Assessing the integrity of water sources in remote rural communities

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Abstract. This study investigates the impact of agricultural practices on water quality in the rural community of Aiton, Romania. Utilizing agri-environmental indicators (AEIs), the research focuses on contamination from nitrates and pesticides in both drinking and surface water sources. Water samples were systematically collected from wells and streams, revealing significant pollution levels in select cases, notably nitrate and pesticide concentrations exceeding national and EU thresholds. Sulfate levels also indicated widespread non-compliance in a minority of cases. These findings highlight the critical health risks and environmental challenges posed by current agricultural practices. The study emphasizes the need for interventions, such as buffer zones, integrated pest management (IPM), and enhanced water treatment solutions, to ensure the sustainability of rural water resources. Concluding with a call for longitudinal monitoring and expanded regional analyses, this work underscores the importance of sustainable water management in achieving environmental and public health goals aligned with the UN Sustainable Development Goals.

Key Words: rural settings, sustainability, water quality, water resources, well water.

Introduction

The research context. The impact of rural activities and farming on local water resources is significant. It affects the availability, quality and long term sustainability of water in these regions (Iglesias & Garrote 2015). The rural communities heavily rely on water for purposes such as production, livestock rearing and household needs (Kang et al 2017; Nwokediegwu et al 2024). However the practices associated with these activities can pose challenges to the human health and sustainability of water systems (Cosgrove & Loucks 2015; Dinar 2024).

Farming plays a major role in economies and food production by involving irrigation, the use of fertilizers and pesticides as well as livestock management. All of these aspects have indirect consequences on water resources (Geissen et al 2015). The runoff and leaching of these chemicals are a consequence of improper treatments applied by farmers and they might find their way into nearby water bodies (Elahi et al 2019). Once contaminated with nutrients and pollutants, water resources quality decreases leading to ecosystem imbalances and can be a threat to human health (Tudi et al 2021). Rosa et al (2019) highlighted that 52% of global irrigation is unsustainable. Farming significantly affects local water resources, with water consumption being a key concern. For instance, the irrigations which are essential for crop production are often leading to significant water withdrawals from lakes, rivers or even underground aquifers. There are regions such as Middle East and Africa (Kuzma et al 2023) where the water availability is already limited and this can lead to strains on the water supply, which affects both rural communities and nearby ecosystems (Lorenzo et al 2020). The inefficiency of water irrigations might result in water loss such as evaporation or runoff, exacerbating the issue of water scarcity (Frisvold et al 2018; Guleria et al 2020).

A key innovation of this study is that it is the first in Romania to utilize AEIs, specifically 27.1 Water Quality - Nitrate Pollution and 27.2 Water Quality - Pesticide Pollution, to assess water quality. In contrast, previous research (Dunca 2018; Iticescu et al 2019; Frîncu 2021) in the studied area has predominantly relied on the Water Quality Index, pollution index, or wastewater quality index. From an international point of view, the relevance of this study lays in the fact that it highlights the potential contamination risks of water resources from nearby agricultural sites. Romanian agriculture plays a pivotal role in Europe due to its extensive arable land, making it one of the largest grain producers in the European Union. Its strategic contribution to the continent's food security is enhanced by its favorable climate, diverse crop production, and growing agricultural exports. According to data published by European Commission, Romania was the biggest and main soft wheat exporter in the European Union in 2023 delivering 1.35 million tons just in the first 2 months. Lastly but not least, water quality is directly linked to several of the United Nations SDGs, including clean water and sanitation (SDG 6), zero hunger (SDG 2), and life below water (SDG 14).

Navigating water vulnerability: challenges and solutions in rural communities. Many rural communities are located in areas with delicate ecosystems and varying rainfall patterns, which makes them more vulnerable to water scarcity (Liu et al 2016). The current on-going climate crisis is exacerbating these challenges and it is causing unpredictable changes in weather patterns altering the local precipitation regimes (He et al 2021). Extended droughts, irregular rainfalls, and reduced snowpack on the mountains are elements leading to depreciation of water supplies, affecting in direct ways rural communities which depend on rivers, lakes or groundwater resources (Alam 2015). Water consumption and its unsustainable usage are global issues; in a recent study, Hartman et al (2021) show how Mexican communities are relying on unsustainable irrigation practices and how United States produce tied to Mexico's unsustainable agricultural water use. Other authors (e.g. Tuninetti et al 2019) provide an overview of critical overuses also found over the High Plain and Indo-Gangetic Plains in Asia. Weed infestation, eutrophication and pesticide contamination in Asian countries were also reported by Shan et al (2020) and Rajan et al (2023).

Unsustainable exploitation of water resources due to lack of proper training, awarness or state of the art infrastructure for efficient irrigation and conservation is often a major issue in rural settings (Ngene et al 2021). Deregulated or poorly regulated water extraction for agricultural activities often leads to local water depletion and incresed water scarcity for both ecosystems and communities (Tuninetti et al 2019). In addition to all of that, the contamination resulted from agricultural runoffs, industrial wastes, scarce sanitation systems, can result in the pollution of water resources which is a significant health risk to rural population (Xia et al 2020).

The health and well-being of rural population lays in their access to clean and safe drinking water. Regrettably, in many rural settings the problem of clean drinking water is still current and pesticide contamination highlights a major concern (Chalchisa et al 2018). The use of agrochemicals or pesticides in farming activities aims to protect crops from pests and diseases diseases (de O. Gomes et al 2020; Tudi et al 2021). Nevertheless, inappropiate handling, disposal or application of those chemicals might result in leaching or migration into water resources and among their effects are contamination and potential heatlth risk for rural populations (Delcour et al 2015). There are various ways in which pesticides might contaminate the rural drinking water. Runoffs coming from farming fields might carry residues in nearby streams, wells, rivers and groundwater (Husk et al 2019). Moreover, innapropiate storage and unsuitable disposal operations can lead to leaching from pesticide containers or storage facilities can contaminate groundwaters which are a common source of drinking water in rural communities as people are using their own wells (Elibariki & Maguta 2017). The consequences of pesticide contamination in rural drinking water are significant because exposure to agrochemicals compounds through ingestion or even cutaneous contact can have severe effects on human health (Daud et al 2017). Depending on their toxicity, pesticides can cause acute or chronic health issues included but not limited to gastrointestinal disorders, organ damages, developmental issues and higher risk of certain cancers (Sankhla et al 2018). Most vulnerable are children and pregnant women being particularly at risk (Lai 2017).

A comprehensive strategy is needed to address the problem of pesticide pollution in rural drinking water (El-Nahhal & El-Nahhal 2021). Primarily, it is very important to stimulate farmers to adopt proper pesticide management practices which include suitable application techniques, well calibrated dosages and not lastly compliance to recommended safety measures (Mekonen et al 2016). Other factors which can play crucial roles in minimizing contamination risks are effective monitoring and enforcement of pesticide regulations (El-Nahhal & El-Nahhal 2021; Wang et al 2021).

Implementation of vegetative strips and buffer zones between farming fields and water bodies can effectively help diminish pesticide runoff and protect water resources (Gautam et al 2017). Adoption of integrated pest management (IPM) practices which are focusing on minimizing the usage of pesticides and commissioning alternative pest control techniques can also contribute to risk of contamination mitigation (Grasswitz 2019).

Additionally to preventive measures, constant water quality examinaton is essential to detect and address contamination issues without delay. In order to do this, government agencies, water management authorities, local communities and farmers must collaborate and ensure regular monitoring and provision of alternative safe water resources when contamination is identified (Gautam et al 2017). The promotion of sustainable pesticide use, improving the surveillance infrastructure and providing access to clean drinking water can safeguard the health and well-being of rural communities supplying them with resources of clean water without of dangerous pesticide residues (Muriithi et al 2016; Bagheri et al 2019).

The effects of both farming and human rural activities on local water resources require a cautious examination of sustainable practices and management approaches. Long-term water security can be achieved only by balancing the water needs of agriculture and rural communities with safeguarding and conserving water resources (Jiang 2015). There are many strategies available which can help minimize the negative impacts on water resources while ensuring the sustainability of rural livelihoods such as improved irrigation technologies, agroecological approaches, precision agriculture and responsible waste management (Romero et al 2022). Advanced oxidation processes are recognized as clean technologies for the treatment of contaminated water with pesticides (Syafrudin et al 2021). Similar research performed in other parts of the world discusses the contamination of surface water by pesticide residues, analyzing water quality and its suitability for consumption (Jokha et al 2014). Other studies (Pradhan et al 2022) explored the consequences of pesticide contamination in water resources, focusing on acute and chronic health effects. Rey-Martínez et al (2022) reviewed current decontamination methods, evaluated the contamination levels of various pollutants, including pesticides, in water recovery systems. Related research was carried out on different continents (Africa, Europe, Asia) and ivestigated the local water quality reaching similar conclusions: everywhere is an urgent need for better water quality monitoring and the continuous need of improvement of the current water management strategies and of this objective, remote sensing solutions might be employed (Adjovu et al 2023).

