg)	22.5
Manganese (Mn)	0.27	Potassium (K)	72.9
Iron (Fe)	0.30	Sulphur (S)	9.4

Table 9. *Pesticide concentration in irrigated water containing fermented sludge of Hungarian case study Sampling 3*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.010
Acenapthylene	<0.030	Desethyl terbutylazine	<0.010
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	<0.030	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020

Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.010	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.010	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.010	Dichlorprop	<0.020
Desisopropyl atrazine	<0.010	Dicamba	<0.020
Hexazinone	<0.010	Bentazon	<0.020
Prometryn	<0.010	Fenoprop	<0.020
Propazine	<0.010	Carbendazim	<0.020
Sebutylazine	<0.010	Ethofumesate	<0.020
Simazine	<0.010	Carbetamide	<0.020
Terbutryn	<0.010	Chlorpropham	<0.020

7.1.4. Sampling 4

Sampling Organization: UNIDEB
Type of Water: Irrigation water containing fermentation sludge (approx. 20%)
Source: irrigated field
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581
Sampling date: 15.11.2021
Analysis date: 20.12.2021

Table 10. *Micronutrient concentration in irrigated water containing fermented sludge of Hungarian case study Sampling 4*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	0.038	Phosphorous (P)	11
Zinc (Zn)	0.091	Calcium (Ca)	38.2
Boron (B)	0.12	Magnesium (Mg)	21.2
Manganese (Mn)	0.21	Potassium (K)	68.3
Iron (Fe)	0.27	Sulphur (S)	8.9

7.1.5. Sampling 5

Sampling Organization: UNIDEB
Type of Water: Fermentation sludge

Source: Outlet point of the biogas fermentation plant
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581
Sampling date: 31.03.2022
Analysis date: 28.04.2022

Table 11. *Micronutrient concentration in fermented sludge of Hungarian case study Sampling 5*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	0.058	Phosphorous (P)	11
Zinc (Zn)	0.18	Calcium (Ca)	10.8
Boron (B)	0.12	Magnesium (Mg)	4.18
Manganese (Mn)	0.067	Potassium (K)	219
Iron (Fe)	2.5	Sulphur (S)	6.6

7.1.6. Sampling 6

Sampling Organization: UNIDEB
Type of Water: Irrigation water containing fermentation sludge (approx. 15-25%)
Source: irrigated field
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581
Sampling date: 31.03.2022
Analysis date: 02.05.2022

Table 12. *Micronutrient concentration in irrigated water containing fermented sludge of Hungarian case study Sampling 6*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	0.019	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	3.47
Boron (B)	<0.10	Magnesium (Mg)	2.16
Manganese (Mn)	<0.010	Potassium (K)	2.50
Iron (Fe)	<0.050	Sulphur (S)	<2.0

Table 13. *Pesticide concentration in irrigated water containing fermented sludge of Hungarian case study Sampling 6*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.010
Acenapthylene	<0.030	Desethyl terbutylazine	<0.010

Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	<0.030	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.010	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.010	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.010	Dichlorprop	<0.020
Desisopropyl atrazine	<0.010	Dicamba	<0.020
Hexazinone	<0.010	Bentazon	<0.020
Prometryn	<0.010	Fenoprop	<0.020
Propazine	<0.010	Carbendazim	<0.020
Sebutylazine	<0.010	Ethofumesate	<0.020
Simazine	<0.010	Carbetamide	<0.020
Terbutryn	<0.010	Chlorpropham	<0.020

7.1.7. Sampling 7

Sampling Organization: UNIDEB
Type of Water: Fermentation sludge
Source: Outlet point of the biogas fermentation plant
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581

Sampling date: 12.07.2022
Analysis date: 27.07.2022

Table 14. *Micronutrient concentration in fermented sludge of Hungarian case study Sampling 7*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	0.040	Phosphorous (P)	5.4
Zinc (Zn)	0.11	Calcium (Ca)	12.1
Boron (B)	0.14	Magnesium (Mg)	2.06
Manganese (Mn)	0.082	Potassium (K)	222
Iron (Fe)	3.0	Sulphur (S)	6.8

7.1.8. Sampling 8

Sampling Organization: UNIDEB
Type of Water: Irrigation water containing fermentation sludge (approx. 20%)
Source: irrigated field
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581
Sampling date: 15.05.2022
Analysis date: 26.07.2022

Table 15. *Micronutrient concentration in irrigated water containing fermented sludge of Hungarian case study Sampling 8*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	0.025	Calcium (Ca)	3.92
Boron (B)	<0.10	Magnesium (Mg)	2.37
Manganese (Mn)	<0.010	Potassium (K)	2.24
Iron (Fe)	<0.050	Sulphur (S)	<2.0

Table 16. *Pesticide concentration in irrigated water containing fermented sludge of Hungarian case study Sampling 8*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.010
Acenapthylene	<0.030	Desethyl terbutylazine	<0.010
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020

Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	<0.030	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.010	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.010	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.010	Dichlorprop	<0.020
Desisopropyl atrazine	<0.010	Dicamba	<0.020
Hexazinone	<0.010	Bentazon	<0.020
Prometryn	<0.010	Fenoprop	<0.020
Propazine	<0.010	Carbendazim	<0.020
Sebutylazine	<0.010	Ethofumesate	<0.020
Simazine	<0.010	Carbetamide	<0.020
Terbutryn	<0.010	Chlorpropham	<0.020

7.1.9. Sampling 9

Sampling Organization: UNIDEB
Type of Water: Irrigation water containing fermentation sludge (approx. 20%)
Source: irrigated field
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581
Sampling date: 12.07.2022
Analysis date: 26.07.2022

Table 17. *Micronutrient concentration in irrigated water containing fermented sludge of Hungarian case study Sampling 9*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	3.78
Boron (B)	<0.10	Magnesium (Mg)	2.07
Manganese (Mn)	<0.010	Potassium (K)	2.0
Iron (Fe)	<0.050	Sulphur (S)	<2.0

Table 18. *Pesticide concentration in irrigated water containing fermented sludge of Hungarian case study Sampling 9*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.010
Acenapthylene	<0.030	Desethyl terbutylazine	<0.010
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	<0.030	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.010	2,4-dichlorophenoxy (Butyric Acid)	<0.020

Cyanazine	<0.010	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.010	Dichlorprop	<0.020
Desisopropyl atrazine	<0.010	Dicamba	<0.020
Hexazinone	<0.010	Bentazon	<0.020
Prometryn	<0.010	Fenoprop	<0.020
Propazine	<0.010	Carbendazim	<0.020
Sebutylazine	<0.010	Ethofumesate	<0.020
Simazine	<0.010	Carbetamide	<0.020
Terbutryn	<0.010	Chlorpropham	<0.020

7.1.10. Sampling 10

Sampling Organization: UNIDEB
Type of Water: Fermented sludge
Source: Outlet point of the biogas fermentation plant
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581
Sampling date: 03.10.2022
Analysis date: 17.11.2022

Table 19. *Micronutrient concentration in fermented sludge of Hungarian case study sampling 10*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	0.018	Phosphorous (P)	2.8
Zinc (Zn)	0.037	Calcium (Ca)	6.78
Boron (B)	0.14	Magnesium (Mg)	1.44
Manganese (Mn)	0.039	Potassium (K)	181
Iron (Fe)	0.90	Sulphur (S)	4.3

7.1.11. Sampling 11

Sampling Organization: UNIDEB
Type of Water: Irrigation water containing fermentation sludge (approx. 15-25%)
Source: irrigated field
Sample site: Nyírbátor
Location: Lat. 47.809606 Long. 22.160581
Sampling date: 03.10.2022
Analysis date: 24.11.2022

Table 20. *Micronutrient concentration in irrigated water containing fermented sludge of Hungarian case study sampling 11.*

Micronutrient	Concentration	Micronutrient	Concentration

	(mg/l)		(mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	3.6
Zinc (Zn)	<0.025	Calcium (Ca)	33.8
Boron (B)	<0.10	Magnesium (Mg)	22.4
Manganese (Mn)	<0.010	Potassium (K)	28.1
Iron (Fe)	<0.050	Sulphur (S)	9.4

Table 21. *Pesticide concentration in irrigated water containing fermented sludge of Hungarian case study Sampling 11*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.050
Acenapthylene	<0.030	Desethyl terbutylazine	<0.050
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	<0.030	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.050	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.050	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.050	Dichlorprop	<0.020

Desisopropyl atrazine	<0.050	Dicamba	<0.020
Hexazinone	<0.050	Bentazon	<0.020
Prometryn	<0.050	Fenoprop	<0.020
Propazine	<0.050	Carbendazim	<0.020
Sebutylazine	<0.050	Ethofumesate	<0.020
Simazine	<0.050	Carbetamide	<0.020
Terbutryn	<0.050	Chlorpropham	<0.020

7.1.12. Sampling 12

Sampling Organization: UNIDEB
Type of Water: Irrigation water containing fermentation sludge (approx. 20%)
Source: irrigated field
Sample site: Nyírbátor
Location: Lat. 47.809606 Long 22.160581
Sampling date: 03.10.2022
Analysis date: 17.11.2022

Table 22. *Micronutrient concentration in irrigated water containing fermented sludge of Hungarian case study Sampling 12*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	3.5
Zinc (Zn)	<0.025	Calcium (Ca)	34.3
Boron (B)	<0.10	Magnesium (Mg)	22.6
Manganese (Mn)	<0.010	Potassium (K)	27.0
Iron (Fe)	<0.050	Sulphur (S)	9.6

7.2. Poland Case Study

7.2.1. Sampling 1

Sampling Organization: UPWr
Type of Water: Drainage
Source: Runoff from drain
Sample site: Uraz
Location: N 51.241426, E 16.880340
Sampling date: 22.02.2022
Analysis date: 25.03.2022

Table 23. *Micronutrient concentration in drainage water of Poland case study Sampling 1*

Micronutrient	Concentration	Micronutrient	Concentration

	(mg/l)		(mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	133
Boron (B)	<0.10	Magnesium (Mg)	11
Manganese (Mn)	<0.010	Potassium (K)	1.57
Iron (Fe)	<0.050	Sulphur (S)	31