***The role of AEIs in the preservation of water resources**.* The AEIs are crucial tools for assessing the sustainability and environmental impact of agricultural practices (Spânu et al 2022). They are defined as a parameter or a value that characterizes the condition of the environment and its effects on humans, ecosystems, and materials, including the environmental pressures, driving forces, and responses shaping that system. The indicator undergoes a selection and/or aggregation process to facilitate its use in guiding future actions (Commission Communication 2018). These indicators are providing quantitative information about the complex relationship between farming activities and environment to policymakers and other stakeholders to make knowledgeable decisions and ellaborate effective mitigation strategies again environmental contamination and pollution. They cover a wide range of aspects, including soil health, water quality, biodiversity, greenhouse gas emissions, and use of pesticides and fertilizers (Salvan et al 2022). AEIs make it possible to identify fields where agricultural activities may be causing negative impacts (Andrade et al 2022). Another role of AEIs is to encourage sustainable farming practices that balance farm production with environmental protection, targeting for long-term ecological resilience and preservation of natural resources for future generations (Bergez et al 2022). For example, in a study by Andrade et al (2022) authors selected and applied AEIs to assess potential technologies for nutrient recovery in agriculture. Harasim et al (2021) evaluated farms' environmental impact on the basis of eight AEIs indicators. Kokkora et al (2023), based on AEIs application, concluded that nitrogen leaching losses from a kiwi farm are indicating potential impact on groundwater quality.

The performance of agriculture in Europe is measured, monitored and assessed by a comprehensive set of AEIs, developed by the Eurostat, statistical office of the European Union (Eurostat 2020). The AEIs cover a variety of agricultural aspects and their environmental impact. They offer valuable information on topics such as land use, water management, soil quality, biodiversity, climate change effects and the use of agrochemicals (Commission Communication 2018).

AEI's are metrics used to identify agricultural practices and environment factors, providing an evaluation of the agricultural processes. This analysis is very much helpful in observing changes in the availability of biodiversity, soil, water and global warming gases, and is very crucial in suggesting policies for enhancing agricultures development. AEIs are used in the process of environmental progression data capture especially in the context of the Common Agriculture Policy (CAP) of the European Union. Other works including those of OECD (2013) and Wuepper et al (2024) that concentrated on the use of the AEIs and their relevance to setting the agriculture policies of different nations across the Europe regions.

Given the significant impact of agricultural practices on water availability and quality, it is essential to examine these effects in depth to identify strategies for sustainable water management. Consequently, this study investigates the effects of agricultural activities on local water resources and aims to deepen our understanding of the current environmental challenges (such as water contamination with pesticides), identify potential solutions, and pave the way for sustainable water management practices using two key agri-environmental indicators (AEIs) indicators on water quality (27.1 Water Quality - Nitrate pollution and 27.2 Water Quality - Pesticide pollution) (Eurostat 2020). Choosing a small village allows for a focused investigation into specific agricultural methods and their impact on water quality, providing a baseline for comparative studies within Romania's diverse agricultural landscape. Conducting research in a small village was logistically manageable and facilitated a more thorough study of water quality dynamics. The chosen indicators aimed to address the issue of nitrate and pesticide pollution, commonly linked to agricultural activities. Nitrate and pesticide pollution are widespread global concerns regarding water quality. Moreover, these types of pollution can have a significant adverse effects on both human health and the environment (Nicholson et al 2020; Dhankhar & Kumar 2023).

Material and Method

Characterization of the study area. Romania is a country located in South-Estern Europe. The total population of Romania is 19 million inhabitants, of which 47.7% are people living in rural settings. The share of agriculture in the gross domestic product of the country was 4% in 2023 and it employs 26% of the total labor force of the country (INS 2021). According to Eurostat (2000), in 2018 Romania was the sixth largest user of pesticides in Europe, with around 10 million kilograms. Our country is surpassed by France (80 million kg), Spain (over 70 million kg), Italy (over 50 million kg), Germany (over 40 million kg) and Poland (over 20 million kg).

Aiton is a rural settlement in the Cluj County of Romania with the traditional agricultural practices being the order of the day and farming being the core economic activity for many residents. The loamy village environment is very functional since it assists in growing crops like wheat, maize and potatoes, covering fruit trees and vine grapes. In addition to crops farming, animals and birds rearing which include among others cattle, sheep, goats and poultry, are also well taken care of here. However, Aiton shares the same challenge as other rural areas in Romania such as the issue of land fragmentation. In spite of all the trials, agriculture from the community level proves to be critical as people in the village survive and their culture is not lost.

We selected Aiton village as our study area. The research timeframe was October-November 2023. As illustrated in Figure 1, Aiton it is located in the Cluj County within the Apuseni Mountains region. Aiton's village central location is north-west at the national level and south-east at the county level of the commune of Aiton and has the following geographic coordinates: 23º39'34'' - 23º47'49'' E longitude and 46º38'26'' - 46º42'48'' N latitude. It has 52.8 km^2 and falls below the surface average, both at the county level county (69th place out of 80 at an average of 82 km^2) and at national level at an average of 74.9 km^2, occupies the 3,182nd position among Romania's 4,010 communes (Aiton Municipality Development Strategy 2014-2050 2014).

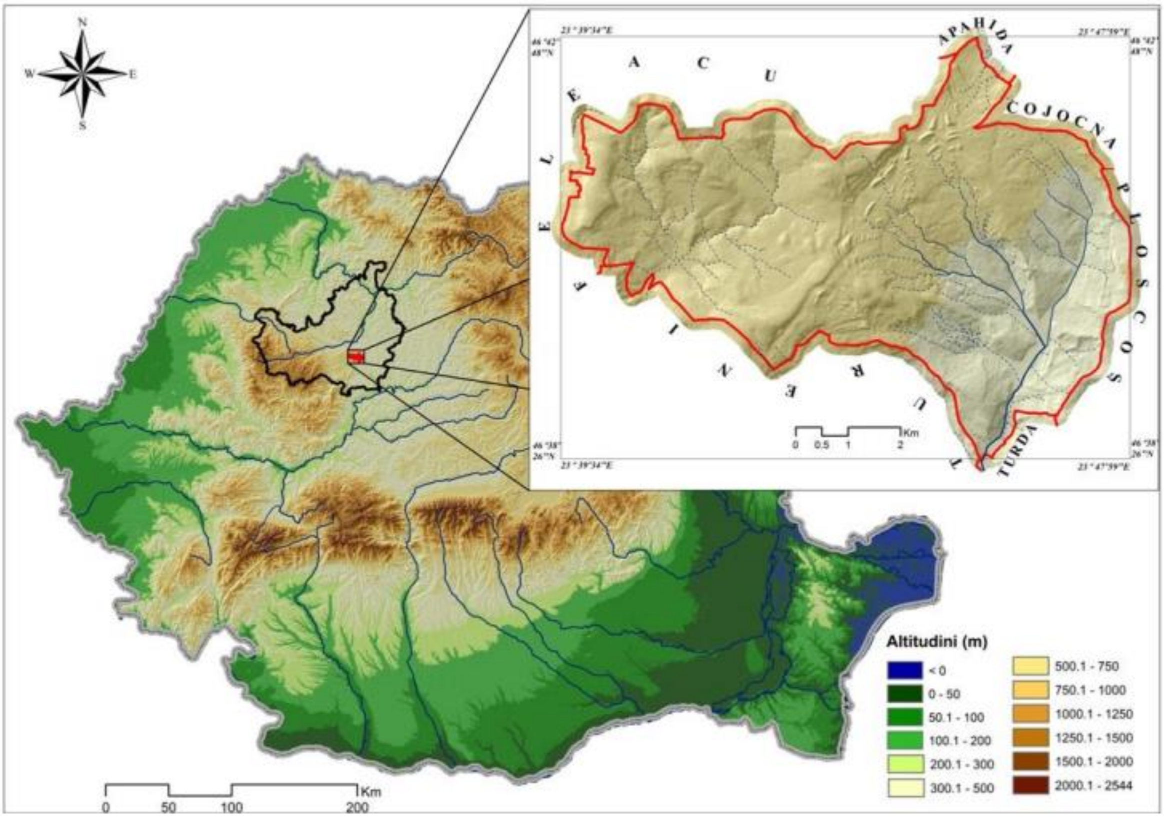

Figure 1. The location at national and county level of the commune of Aiton. Source: Aiton Municipality Development Strategy 2014-2050 (2014).

The climate of the commune of Aiton is temperate-continental. Figure 2 displays the hydrographic network of Aiton commune. As it can be observed, the commune of Aiton has in its composition two villages: Rediu and Aiton. The phreatic waters retain the note of the Transylvanian Plain, where the rainfall is relatively low, the modest degree of coverage with forest vegetation and the presence of formations impermeable (clays), which favor a relatively rapid drainage, are significant factors of restrictiveness in the existence of rich aquifer horizons. The depth of the first groundwater is approximatively 5 m. The hydrographic network has a low density of only 0.4 $km\ km^{-2}$. Existing streams have a low flow and during prolonged drought periods they dry. The area where the village of Aiton is located is affected by climatic risk phenomena that fall into two categories: medium and long term phenomena. The first category includes heat waves and abundant precipitations (generated by continental or Atlantic extratropical cyclones) and from the second the pluviometric deficit periods (Aiton Municipality Development Strategy 2014-2050 2014).

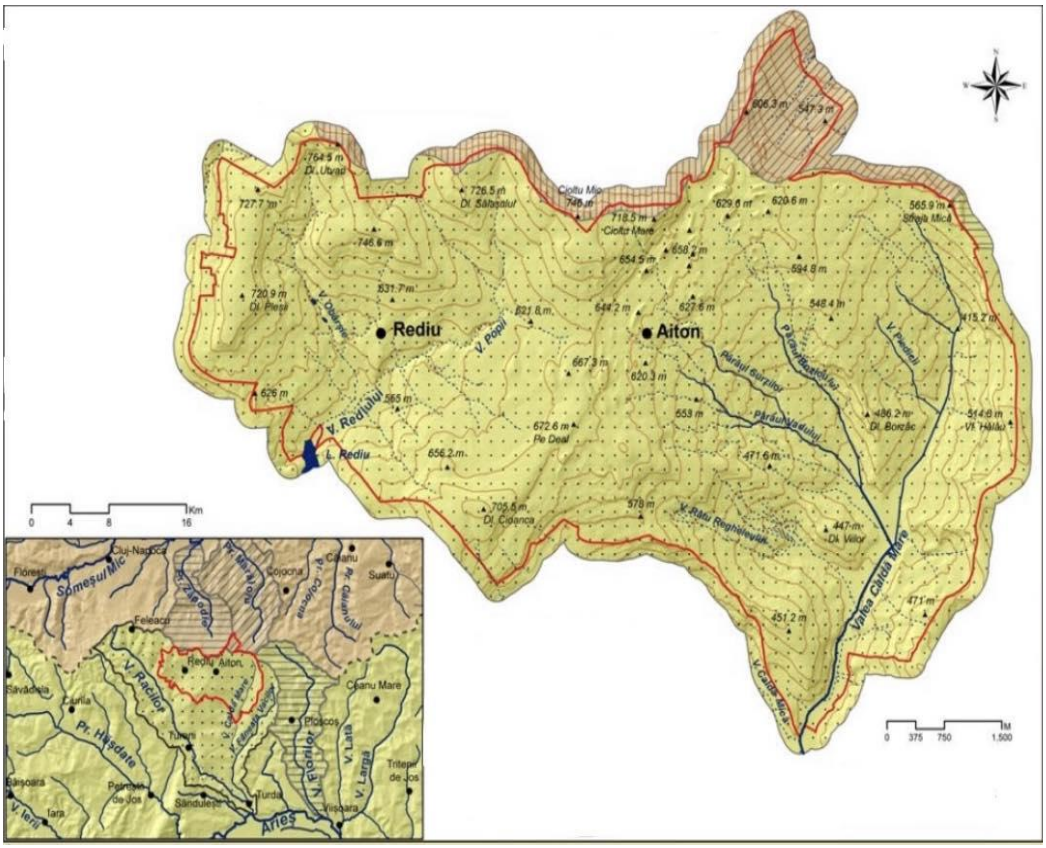

Figure 2. Hydrographic network of Aiton commune. Source: Aiton Municipality Development Strategy 2014-2050 (2014).

According to Aiton’s Municipality website, the village has a population of just 1000 permanent residents and and 1786 households, however the village hosts many vacation homes of people who left the area for better opprotunities. The main source of the income for population is traditional agriculture intensively practiced and the main employer is a livestock farm, therefore agriculture (animal husbandry and plant cultivation) is the main source of income for this village’s inhabitants.

This study area encompasses a variety of cultural features that contribute to its scientific significance. Among the cultural features of scientific significance from Aiton, traditional agricultural practices, architectural heritage, ethnobotanical knowledge, local water management and cultural landscapes can be listed. That is why the commune of Aiton is an excellent example of a bipolar rural system, made up of two settlements, Aiton and Rediu, spatially adjacent, with a relative close economic and social potential.

Research design; samples collection and analysis. In order to analyze and evaluate the water resources quality, a total of 40 water samples (37 samples from locals wells from a total of 115 and 3 samples collected from nearby streams) were collected from Aiton village, following the methodology given in ISO 5667-5:2006 (ISO/TC 147/SC 6, n.d.). Apart from techniques that measure specific water parameters using standardized instruments, 33 pesticides chemical compounds were searched in the water samples through laboratory analysis.

Addressing the first objective of the study, namely evaluation of the water quality parameters, the following parameters were investigated for each of the 40 samples: pH, oxido-reduction potential (ORP), electrical conductivity (EC), total dissolved solids (TDS), salinity, iron concentration, chlorine, nitrites, nitrates, and sulphates. For the purpose of this paper, the maximum allowable concentrations for drinking water were extracted from

Romanian national law no. 458/2002 which has the same maximum allowable concentrations for drinking water like the Directive (EU) 2020/2184 (The European Parliament and of the Council 2020) on the quality of water intended for human consumption or Water Framework Directive as it is widely known. For the maximum allowable concentrations for water samples collected from streams authors reffered to Order 161/2006, which regulates the concentrations and classifies the surface waters into 5 quality classes (1st class being having the highest quality (potable after simple treatment) and 5th class having the lowest quality).

Prior to conducting fieldwork in Aiton village for water sample collection, systematic sampling points were established on Google Earth, as depicted in Figure 3. The sampling points denoted by "F" corresponded to samples sourced from local wells, while those labeled as "R" indicated samples obtained from surface streams. To ensure a comprehensive assessment of water resource contamination with nitrates or pesticides, it was imperative to acquire both drinking water samples and samples from rivers, thereby ensuring a standardized and uniform sampling approach across the entire village.