Table 24. *Pesticide concentration in drainage water of Poland case study Sampling 1*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.050
Acenapthylene	<0.030	Desethyl terbutylazine	<0.050
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	<0.030	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.050	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.050	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.050	Dichlorprop	<0.020

Desisopropyl atrazine	<0.050	Dicamba	<0.020
Hexazinone	<0.050	Bentazon	<0.020
Prometryn	<0.050	Fenoprop	<0.020
Propazine	<0.050	Carbendazim	<0.020
Sebutylazine	<0.050	Ethofumesate	<0.020
Simazine	<0.050	Carbetamide	<0.020
Terbutryn	<0.050	Chlorpropham	<0.020

7.2.2. Sampling 2

Sampling Organization: UPWr
Type of Water: Surface water
Source: Ditch
Sample site: Pęgów
Location: N 51.284006, E 16.902855
Sampling date: 22.02.2022
Analysis date: 25.03.2022

Table 25. *Micronutrient concentration in surface water of Poland case study Sampling 2*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.080
Zinc (Zn)	<0.050	Calcium (Ca)	71.7
Boron (B)	<0.50	Magnesium (Mg)	10.4
Manganese (Mn)	0.093	Potassium (K)	10.6
Iron (Fe)	<0.10	Sulphur (S)	32

Table 26. *Pesticide concentration in surface water of Poland case study Sampling 2*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	0.035
Acenapthylene	<0.030	Desethyl terbutylazine	<0.025
Acenaphtene	<0.030	Chlorotoluron	0.15*
Fluorene	<0.030	Diuron	<0.025
Benzo(a)pyrene	<0.030	Isoproturon	<0.025
Anthracene	<0.030	Linuron	<0.025
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.025
Pyrene	<0.030	Metobromuron	<0.025

Benzo(b)fluoranthene	<0.030	Metazachlor	0.027
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.025
Chrysene	<0.030	Propachlor	<0.025
Phenanthrene	<0.030	Metoxuron	<0.025
Fluranthene	<0.030	Monolinuron	<0.025
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.025
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.025
Naphthalene	<0.010	Metamitron	<0.025
Sum of PAHs	<0.010	Bromacil	<0.025
2,6-Dichlorobenzamid	<0.025	Propanil	<0.025
Metribuzin	<0.025	MCPB	<0.025
MCPA	<0.025	MCPP	<0.025
Fluroxypyr	<0.025	2,4-dichlorophenoxyacetic acid	<0.025
Atrazine	<0.025	2,4-dichlorophenoxy (Butyric Acid)	<0.025
Cyanazine	<0.025	2,4,5-trichlorophenoxyacetic acid	<0.025
Desethyl atrazine	<0.025	Dichlorprop	<0.025
Desisopropyl atrazine	<0.025	Dicamba	<0.025
Hexazinone	<0.025	Bentazon	<0.025
Prometryn	<0.025	Fenoprop	<0.025
Propazine	<0.025	Carbendazim	<0.025
Sebutylazine	<0.025	Ethofumesate	<0.025
Simazine	<0.025	Carbetamide	<0.025
Terbutryn	<0.025	Chlorpropham	<0.025

* Presence over normal limit detected in (without taking into account the measurement uncertainty)

7.2.3. Sampling 3

Sampling Organization: UPWr
Type of Water: Drainage
Source: Runoff from drain
Sample site: Uraz
Location: N 51.241426, E 16.880340
Sampling date: 24.03.2022
Analysis date: 30.03.2022

Table 27. *Micronutrient concentration in drainage water of Poland case study Sampling 3*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)

Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	137
Boron (B)	<0.10	Magnesium (Mg)	10.3
Manganese (Mn)	<0.010	Potassium (K)	1.46
Iron (Fe)	<0.050	Sulphur (S)	31

7.2.4. Sampling 4

Sampling Organization: UPWr
Type of Water: Surface water
Source: Ditch
Sample site: Pęgów
Location: N 51.284006, E 16.902855
Sampling date: 24.03.2022
Analysis date: 31.03.2022

Table 28. *Micronutrient concentration in surface water of Poland case study Sampling 4*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.080
Zinc (Zn)	<0.050	Calcium (Ca)	70.2
Boron (B)	<0.050	Magnesium (Mg)	10.5
Manganese (Mn)	0.049	Potassium (K)	11.9
Iron (Fe)	0.10	Sulphur (S)	35

7.2.5. Sampling 5

Sampling Organization: UPWr
Type of Water: Drainage
Source: Runoff from drain
Sample site: Uraz
Location: N 51.241426, E 16.880340
Sampling date: 20.04.2022
Analysis date: 28.04.2022

Table 29. *Micronutrient concentration in drainage water of Poland case study Sampling 5*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	131
Boron (B)	<0.10	Magnesium (Mg)	9.43

Manganese (Mn)	<0.010	Potassium (K)	1.44
Iron (Fe)	<0.050	Sulphur (S)	28

7.2.6. Sampling 6

Sampling Organization: UPWr
Type of Water: Surface water
Source: Ditch
Sample site: Pęgów
Location: N 51.284006, E 16.902855
Sampling date: 20.04.2022
Analysis date: 28.04.2022