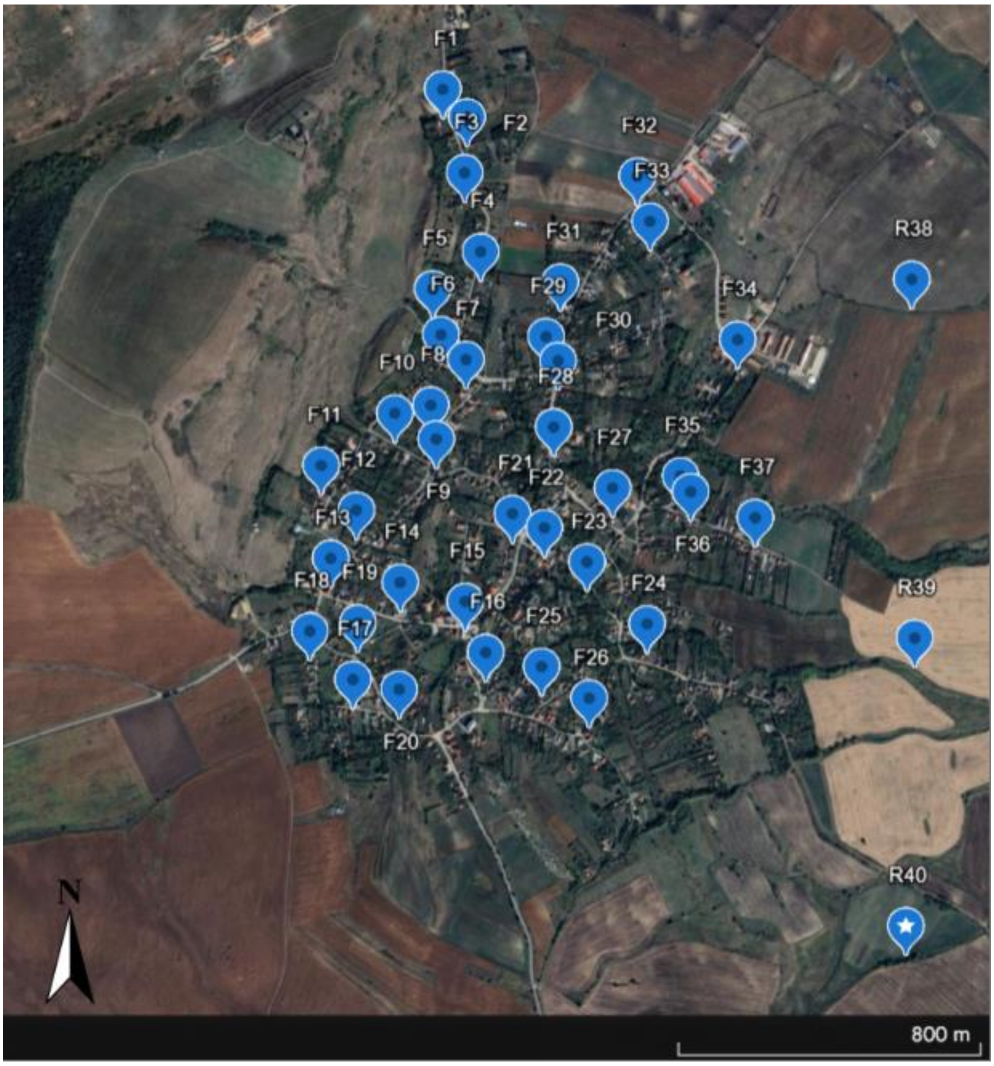

Figure 3. Sampling area. Source: screenshot Google Earth.

Considering the substantial agricultural activities, notably in proximity to local households, the investigation encompassed not only nitrate pollution but also an additional 33 pesticide chemical compounds present in the water derived from both wells and rivers which are displayed in Table 1 together with the Chemical Abstract Service (CAS) registry number, scientific name and molecular formula.

The authors used the following instruments in the laboratory to analyze the water samples: professional turbidimeter for water, according to ISO 7027, a professional laboratory multiparameter and a Ion HPLC high-performance liquid chromatograph.

Table 1

Chemical compounds

Chemical compound	*Scientific name*	*Molecular formula*	*CAS No.*
Alfa - HCH	Alpha-Hexachlorocyclohexane	$C_6H_6Cl_6$	86194-41-4
Beta - HCH	Beta-Hexachlorocyclohexane	$ClCH(CHCl)_4CHCl$	319-84-6
Gama - HCH	Gamma-Hexachlorocyclohexane	$C_6H_6Cl_6$	104215-85-2
Delta - HCH	Delta-Hexachlorocyclohexane	$C_6H_6Cl_6$	319-86-8
Epsilon-HCH	Epsilon-Hexachlorocyclohexane	$C_6H_6Cl_6$	6108-10-7
Pentaclornitrobenzene	Pentachloronitrobenzene	$C_6Cl_5NO_2$	82-68-8
Aldrin	Aldrin	$C_{12}H_8Cl_6$	309-00-2
Dieldrin	Dieldrin	$C_{12}H_8Cl_6O$	60-57-1
Heptachlor	Heptachlor	$C_{10}H_5Cl_7$	76-44-8
Heptachlor epoxide beta	Heptachlor epoxide	$C_{10}H_5Cl_7O$	1024-57-3
Heptachlor epoxide alfa	Heptachlor epoxide	$C_{10}H_5Cl_7O$	1024-57-9
beta-Endosulfan	Beta-Endosulfan	$C_9H_6Cl_6O_3S$	959-98-8
alpha-Endosulfan	Alpha-Endosulfan	$C_9H_6Cl_6O_3S$	959-98-8
2,4'-DDE	Dichlorodiphenyldichloroethylene	$C_{14}H_8Cl_4$	3424-82-6
4,4'-DDE	4,4'-Dichlorodiphenyldichloroethylene	$C_{14}H_8Cl_4$	72-55-9
2,4'-DDD	Dichlorodiphenyldichloroethane	$C_{14}H_{10}Cl_4$	72-54-8
4,4'-DDD	Dichlorodiphenyldichloroethane	$C_{14}H_{10}Cl_4$	72-54-8
2,4'-DDT	Isomer of dichlorodiphenyltrichloroethane	$C_{14}H_9Cl_5$	789-02-6
4,4'-DDT	Dichlorodiphenyltrichloroethane	$C_{14}H_9Cl_5$	104215-84-1
PCB 28	2,4,4'-Trichlorobiphenyl	$C_{12}H_7Cl_3$	7012-37-5
PCB 52	2,2',5,5'-Tetrachlorobiphenyl	$C_{12}H_6Cl_4$	35693-99-3
PCB 101	2,2',4,5,5'-Pentachlorobiphenyl	$C_{12}H_5Cl_5$	37680-73-2
PCB 138	2,2',3,4,4',5'-Hexachlorobiphenyl	$C_{12}H_4Cl_6$	35065-28-2
PCB 153	2,2',4,4',5,5'-Hexachlorobiphenyl	$C_{12}H_4Cl$	35065-27-1
PCB 180	2,2',3,4,4',5,5'-Heptachlorobiphenyl	$C_{12}H_3Cl_7$	35065-29-3
PCB194	2,2',3,3',4,4',5,5'-Octachlorobiphenyl	$C_{12}H_2Cl_8$	35694-08-7
1,2,3-tricorbenzene	Vic-Trichlorobenzene	$C_6H_3Cl_3$	87-61-6
1,2,4-tridorbenzene	1,2,4-Benzenetriol	$C_6H_6O_3$	33-73-3
1,3,5-tridorbenzene	1,3,5-Tris(bromomethyl)benzene	$C_9H_9Br_3$	18226-42-1
1,2,3,5 - tetraclorbenzene	1,2,3,5-Tetrahydroxybenzene	$C_6H_6O_4$	634-94-6
1,2,3,4 - tetraclorbenzene	1,2,3,4-Benzenetetrol	$C_6H_6O_4$	642-96-6
1,2,4,5 - tetraclorbenzene	1,2,4,5-Tetraisopropylbenzene	$C_{18}H_{30}$	635-11-0
Pentadorbenzene	3-phenylpentadiene	$C_{11}H_{12}$	37580-41-9

Note: CAS = Chemical Abstract Service.

Results and Discussion. For the following parameters, the analyses showcased normal values in all water samples (both wells and streams): pH, oxido-reduction potential (ORP), electrical conductivity (EC), total dissolved solids (TDS), salinity and iron concentration. The red line on each chart represents the maximum allowable limit stated by law. However, as it can be observed in Figure 4, the concentration of chloride in two water samples exceeds the maximum allowable limit of 250 mg L^{-1}.

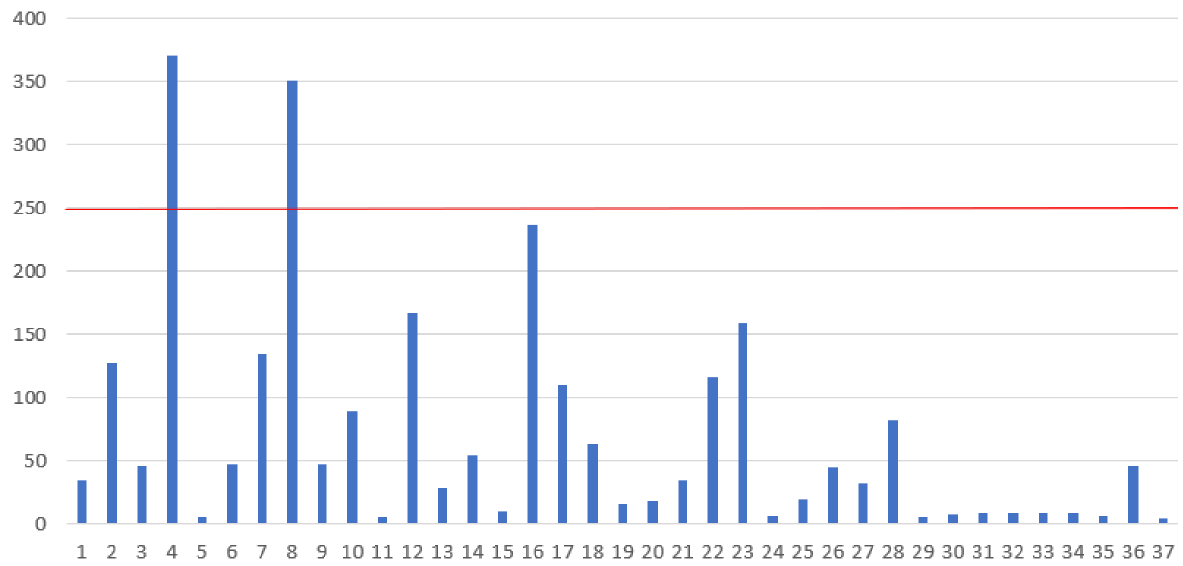

Figure 4. Chlorine concentration (mg L^{-1}) in collected water samples (wells). Note: the red line represents the maximum allowable limit stated by law.