Table 30. *Micronutrient concentration in surface water of Poland case study Sampling 6*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	69.2
Boron (B)	<0.10	Magnesium (Mg)	10.4
Manganese (Mn)	0.11	Potassium (K)	10.4
Iron (Fe)	0.065	Sulphur (S)	31

7.2.7. Sampling 7

Sampling Organization: UPWr
Type of Water: Drainage
Source: Runoff from drain
Sample site: Uraz
Location: N 51.241426, E 16.880340
Sampling date: 17.05.2022
Analysis date: 31.05.2022

Table 31. *Micronutrient concentration in drainage water of Poland case study Sampling 7*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	143
Boron (B)	<0.10	Magnesium (Mg)	12.6
Manganese (Mn)	0.010	Potassium (K)	1.15
Iron (Fe)	<0.050	Sulphur (S)	35

***Table 32.** Pesticide concentration in drainage water of Poland case study Sampling 7*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.050
Acenapthylene	<0.030	Desethyl terbutylazine	<0.050
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	0.031	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.050	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.050	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.050	Dichlorprop	<0.020
Desisopropyl atrazine	<0.050	Dicamba	<0.020
Hexazinone	<0.050	Bentazon	<0.020
Prometryn	<0.050	Fenoprop	<0.020
Propazine	<0.050	Carbendazim	<0.020
Sebutylazine	<0.050	Ethofumesate	<0.020
Simazine	<0.050	Carbetamide	<0.020
Terbutryn	<0.050	Chlorpropham	<0.020

7.2.8. Sampling 8

Sampling Organization: UPWr
Type of Water: Surface water
Source: Ditch
Sample site: Pęgów
Location: N 51.284006, E 16.902855
Sampling date: 17.05.2022
Analysis date: 1.06.2022

Table 33. *Micronutrient concentration in surface water of Poland case study Sampling 8*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.080
Zinc (Zn)	<0.050	Calcium (Ca)	64.2
Boron (B)	<0.050	Magnesium (Mg)	9.75
Manganese (Mn)	0.52	Potassium (K)	8.41
Iron (Fe)	<0.10	Sulphur (S)	30

Table 34. *Pesticide concentration in surface water of Poland case study Sampling 8*

Pesticide	Concentration (μg/l)	Pesticide	Concentration (μg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.030
Acenapthylene	<0.030	Desethyl terbutylazine	<0.030
Acenaphtene	<0.030	Chlorotoluron	<0.030
Fluorene	<0.030	Diuron	<0.030
Benzo(a)pyrene	<0.030	Isoproturon	<0.030
Anthracene	<0.030	Linuron	<0.030
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.030
Pyrene	<0.030	Metobromuron	<0.030
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.030
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.030
Chrysene	<0.030	Propachlor	<0.030
Phenanthrene	<0.030	Metoxuron	<0.030
Fluranthene	<0.030	Monolinuron	<0.030
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.030
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.030

Naphthalene	<0.010	Metamitron	<0.030
Sum of PAHs	<0.010	Bromacil	<0.030
2,6-Dichlorobenzamid	<0.030	Propanil	<0.030
Metribuzin	<0.030	MCPB	<0.030
MCPA	<0.030	MCPP	<0.030
Fluroxypyr	<0.030	2,4-dichlorophenoxyacetic acid	<0.030
Atrazine	<0.030	2,4-dichlorophenoxy (Butyric Acid)	<0.030
Cyanazine	<0.030	2,4,5-trichlorophenoxyacetic acid	<0.030
Desethyl atrazine	<0.030	Dichlorprop	<0.030
Desisopropyl atrazine	<0.030	Dicamba	<0.30
Hexazinone	<0.030	Bentazon	<0.030
Prometryn	<0.030	Fenoprop	<0.030
Propazine	<0.030	Carbendazim	<0.030
Sebutylazine	<0.030	Ethofumesate	<0.030
Simazine	<0.030	Carbetamide	<0.030
Terbutryn	<0.030	Chlorpropham	<0.030

7.2.9. Sampling 9

Sampling Organization: UPWr
Type of Water: Drainage
Source: Runoff from drain
Sample site: Uraz
Location: N 51.241426, E 16.880340
Sampling date: 30.08.2022
Analysis date: 06.09.2022

Table 35. *Micronutrient concentration in drainage water of Poland case study Sampling 9*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	90.6
Boron (B)	<0.10	Magnesium (Mg)	4.60
Manganese (Mn)	<0.010	Potassium (K)	2.98
Iron (Fe)	<0.050	Sulphur (S)	13

7.2.10. Sampling 10

Sampling Organization: UPWr
Type of Water: Surface water

Source: Ditch
Sample site: Pęgów
Location: N 51.284006, E 16.902855
Sampling date: 30.08.2022
Analysis date: 06.09.2022

Table 36. *Micronutrient concentration in surface water of Poland case study Sampling 10*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.080
Zinc (Zn)	<0.050	Calcium (Ca)	72.2
Boron (B)	<0.050	Magnesium (Mg)	10.3
Manganese (Mn)	0.051	Potassium (K)	12.5
Iron (Fe)	0.10	Sulphur (S)	34