In regards to the water samples collected from streams, chloride concentration was obviously higher in 1 sample than in the others 2, making the same 38r being classified as 2nd class stream water. Figure 5 displays the results.

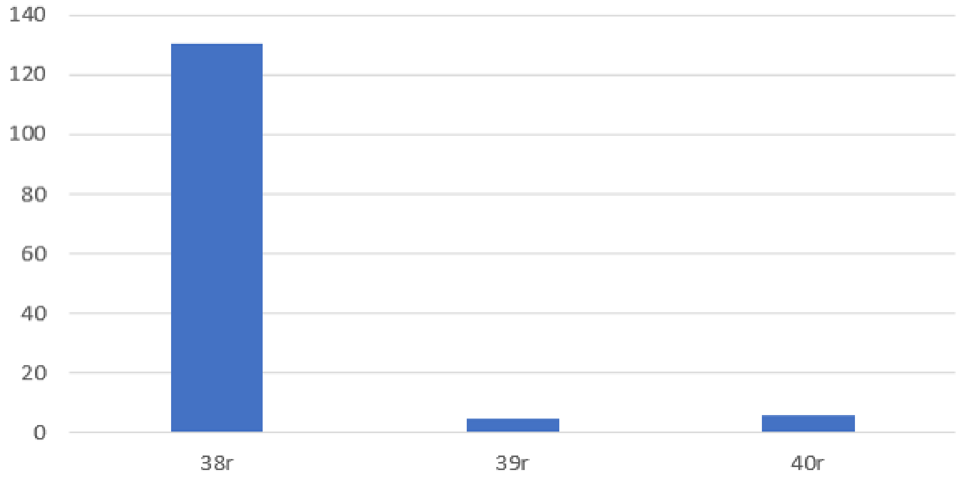

Figure 5. Chlorine concentration (mg L^{-1}) in collected water samples (streams).

Nitrites were identified in 11 water samples from wells and in the samples collected from streams they were under the detection limit. Figure 6 displays the nitrites concentration and the maximum allowable concentration in drinking water (0.50 mg L^{-1}).

Figure 7 displays the nitrates concentrations in the collected water samples both wells and streams. It is shown that in the samples collected from streams there are insignificant values of nitrates, while in the samples collected from wells there are significantly higher values determined. The maximum allowable concentration of nitrates in drinking water is 50 mg L^{-1}. Eight wells had concentrations over the maximum allowable limit.

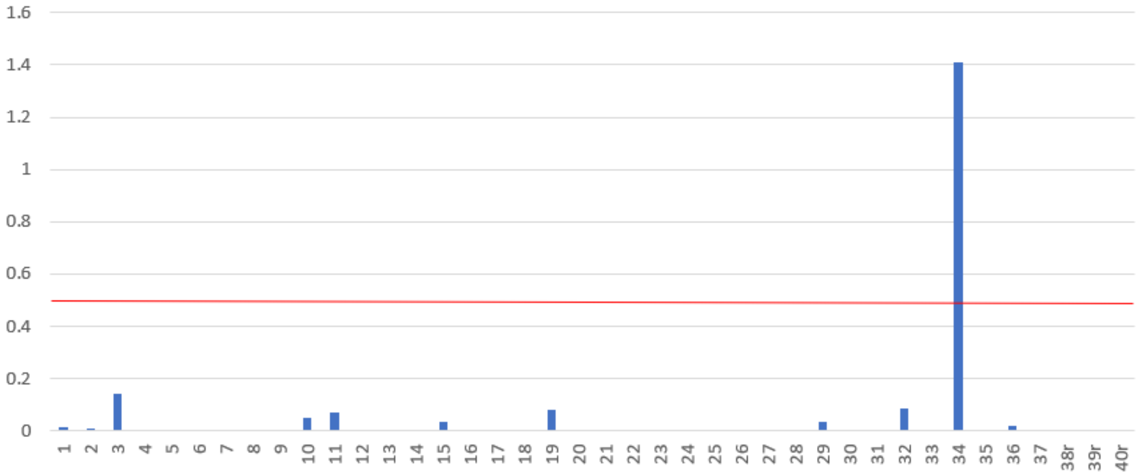

Figure 6. Nitrites concentration (mg L^{-1}) in collected water samples (wells + streams). Note: the red line represents the maximum allowable limit stated by law.

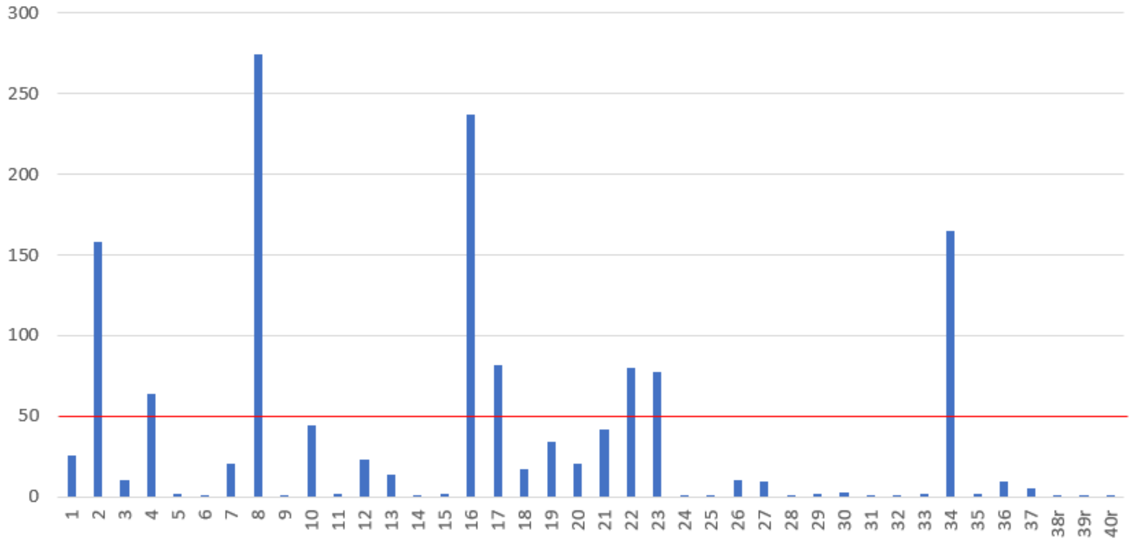

Figure 7. Nitrates concentration (mg L^{-1}) in collected water samples (wells + streams). Note: the red line represents the maximum allowable limit stated by law.

Approximately 21.6% of the samples exceed the allowable nitrate limit. It is a significant proportion of non-compliant samples. Four samples are reported to have nitrate concentrations that are 3 to 4 times the allowable limit. In these cases, the contamination is particularly severe. Such high levels could have serious health implications and suggest a more acute contamination issue in those specific samples. Investigating these sources can help identify the cause of elevated nitrate levels. The depth of the wells varied between 4 and 15-20 meteres approximately according to locals. From a total of 37 wells, 45.94% of them were regularly treated with chlorine pills by their owners twice a year during spring and autumn. When asked about their perception of water quality, 40.54% of the respondents stated that their wells water quality is "bad" mostly because of it durity. Only 4 out of 37 wells investigated are drying once a year or rarely.

Another parameter which indicated over the maximum allowable limit concentrations in drinking water is sulphate. The maximum allowable limit is 250 mg L^{-1} and in 10 samples out of 37 this limit has been over-reached as shown in Figure 8.