7.2.11. Sampling 11

Sampling Organization: UPWr
Type of Water: Drainage
Source: Runoff from drain
Sample site: Uraz
Location: N 51.241426, E 16.880340
Sampling date: 5.10.2022
Analysis date: 11.10.2022

Table 37. *Micronutrient concentration in drainage water of Poland case study Sampling 11*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	91.7
Boron (B)	<0.10	Magnesium (Mg)	4.88
Manganese (Mn)	<0.010	Potassium (K)	3.0
Iron (Fe)	<0.050	Sulphur (S)	14

Table 38. *Pesticide concentration in drainage water of Poland case study Sampling 11*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.050
Acenapthylene	<0.030	Desethyl terbutylazine	<0.050

Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	<0.030	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.050	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.050	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.050	Dichlorprop	<0.020
Desisopropyl atrazine	<0.050	Dicamba	<0.020
Hexazinone	<0.050	Bentazon	<0.020
Prometryn	<0.050	Fenoprop	<0.020
Propazine	<0.050	Carbendazim	<0.020
Sebutylazine	<0.050	Ethofumesate	<0.020
Simazine	<0.050	Carbetamide	<0.020
Terbutryn	<0.050	Chlorpropham	<0.020

7.2.12. Sampling 12

Sampling Organization: UPWr
Type of Water: Surface water
Source: Ditch
Sample site: Pęgów
Location: N 51.284006, E 16.902855

Sampling date: 5.10.2022
Analysis date: 11.10.2022

Table 39. *Micronutrient concentration in surface water of Poland case study Sampling 12*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.080
Zinc (Zn)	<0.050	Calcium (Ca)	70.9
Boron (B)	<0.050	Magnesium (Mg)	10
Manganese (Mn)	0.081	Potassium (K)	11.1
Iron (Fe)	0.11	Sulphur (S)	34

Table 40. *Pesticide concentration in surface water of Poland case study Sampling 12*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Desethyl terbutylazine	<0.030
Acenapthylene	<0.030	Chlorotoluron	<0.030
Acenaphtene	<0.030	Diuron	<0.030
Fluorene	<0.030	Isoproturon	<0.030
Benzo(a)pyrene	<0.030	Linuron	<0.030
Anthracene	<0.030	Metabenzthiazuron	<0.030
Benzo(ghi)perylene	<0.030	Metobromuron	<0.030
Pyrene	<0.030	Metazachlor	<0.030
Benzo(b)fluoranthene	<0.030	Metazachlor OA	0.30*
Benzo(k)fluoranthene	<0.030	Metazachlor ESA	0.15*
Chrysene	<0.030	Metolachlor	<0.030
Phenanthrene	<0.030	Propachlor	<0.030
Fluranthene	<0.030	Metoxuron	<0.030
Indeno(1,2,3,c,d)pyrene	<0.030	Monolinuron	<0.030
Dibenz(a,h)anthracene	<0.030	Alachlor	<0.030
Naphthalene	<0.010	Chloridazon	<0.030
Sum of PAHs	<0.010	Metamitron	<0.030
2,6-Dichlorobenzamid	<0.030	Bromacil	<0.030
Metribuzin	<0.030	Propanil	<0.030
MCPA	<0.030	MCPB	<0.030

Fluroxypyr	<0.030	MCPP	<0.030
Atrazine	<0.030	2,4-dichlorophenoxyacetic acid	<0.030
Cyanazine	<0.030	2,4-dichlorophenoxy (Butyric Acid)	<0.030
Desethyl atrazine	<0.030	2,4,5-trichlorophenoxyacetic acid	<0.030
Desisopropyl atrazine	<0.030	Dichlorprop	<0.030
Hexazinone	<0.030	Dicamba	<0.30
Prometryn	<0.030	Bentazon	<0.030
Propazine	<0.030	Fenoprop	<0.030
Sebutylazine	<0.030	Carbendazim	<0.030
Simazine	<0.030	Ethofumesate	<0.030
Terbutryn	<0.030	Carbetamide	<0.030
Terbutylazine	<0.030	Ethofumesate	<0.030

* Presence over normal limit detected in (without taking into account the measurement uncertainty)

7.2.13. Sampling 13

Sampling Organization: UPWr
Type of Water: Drainage
Source: Runoff from drain
Sample site: Uraz
Location: N 51.241426, E 16.880340
Sampling date: 29.11.2022
Analysis date: 07.12.2022

Table 41. *Micronutrient concentration in drainage water of Poland case study Sampling 13*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	123.0
Boron (B)	<0.10	Magnesium (Mg)	7.57
Manganese (Mn)	0.058	Potassium (K)	0.647
Iron (Fe)	<0.050	Sulphur (S)	22

Table 42. *Pesticide concentration in drainage water of Poland case study Sampling 13*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.050
Acenapthylene	<0.030	Desethyl terbutylazine	<0.050