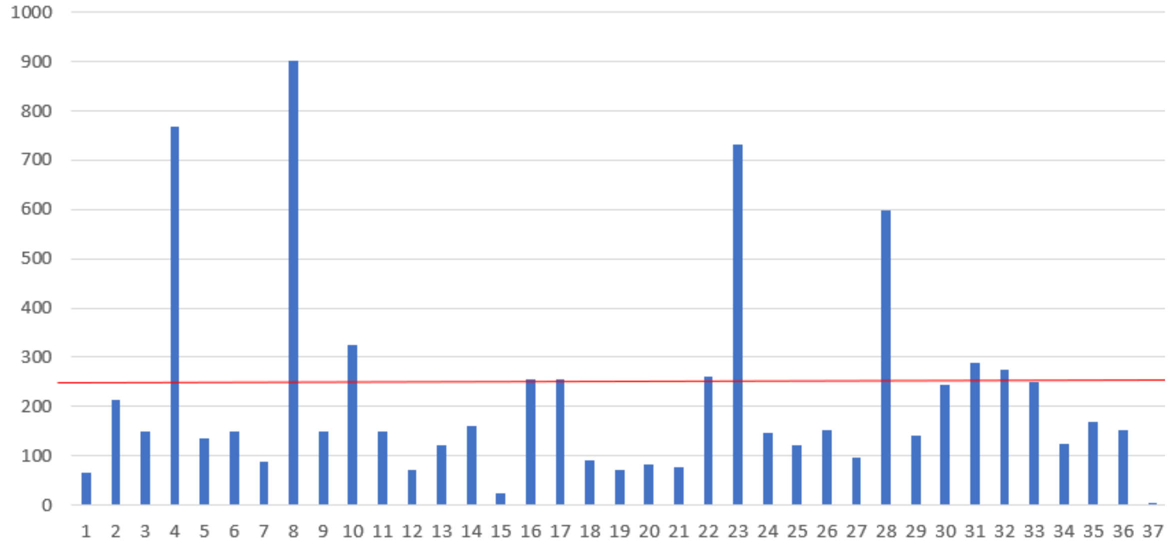

Figure 8. Sulphates concentration (mg L^{-1}) in the collected water samples (wells). Note: the red line represents the maximum allowable limit stated by law.

Approximately 21.6% of the samples exceed the allowable sulphate limit. This suggests that a minority of the samples are not compliant with the regulatory standards. The concentrations in the samples 4 and 23 are 3 times the maximum allowable limit meanwhile in the same 8 the concentration is almost 4 times higher. This indicates a particularly severe exceedance in these cases. With 8 out of 37 samples exceeding the limit, the majority (29 samples) are still within the allowable limit, but the fact that a notable proportion exceeds the limit indicates a potential concern.

For the water samples collected from streams, significant concentrations of sulphate were found in all water samples as depicted in Figure 9. According to Order 161/2006, the samples 38r and 40r are classified as fifth class quality surface waters (lowest class) and the sample 39r as forth class.

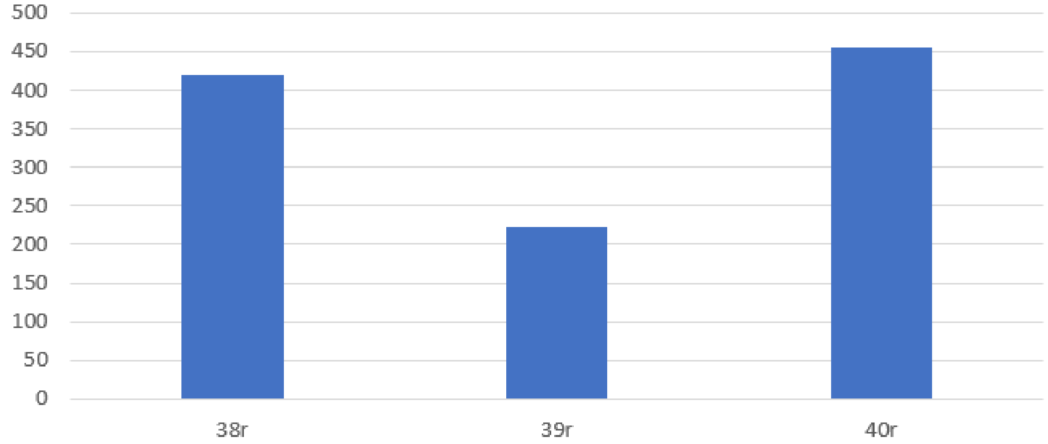

Figure 9. Sulphates concentration (mg L^{-1}) in the collected water samples (streams).

Both European Water Directive and Romanian national law are setting 0.10 µg L^{-1} as maximum allowable concentrations for each pesticide in drinking water and the sum of all pesticides cannot exceed 0.50 µg L^{-1}. Even if traces of pesticides were found in almost all water samples, in 4 samples the sum of pesticides exceeded the maximum allowable limt as depicted in Figure 10, which is a threat to human health. Most of the water samples from wells were contaminated with chemical compounds exceeding 0.10 µg L^{-1}.

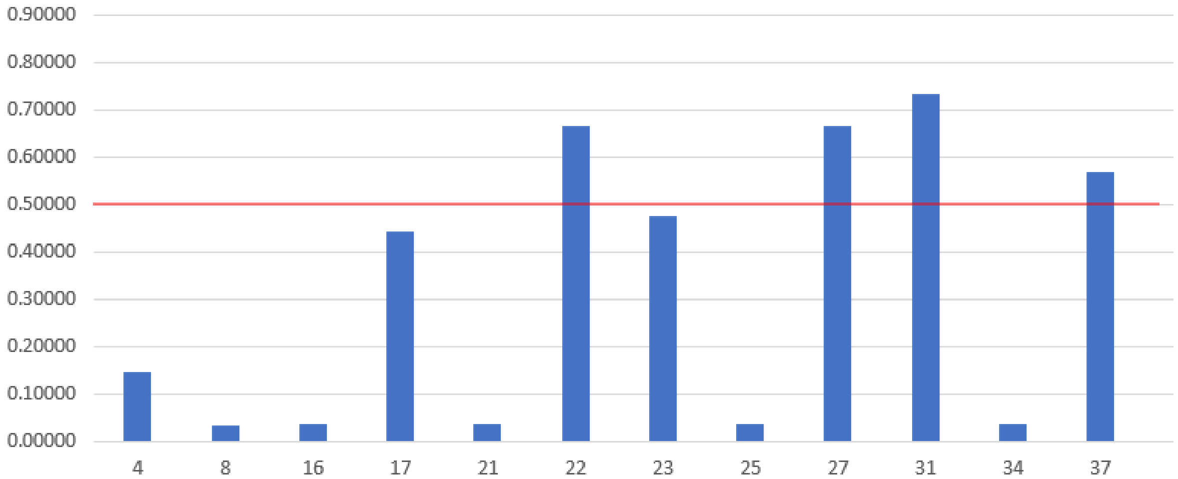

Figure 10. Total of pesticides (μg L^{-1}) found in the wells water. Note: the red line represents the maximum allowable limit stated by law.

The sum of pesticides exceeds the maximum allowable limit in 4 out of 37 wells or samples which means that approximately 10.8% of the samples have pesticide levels above the allowable limit. This indicates a minority of the samples exceed the regulatory threshold. Since only 4 out of 37 samples exceed the limit, the majority (33 samples) are within the allowable limits. This suggests that, overall, most of the wells or samples are compliant with the pesticide regulations. The presence of pesticide levels exceeding the maximum allowable limit in a few samples might raise concerns about potential health risks or environmental impact, especially if these wells are sources of drinking water or used in agriculture. This overall result might be influenced by the local community still employing local traditional agricultural practices in which chemical pesticides are not included. A potential source of contamination might be the small vegetable gardens people have near the wells.

According to the legislation, the concentration of individual and total pesticides allowed in surface waters assigned as drinking water sources are 0.1 μg L^{-1} and 0.5 μg L^{-1}, respectively, the same as for drinking waters (established by the 98/83/EC). In the Figure 11 it can be observed that in one of the rivers the sum of pesticides exceeded the maximum allowable limit.