Acenaphtene	<0.030	Chlorotoluron	<0.20
Fluorene	<0.030	Diuron	<0.20
Benzo(a)pyrene	<0.030	Isoproturon	<0.20
Anthracene	<0.030	Linuron	<0.20
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.20
Pyrene	<0.030	Metobromuron	<0.20
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.20
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.20
Chrysene	<0.030	Propachlor	<0.20
Phenanthrene	<0.030	Metoxuron	<0.20
Fluranthene	<0.030	Monolinuron	<0.20
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.20
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.20
Naphthalene	<0.010	Metamitron	<0.20
Sum of PAHs	<0.010	Bromacil	<0.20
2,6-Dichlorobenzamid	<0.020	Propanil	<0.20
Metribuzin	<0.020	MCPB	<0.20
MCPA	<0.020	MCPP	<0.20
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.20
Atrazine	<0.050	2,4-dichlorophenoxy (Butyric Acid)	<0.20
Cyanazine	<0.050	2,4,5-trichlorophenoxyacetic acid	<0.20
Desethyl atrazine	<0.050	Dichlorprop	<0.20
Desisopropyl atrazine	<0.050	Dicamba	<0.20
Hexazinone	<0.050	Bentazon	<0.20
Prometryn	<0.050	Fenoprop	<0.20
Propazine	<0.050	Carbendazim	<0.20
Sebutylazine	<0.050	Ethofumesate	<0.20
Simazine	<0.050	Carbetamide	<0.20
Terbutryn	<0.050	Chlorpropham	<0.20

7.2.14. Sampling 14

Sampling Organization: UPWr
Type of Water: Drainage
Source: Runoff from drain
Sample site: Uraz
Location: N 51.241426, E 16.880340

Sampling date: 29.11.2022
Analysis date: 05.12.2022

Table 43. *Micronutrient concentration in drainage water of Poland case study Sampling 14*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.080
Zinc (Zn)	<0.050	Calcium (Ca)	69.4
Boron (B)	<0.050	Magnesium (Mg)	10.3
Manganese (Mn)	0.055	Potassium (K)	10.4
Iron (Fe)	<0.10	Sulphur (S)	35

Table 44. *Pesticide concentration in drainage water of Poland case study Sampling 14*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Desethyl terbutylazine	<0.030
Acenapthylene	<0.030	Chlorotoluron	<0.030
Acenaphtene	<0.030	Diuron	<0.030
Fluorene	<0.030	Isoproturon	<0.030
Benzo(a)pyrene	<0.030	Linuron	<0.030
Anthracene	<0.030	Metabenzthiazuron	<0.030
Benzo(ghi)perylene	<0.030	Metobromuron	<0.030
Pyrene	<0.030	Metazachlor OA	0.50
Benzo(b)fluoranthene	<0.030	Metazachlor ESA	0.33*
Benzo(k)fluoranthene	<0.030	Metolachlor ESA	0.32*
Chrysene	<0.030	Metolachlor	0.33*
Phenanthrene	<0.030	Propachlor	<0.030
Fluranthene	<0.030	Metoxuron	<0.030
Indeno(1,2,3,c,d)pyrene	<0.030	Monolinuron	<0.030
Dibenz(a,h)anthracene	<0.030	Alachlor	<0.030
Naphthalene	<0.10	Chloridazon	<0.030
Sum of PAHs	<0.10	Metamitron	<0.030
2,6-Dichlorobenzamid	<0.030	Bromacil	<0.030
Metribuzin	<0.030	Propanil	<0.030
MCPA	<0.030	MCPB	<0.030

Fluroxypyr	<0.030	MCPP	<0.030
Atrazine	<0.030	2,4-dichlorophenoxyacetic acid	<0.030
Cyanazine	<0.030	2,4-dichlorophenoxy (Butyric Acid)	<0.030
Desethyl atrazine	<0.030	2,4,5-trichlorophenoxyacetic acid	<0.030
Desisopropyl atrazine	<0.030	Dichlorprop	<0.030
Hexazinone	<0.030	Dicamba	<0.30
Prometryn	<0.030	Bentazon	<0.030
Propazine	<0.030	Fenoprop	<0.030
Sebutylazine	<0.030	Carbendazim	<0.030
Simazine	<0.030	Ethofumesate	<0.030
Terbutryn	<0.030	Carbetamide	<0.030
Terbutylazine	<0.030	Chlorpropham	<0.030

* Presence over normal limit detected in (without taking into account the measurement uncertainty)

7.3. Italy Case Study

7.3.1. Sampling 1

Sampling Organization: UNIBO
Type of Water: Agricultural drainage water
Sampling date: 10.11.2021
Analysis date: 19.01.2022

Table 45. *Micronutrient concentration in drainage water of Italy case study Sampling 1*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	78.9
Boron (B)	<0.10	Magnesium (Mg)	25.0
Manganese (Mn)	0.26	Potassium (K)	3.73
Iron (Fe)	<0.050	Sulphur (S)	20

7.3.2. Sampling 2

Sampling Organization: UNIBO
Type of Water: Agricultural drainage water
Sampling date: 24.11.2021
Analysis date: 19.01.2022

Table 46. *Pesticide concentration in drainage water of Italy case study Sampling 2*

Micronutrient	Concentration	Micronutrient	Concentration

	(mg/l)		(mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	0.069	Calcium (Ca)	142
Boron (B)	0.20	Magnesium (Mg)	51.8
Manganese (Mn)	0.19	Potassium (K)	4.33
Iron (Fe)	<0.050	Sulphur (S)	86

7.3.3. Sampling 3

Sampling Organization: UNIBO
Type of Water: Irrigation water
Sampling date: 10.12.2021
Analysis date: 20.01.2022

Table 47. *Micronutrient concentration in irrigation water of Italy case study Sampling 3*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	40.9
Boron (B)	<0.10	Magnesium (Mg)	12.6
Manganese (Mn)	<0.010	Potassium (K)	4.35
Iron (Fe)	<0.050	Sulphur (S)	13

Table 48. *Pesticide concentration in irrigation water of Italy case study Sampling 3*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.050
Acenapthylene	<0.030	Desethyl terbutylazine	<0.050
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	0.37*	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020

Phenanthrene	0.11*	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	0.48*	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.050	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.050	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.050	Dichlorprop	<0.020
Desisopropyl atrazine	<0.050	Dicamba	<0.020
Hexazinone	<0.050	Bentazon	<0.020
Prometryn	<0.050	Fenoprop	<0.020
Propazine	<0.050	Carbendazim	<0.020
Sebutylazine	<0.050	Ethofumesate	<0.020
Simazine	<0.050	Carbetamide	<0.020
Terbutryn	<0.050	Chlorpropham	<0.020

* Presence over normal limit detected in (without taking into account the measurement uncertainty)

7.3.4. Sampling 4

Sampling Organization: UNIBO
Type of Water: Agricultural drain water
Sampling date: 10.12.2021
Analysis date: 20.01.2022

Table 49. *Micronutrient concentration in drainage water of Italy case study Sampling 4*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	124
Boron (B)	0.14	Magnesium (Mg)	43.8
Manganese (Mn)	0.090	Potassium (K)	3.99
Iron (Fe)	<0.050	Sulphur (S)	64

Table 50. *Pesticide concentration in drainage water of Italy case study Sampling 4*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.050
Acenapthylene	<0.030	Desethyl terbutylazine	<0.050
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	0.47*	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	0.15*	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	0.62*	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.050	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.050	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.050	Dichlorprop	<0.020
Desisopropyl atrazine	<0.050	Dicamba	<0.020
Hexazinone	<0.050	Bentazon	<0.020
Prometryn	<0.050	Fenoprop	<0.020
Propazine	<0.050	Carbendazim	<0.020
Sebutylazine	<0.050	Ethofumesate	<0.020
Simazine	<0.050	Carbetamide	<0.020

Terbutryn	<0.050	Chlorpropham	<0.020

* Presence over normal limit detected in (without taking into account the measurement uncertainty)

7.3.5. Sampling 5

Sampling Organization: UNIBO
Type of Water: Agricultural drain water
Sampling date: 18.02.2022
Analysis date: 02.05.2022

Table 51. *Micronutrient concentration in drainage water of Italy case study Sampling 5*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	170
Boron (B)	0.15	Magnesium (Mg)	60.1
Manganese (Mn)	0.14	Potassium (K)	4.47
Iron (Fe)	<0.050	Sulphur (S)	120

Table 52. *Pesticide concentration in drainage water of Italy case study Sampling 5*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.050
Acenapthylene	<0.030	Desethyl terbutylazine	<0.050
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	<0.030	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020

Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.050	2,4-dichlorophenoxy (Butyric Acid)	<0.020
Cyanazine	<0.050	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.050	Dichlorprop	<0.020
Desisopropyl atrazine	<0.050	Dicamba	<0.020
Hexazinone	<0.050	Bentazon	<0.020
Prometryn	<0.050	Fenoprop	<0.020
Propazine	<0.050	Carbendazim	<0.020
Sebutylazine	<0.050	Ethofumesate	<0.020
Simazine	<0.050	Carbetamide	<0.020
Terbutryn	<0.050	Chlorpropham	<0.020

7.3.6. Sampling 6

Sampling Organization: UNIBO
Type of Water: Agricultural drain water
Sampling date: 01.04.2022
Analysis date: 02.05.2022

Table 53. *Micronutrient concentration in drainage water of Italy case study Sampling 6*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	98.7
Boron (B)	<0.10	Magnesium (Mg)	26.3
Manganese (Mn)	<0.010	Potassium (K)	5.93
Iron (Fe)	<0.050	Sulphur (S)	29

7.3.7. Sampling 7

Sampling Organization: UNIBO
Type of Water: Agricultural drain water
Sampling date: 22.04.2022
Analysis date: 04.05.2022

Table 54. *Micronutrient concentration in drainage water of Italy case study Sampling 7*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	0.017	Phosphorous (P)	0.43
Zinc (Zn)	<0.025	Calcium (Ca)	58.4
Boron (B)	<0.10	Magnesium (Mg)	13.9
Manganese (Mn)	0.064	Potassium (K)	12.5
Iron (Fe)	0.25	Sulphur (S)	14