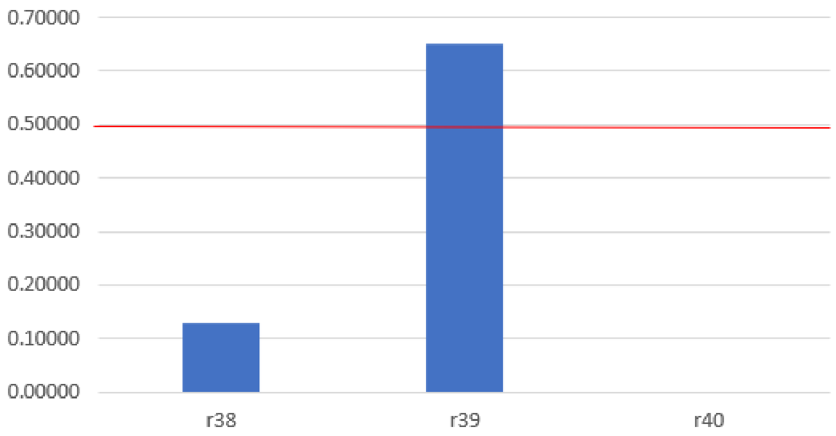

Figure 11. Total of pesticides (μg L^{-1}) found in the rivers. Note: the red line represents the maximum allowable limit stated by law.

Approximately 33.3% of the surface water samples exceed the allowable pesticide limit (1 out of 3). This is a significant proportion compared to the scenario where only a few samples exceeded the limit.

In summary, the analysis of water samples reveals notable concerns regarding contamination levels. Pesticide levels exceeded the maximum allowable limit in 4 out of 37 samples, with a significant percentage showing high concentrations. Sulphate levels were above the limit in 8 samples, with some concentrations 3 times higher, indicating a severe contamination issue. Additionally, nitrate concentrations exceeded the limit in 8 out of 37 samples, with 4 samples showing levels 3 to 4 times higher than permissible, highlighting a serious health risk. Addressing these issues will require targeted investigations, improved management practices, and increased monitoring to ensure water quality and safety.

As future research directions, authors propose the following: longitudinal studies (extended water quality monitoring and temporal analysis) and expanded geographical scope in which research is being conducted in different regions of Romania to compare water quality and identify regional patterns and sources of contamination. Then, watershed analysis would help investigate surface water quality across entire watersheds to understand how upstream activities affect downstream water quality. Further research, exploration and intervention is needed to address the emerging issues of water quality and ensure safe drinking water in rural areas.

As research limitations of the present study the authors would like to acknowledge the following: limited sample size and seasonal variations such as natural shifts in environmental conditions over different seasons, recurring changes that follow a seasonal pattern or temperature, precipitation, and daylight length vary by season

Conclusions. The study has revealed the following conclusions:

- widespread contamination: significant contamination of both well water and surface water with pesticides and nitrates, posing a serious threat to water quality and public health. The dual presence indicates agricultural runoff as a primary source, driven by intensive use of chemical fertilizers and pesticides;
- health and environmental risks: significant contamination of both well water and surface water with pesticides and nitrates, posing a serious threat to water quality and public health. The dual presence indicates agricultural runoff as a primary source, driven by intensive use of chemical fertilizers and pesticides;
- agricultural practices: the findings underscore the need for urgent intervention in agricultural practices, particularly in areas dependent on these water sources for drinking and irrigation such as Aiton village.

Potential solutions identified:

- buffer zones: establish vegetative buffer zones between agricultural fields and water bodies to filter runoff before it reaches water sources;
- integrated pest management (IPM): promote the adoption of IPM techniques to reduce reliance on chemical pesticides and prioritize biological and mechanical controls;
- water treatment systems: encourage the implementation of affordable nitrate and pesticide removal systems, such as reverse osmosis or activated carbon filters, for rural communities;
- policy and education: advocate for stricter regulation of pesticide and fertilizer application, alongside community education programs on sustainable farming practices and water conservation;
- monitoring programs: develop continuous water quality monitoring systems to track contamination trends and evaluate the effectiveness of implemented measures.

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References

Adjovu G. E., Stephen H., James D., Ahmad S., 2023 Overview of the application of remote sensing in effective monitoring of water quality parameters. Remote Sensing 15(7):1938.

Aiton Municipality Development Strategy 2014-2050, 2014 Available at: http://primariaaiton.ro/wp-content/uploads/2019/02/Strategia-de-dezvoltare-a-comunei-Aiton.pdf. Accessed: June, 2024. [in Romanian]

Alam K., 2015 Farmers' adaptation to water scarcity in drought-prone environments: a case study of Rajshahi District, Bangladesh. Agricultural Water Management 148: 196-206.

Andrade E. P., Bonmati A., Esteller L. J., Brunn S., Jensen L. S., Meers E., Anton A., 2022 Selection and application of agri-environmental indicators to assess potential technologies for nutrient recovery in agriculture. Ecological Indicators 134:108471.

Bagheri A., Bondori A., Allahyari M. S., Damalas C. A., 2019 Modeling farmers' intention to use pesticides: an expanded version of the theory of planned behavior. Journal of Environmental Management 248:109291.

Bergez J. E., Béthinger A., Bockstaller C., Cederberg C., Ceschia E., Guilpart N., Lange S., Müller F., Reidsma P., Riviere C., Schader C., Therond O., van der Werf H. M. G., 2022 Integrating agri-environmental indicators, ecosystem services assessment, life cycle assessment and yield gap analysis to assess the environmental sustainability of agriculture. Ecological Indicators 141:109107.

Chalchisa D., Megersa M., Beyene A., 2018 Assessment of the quality of drinking water in storage tanks and its implication on the safety of urban water supply in developing countries. Environmental Systems Research 6:12.

Commission Communication, 2018 Agri-environmental indicators (AEIs). Eurostat. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_consumption_of_pesticides#Key_messages. Accessed: June, 2024.

Cosgrove W. J., Loucks D. P., 2015 Water management: current and future challenges and research directions. Water Resources Research 51(6):4823-4839.

Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption, European Parliament.

Daud M. K., Nafees M., Ali S., Rizwan M., Bajwa R. A., Shakoor M. B., Arshad M. U., Chatha S. A. S., Deeba F., Murad W., Malook I., Zhu S. J., 2017 Drinking water quality status and contamination in Pakistan. BioMed Research International 2017: 7908183.

de O. Gomes H., Menezes J. M. C., da Costa J. G. M., Coutinho H. D. M., Teixeira R. N. P., do Nascimento R. F., 2020 A socio-environmental perspective on pesticide use and food production. Ecotoxicology and Environmental Safety 197:110627.

Delcour I., Spanoghe P., Uyttendaele M., 2015 Literature review: impact of climate change on pesticide use. Food Research International 68:7-15.

Dhankhar N., Kumar J., 2023 Impact of increasing pesticides and fertilizers on human health: a review. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.03.766

Dinar A., 2024 Challenges to water resource management: the role of economic and modeling approaches. Water 16(4):610.

Dunca A. M., 2018 Water pollution and water quality assessment of major transboundary rivers from Banat (Romania). Journal of Chemistry 2018:e9073763.

Elahi E., Weijun C., Zhang H., Nazeer M., 2019 Agricultural intensification and damages to human health in relation to agrochemicals: application of artificial intelligence. Land Use Policy 83:461-474.

Elibariki R., Maguta M. M., 2017 Status of pesticides pollution in Tanzania – a review. Chemosphere 178:154-164.

El-Nahhal I., El-Nahhal Y., 2021 Pesticide residues in drinking water, their potential risk to human health and removal options. Journal of Environmental Management 299: 113611.

EUROSTAT, 2020 EUROSTAT. Available at: https://ec.europa.eu/eurostat/web/agriculture/database/agri-environmental-indicators . Accessed: June, 2024.

Frîncu R. M., 2021 Long-term trends in water quality indices in the Lower Danube and tributaries in Romania (1996-2017). International Journal of Environmental Research and Public Health 18(4):1665.

Frisvold G., Sanchez C., Gollehon N., Megdal S. B., Brown P., 2018 Evaluating gravity-flow irrigation with lessons from Yuma, Arizona, USA. Sustainability 10(5):1584.

Gautam S., Schreinemachers P., Uddin M. N., Srinivasan R., 2017 Impact of training vegetable farmers in Bangladesh in integrated pest management (IPM). Crop Protection 102:161-169.

Geissen V., Mol H., Klumpp E., Umlauf G., Nadal M., van der Ploeg M., van de Zee S. E. A. T. M., Ritsema C. J., 2015 Emerging pollutants in the environment: a challenge for water resource management. International Soil and Water Conservation Research 3(1):57-65.

Grasswitz T. R., 2019 Integrated pest management (IPM) for small-scale farms in developed economies: challenges and opportunities. Insects 10(6):179.

Guleria M., Rajesh T., Panicker A. J., Rayappa Raja S. R., Soundharajan B., Frey L. M., Nandanan K., 2020 Using human centered design to improve socio-economic livelihoods with modernized irrigation systems. 2020 IEEE 8th R10 Humanitarian Technology Conference (R10-HTC), Kuching, Malaysia, 7 pp.

Harasim A., Madej A., Zarychta M., 2021 Agri-environmental aspects of the activity of farms with different production profiles. Polish Journal of Agronomy 46:3-8.

Hartman S., Chiarelli D. D., Rulli M. C., D’Odorico P., 2021 A growing produce bubble: United States produce tied to Mexico’s unsustainable agricultural water use. Environmental Research Letters 16(10):105008.

He C., Liu Z., Wu J., Pan X., Fang Z., Li J., Bryan B. A., 2021 Future global urban water scarcity and potential solutions. Nature Communications 12:4667.

Husk B., Sanchez J. S., Leduc R., Takser L., Savary O., Cabana H., 2019 Pharmaceuticals and pesticides in rural community drinking waters of Quebec, Canada – a regional study on the susceptibility to source contamination. Water Quality Research Journal 54(2):88-103.

Iglesias A., Garrote L., 2015 Adaptation strategies for agricultural water management under climate change in Europe. Agricultural Water Management 155:113-124.

INS, 2021 National Institute of Statistics. Available at: https://insse.ro/cms/. Accessed: July, 2024.

ISO/TC 147/SC 6 (n.d.), ISO 5667-5:2006. ISO. Available at: https://www.iso.org/standard/36694.html. Accessed: August, 2024.

Iticescu C., Georgescu L. P., Murariu G., Topa C., Timofti M., Pintilie V., Arseni M., 2019 Lower Danube water quality quantified through WQI and multivariate analysis. Water 11(6):1305.

Jiang Y., 2015 China’s water security: current status, emerging challenges and future prospects. Environmental Science and Policy 54:106-125.

Jokha M., Murimi S., Kihampa C., 2014 Degradation of water resources by agricultural pesticides and nutrients, Weruweru, Tanzania. Iranica Journal of Energy and Environment 5(2):192-201.

Kang S., Hao X., Du T., Tong L., Su X., Lu H., Li X., Huo Z., Li S., Ding R., 2017 Improving agricultural water productivity to ensure food security in China under changing environment: from research to practice. Agricultural Water Management 179:5-17.

Kokkora M., Koukouli P., Karpouzos D., Georgiou P., 2023 Model application for estimation of agri-environmental indicators of kiwi production: a case study in Northern Greece. Environments 10(4):69.

Kuzma S., Saccoccia L., Chertock M., 2023 25 countries, housing one-quarter of the population, face extremely high water stress. Available at: https://www.wri.org/insights/highest-water-stressed-countries. Accessed: October, 2024.

Lai W., 2017 Pesticide use and health outcomes: evidence from agricultural water pollution in China. Special Issue on Environmental Economics in Developing Countries 86:93-120.

Liu J., Liu Q., Yang H., 2016 Assessing water scarcity by simultaneously considering environmental flow requirements, water quantity, and water quality. Ecological Indicators 60:434-441.

Lorenzo R., Chiarelli D. D., Rulli C. M., Dell'Angelo J., D'Odorico P., 2020 Global agricultural economic water scarcity. Science Advances 6(18):eaaz6031.

Mekonen S., Argaw R., Simanesew A., Houbraken M., Senaeve D., Ambelu A., Spanoghe P., 2016 Pesticide residues in drinking water and associated risk to consumers in Ethiopia. Chemosphere 162:252-260.

Muriithi B. W., Affognon H. D., Diiro G. M., Kingori S. W., Tanga C. M., Nderitu P. W., Mohamed S. A., Ekesi S., 2016 Impact assessment of integrated pest management (IPM) strategy for suppression of mango-infesting fruit flies in Kenya. Crop Protection 81:20-29.

Ngene B. U., Nwafor C. O., Bamigboye G. O., Ogbiye A. S., Ogundare J. O., Akpan V. E., 2021 Assessment of water resources development and exploitation in Nigeria: a review of integrated water resources management approach. Heliyon 7(1):e05955.

Nicholson F., Krogshave Laursen R., Cassidy R., Farrow L., Tendler L., Williams J., Surdyk N., Velthof G., 2020 How can decision support tools help reduce nitrate and pesticide pollution from agriculture? A literature review and practical insights from the EU FAIRWAY project. Water 12(3):768.

Nwokediegwu Z. Q. S., Adefemi A., Ayorinde O. B., Ilojianya V. I., Etukudoh E. A., 2024 Review of water policy and management: comparing the USA and Africa. Engineering Science and Technology Journal 5(2):402-411.

OECD Compendium of Agri-environmental Indicators, 2013 OECD. Available at: https://www.oecd.org/en/publications/2013/06/oecd-compendium-of-agri-environmental-indicators_g1g220a0.html. Accessed: June, 2024.

Pradhan S. S., Gowda G. B., Adak T., Guru-Pirasanna-Pandi G., Patil N. B., Annamalai M., Rath P. C., 2022 Pesticides occurrence in water sources and decontamination techniques. In: Pesticides - updates on toxicity, efficacy and risk assessment. Larramendy M. L., Soloneski S. (eds), IntechOpen. doi: 10.5772/intechopen.103812.

Rajan S., Parween M., Raju N. J., 2023 Pesticides in the hydrogeo-environment: a review of contaminant prevalence, source and mobilisation in India. Environmental Geochemistry and Health 45(8):5481-5513.

Rey-Martínez N., Guisasola A., Baeza J. A., 2022 Assessment of the significance of heavy metals, pesticides and other contaminants in recovered products from water resource recovery facilities. Resources, Conservation and Recycling 182:106313.

Romero P., Navarro J. M., Ordaz P. B., 2022 Towards a sustainable viticulture: the combination of deficit irrigation strategies and agroecological practices in Mediterranean vineyards. A review and update. Agricultural Water Management 259:107216.

Rosa L., Chiarelli D. D., Tu C., Rulli M. C., D'Odorico P., 2019 Global unsustainable virtual water flows in agricultural trade. Environmental Research Letters 14(11):114001.

Salvan M. G., Bertoni D., Cavicchioli D., Bocchi S., 2022 Agri-environmental indicators: a selected review to support impact assessment of new EU Green Deal policies. Agronomy 12(4):798

Sankhla M. S., Kumari M., Sharma K., Kushwah R. S., Kumar R., 2018 Water contamination through pesticide and their toxic effect on human health. International Journal for Research in Applied Science and Engineering Technology 6(1):967-970.

Shan V., Singh S. K., Haritash A. K., 2020 Water crisis in the Asian countries: status and future trends. In: Resilience, response, and risk in water systems: shifting management and natural forcings paradigms. Kumar M., Munoz-Arriola F., Furumai H., Chaminda T. (eds), Springer, pp. 173-194.

Spânu I. A., Ozunu A., Petrescu D. C., Petrescu-Mag R. M., 2022 A comparative view of agri-environmental indicators and stakeholders' assessment of their quality. Agriculture 12(4):490.

Syafrudin M., Kristanti R. A., Yuniarto A., Hadibarata T., Rhee J., Al-Onazi W. A., Algarni T. S., Almarri A. H., Al-Mohaimeed A. M., 2021 Pesticides in drinking water - a review. International Journal of Environmental Research and Public Health 18(2): 468.

Tudi M., Ruan H. D., Wang L., Lyu J., Sadler R., Connell D., Chu C., Phung D. T., 2021 Agriculture development, pesticide application and its impact on the environment. International Journal of Environmental Research and Public Health 18(3):1112.

Tuninetti M., Tamea S., Dalin C., 2019 Water debt indicator reveals where agricultural water use exceeds sustainable levels. Water Resources Research 55(3):2464-2477.

Wang R., Wang Q., Dong L., Zhang J., 2021 Cleaner agricultural production in drinking-water source areas for the control of non-point source pollution in China. Journal of Environmental Management 285:112096.

Wuepper D., Wiebecke I., Meier L., Vogelsanger S., Bramato S., Fürholz A., Finger R., 2024 Agri-environmental policies from 1960 to 2022. Nature Food 5(4):323-331.

Xia Y., Zhang M., Tsang D. C. W., Geng N., Lu D., Zhu L., Igalavithana A. D., Dissanayake P. D., Rinklebe J., Yang X., Ok S. Y., 2020 Recent advances in control technologies for non-point source pollution with nitrogen and phosphorous from agricultural runoff: current practices and future prospects. Applied Biological Chemistry 63:8.

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