Table 55. *Pesticide concentration in drainage water of Italy case study Sampling 7*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	0.065
Acenapthylene	<0.030	Desethyl terbutylazine	<0.050
Acenaphtene	<0.030	Chlorotoluron	<0.020
Fluorene	<0.030	Diuron	<0.020
Benzo(a)pyrene	<0.030	Isoproturon	<0.020
Anthracene	<0.030	Linuron	<0.020
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.020
Pyrene	<0.030	Metobromuron	<0.020
Benzo(b)fluoranthene	<0.030	Metazachlor	<0.020
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.020
Chrysene	<0.030	Propachlor	<0.020
Phenanthrene	<0.030	Metoxuron	<0.020
Fluranthene	<0.030	Monolinuron	<0.020
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.020
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.020
Naphthalene	<0.010	Metamitron	<0.020
Sum of PAHs	<0.010	Bromacil	<0.020
2,6-Dichlorobenzamid	<0.020	Propanil	<0.020
Metribuzin	<0.020	MCPB	<0.020
MCPA	<0.020	MCPP	<0.020
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.020
Atrazine	<0.050	2,4-dichlorophenoxy (Butyric Acid)	<0.020

Cyanazine	<0.050	2,4,5-trichlorophenoxyacetic acid	<0.020
Desethyl atrazine	<0.050	Dichlorprop	<0.020
Desisopropyl atrazine	<0.050	Dicamba	<0.020
Hexazinone	<0.050	Bentazon	<0.020
Prometryn	<0.050	Fenoprop	<0.020
Propazine	<0.050	Carbendazim	<0.020
Sebutylazine	<0.050	Ethofumesate	<0.020
Simazine	<0.050	Carbetamide	<0.020
Terbutryn	<0.050	Chlorpropham	<0.020

7.3.8. Sampling 8

Sampling Organization: UNIBO
Type of Water: Agricultural drain water
Sampling date: 30.11.2022
Analysis date: 01.02.2023

Table 56. *Micronutrient concentration in drainage water of Italy case study Sampling 8*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	146
Boron (B)	0.13	Magnesium (Mg)	37.0
Manganese (Mn)	<0.010	Potassium (K)	5.29
Iron (Fe)	0.066	Sulphur (S)	410

Table 57. *Pesticide concentration in drainage water of Italy case study Sampling 8*

Pesticide	Concentration (µg/l)	Pesticide	Concentration (µg/l)
Benzo(a)anthracene	<0.030	Terbutylazine	<0.050
Acenapthylene	<0.030	Desethyl terbutylazine	<0.050
Acenaphtene	<0.030	Chlorotoluron	<0.20
Fluorene	<0.030	Diuron	<0.20
Benzo(a)pyrene	<0.030	Isoproturon	<0.20
Anthracene	<0.030	Linuron	<0.20
Benzo(ghi)perylene	<0.030	Metabenzthiazuron	<0.20
Pyrene	<0.030	Metobromuron	<0.20

Benzo(b)fluoranthene	<0.030	Metazachlor	<0.20
Benzo(k)fluoranthene	<0.030	Metolachlor	<0.20
Chrysene	<0.030	Propachlor	<0.20
Phenanthrene	<0.030	Metoxuron	<0.20
Fluranthene	<0.030	Monolinuron	<0.20
Indeno(1,2,3,c,d)pyrene	<0.030	Alachlor	<0.20
Dibenz(a,h)anthracene	<0.030	Chloridazon	<0.20
Naphthalene	<0.010	Metamitron	<0.20
Sum of PAHs	<0.010	Bromacil	<0.20
2,6-Dichlorobenzamid	<0.020	Propanil	<0.20
Metribuzin	<0.020	MCPB	<0.20
MCPA	<0.020	MCPP	<0.20
Fluroxypyr	<0.020	2,4-dichlorophenoxyacetic acid	<0.20
Atrazine	<0.050	2,4-dichlorophenoxy (Butyric Acid)	<0.20
Cyanazine	<0.050	2,4,5-trichlorophenoxyacetic acid	<0.20
Desethyl atrazine	<0.050	Dichlorprop	<0.20
Desisopropyl atrazine	<0.050	Dicamba	<0.20
Hexazinone	<0.050	Bentazon	<0.20
Prometryn	<0.050	Fenoprop	<0.20
Propazine	<0.050	Carbendazim	<0.20
Sebutylazine	<0.050	Ethofumesate	<0.20
Simazine	<0.050	Carbetamide	<0.20
Terbutryn	<0.050	Chlorpropham	<0.20

7.3.9. Sampling 9

Sampling Organization: UNIBO
Type of Water: Agricultural drain water
Sampling date: 30.11.2022
Analysis date: 30.01.2023

Table 58. *Micronutrient concentration in drainage water of Italy case study Sampling 9*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	151
Boron (B)	0.14	Magnesium (Mg)	40.6

Manganese (Mn)	<0.010	Potassium (K)	5.20
Iron (Fe)	<0.050	Sulphur (S)	300

7.3.10. Sampling 10

Sampling Organization: UNIBO
Type of Water: Agricultural drain water
Sampling date: 30.11.2022
Analysis date: 30.01.2023

Table 59. *Micronutrient concentration in drainage water of Italy case study Sampling 10*

Micronutrient	Concentration (mg/l)	Micronutrient	Concentration (mg/l)
Copper (Cu)	<0.010	Phosphorous (P)	<0.20
Zinc (Zn)	<0.025	Calcium (Ca)	168
Boron (B)	0.20	Magnesium (Mg)	43.1
Manganese (Mn)	<0.010	Potassium (K)	5.80
Iron (Fe)	<0.050	Sulphur (S)	320