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Agricultural runoff and relief factors as determinants of well water contamination in Kosovo's vineyard region

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ABSTRACT

The aim was to study the impact of relief (slope, soil composition) and vineyard-related agricultural activities on groundwater contamination in the Rrezina area of Kosovo, a region with limited prior hydrological research. The research area was in Suhareka municipality, which has 40% of Kosovo's vineyards, making it a major grape-growing region. This vineyard area slopes directly towards the neighborhood and private wells. The water sampling and measurements procedure were followed in accordance with the standard methods for water examination according to EPA 2016. The physical parameters of the water were studied during the sampling process. Results of the chemical analyses of lead and iron concentration showed major contamination of the water of the wells. Lead values exceeded the minimum values set by EPA and WHO in 19 of 20 wells, with an average value of 0.0358 mg/L. The concentration of iron was higher, and it exceeded the minimum values of EPA and WHO in all samples, with an average of 0.093 mg/L. The physical parameters of the water showed stable values of pH, conductivity, and temperature of the water; these values did not exceed the EPA or WHO values. Microbiological parameters of total coliforms, E. coli and pseudomonas showed high fecal contamination of water, and all the wells exceeded the minimum value of WHO or EPA. Relief driven runoff from vineyards constitutes the primary contamination source and there is high correlation (-0.81) between distance from the vineyards and lead concentration. This is the first integrated analysis of relief, agriculture, and multi-parameter contamination in the groundwater of Kosovo, even though the study is focused on 20 wells, which limits broader generalizations. The study highlights the need for periodic monitoring of wells near agricultural zones and improved wastewater management.

Keywords: runoff water, agriculture, contamination, coliform.

INTRODUCTION

The United Nations (UN) World Water Development Report (2021) forecasts a 55% rise in freshwater demand by 2050 due to population growth, urbanization, and unsustainable consumption practices. Challenges are especially obvious in the areas where climate change results in heightened precipitation variability and worsening droughts, compounding pre-existing water scarcity problems.

Research by de Fraiture et al. (2007) confirms that worldwide water demand has been consistently increasing, mostly due to agricultural requirements. Agriculture utilizes around 70% of the world's freshwater, leading to intensified competition among agricultural, industrial, and domestic demands (Berisha and Goessler, 2013). In the regions where infrastructure and governance systems are inadequate, this competition can lead to over-extraction and pollution of water resources, further straining availability.

The risk of contaminant intrusion in water distribution networks has been documented as a prevalent threat. Contamination can result from various factors, including accidental incidents or infrastructure failures, placing substantial health risks on consumers (Zeng et al., 2016), Islam et al., 2015). Contaminants may infiltrate distribution systems during transient events, including water main breaks or pressure fluctuations, resulting in harmful chemicals or pathogens reaching consumers prior to sufficient treatment (Mahmoud et al., 2019). Multiple techniques are available to mitigate these risks, including cost-effective sensor placements aimed at the proactive identification of contamination events (Zeng et al., 2016).

There is a significant reliance on outdated infrastructure that hinders effective management, as many water utilities face challenges in system maintenance due to financial constraints and limited resources (Tariq et al., 2023). The public's comprehension of drinking water issues is essential for shaping responses and management strategies. Research indicates that locals usually lack the knowledge of the dangers related to their drinking water quality (Zahid et al., 2022; Li et al., 2018). Empowering communities to fight for improved water safety standards and engage actively in local water governance depends on good communication and community education (Zahid et al., 2022). Improving consumer confidence in the safety of drinking water sources calls for a thorough strategy to match public perception with factual water quality data (Li et al., 2018; Shahra et al., 2021).

Berisha and Goessler's study (2013) reveals that levels of several dangerous trace elements in Kosovo's drinking water frequently surpass EU and WHO recommendations. Manganese (Mn), arsenic (As), and uranium (U) are present at alarming concentrations, underscoring the urgent necessity for improved monitoring and management of regional water resources (Berisha and Goessler, 2013). Furthermore, wastewater management systems are critically deficient, with merely 0.7% of wastewater undergoing treatment prior to its discharge into natural water bodies, including rivers.

Reports indicate a significant gap in the necessary infrastructure for wastewater treatment, which has detrimental effects on both surface and groundwater quality (Kajtazi and Floqi, 2021; (Kajtazi, 2021). For instance, untreated discharge from urban areas, along with industrial pollutants from facilities such as the Kosovo B power plant, heavily impacts the local hydrological systems, particularly the Sitnica River (Kajtazi and Floqi, 2021).

The Rural Water and Sanitation Support Program (RWSSP) in Kosovo, however, has achieved progress in increasing the access to public water supply for rural populations by means of improved groundwater protection policies (Osmanaj et al., 2021). Still, to guarantee the safety and sustainability of Kosovo's drinking water sources, more thorough and methodical strategies are needed. This calls for more stringent pollution control policies as well as building controlled and monitored wastewater treatment plants to protect public health and the environment. Furthermore, the waste management systems are deficient; just 0.7% of waste is processed before being released into natural water bodies including rivers.

Although earlier studies draws attention to the water quality problems of Kosovo, none have methodically connected local relief characteristics, slope, soil permeability and vineyard runoff to groundwater pollution. This study intended to (1) measure the degree that water quality is affected by slope-driven agricultural runoff and (2) find the pollution trends related to geological and anthropogenic influences in the Rrezina region. Hypothesis: Enhanced pollutant movement on steeper slopes and closer vineyard vicinity relates to greater Pb, Fe, and microbiological contamination.

METHODS AND MATERIAL

The selection of wells, was based on the distribution of wells and the natural relief of the researched area. The study area is in the Rrezina (area of Xhavit Syla), northeast of the municipality of Suharekë (Figure 1a and 1b-42.36°N, 20.85°E). It is bordered to the west by the Prizren-Prishtinë highway and to the south by the Suharekë-Reqan road. The geological composition of the terrain consists of sedimentary rocks of fluvial and lacustrine origin, represented by sand, clay, and gravel. The terrain slopes southward toward Toplluha and exhibits southern as well as southwestern exposures.

Four depressions (gully-like formations) are present on the terrain. The slope gradient ranges between 4–8° (Figure 1c), predominantly oriented southward. No surface watercourses exist in the area, while groundwater drains toward the southern part. The groundwater table is deeper in the upper section compared to the southern portion (proluvium deposits).

The lower section features loamy diluvial soils, whereas most of the locality is characterized by reddish-brown leached soils overlying reddish sediments. Shrub vegetation has developed within the depressions, while the remaining area is covered by vineyards.

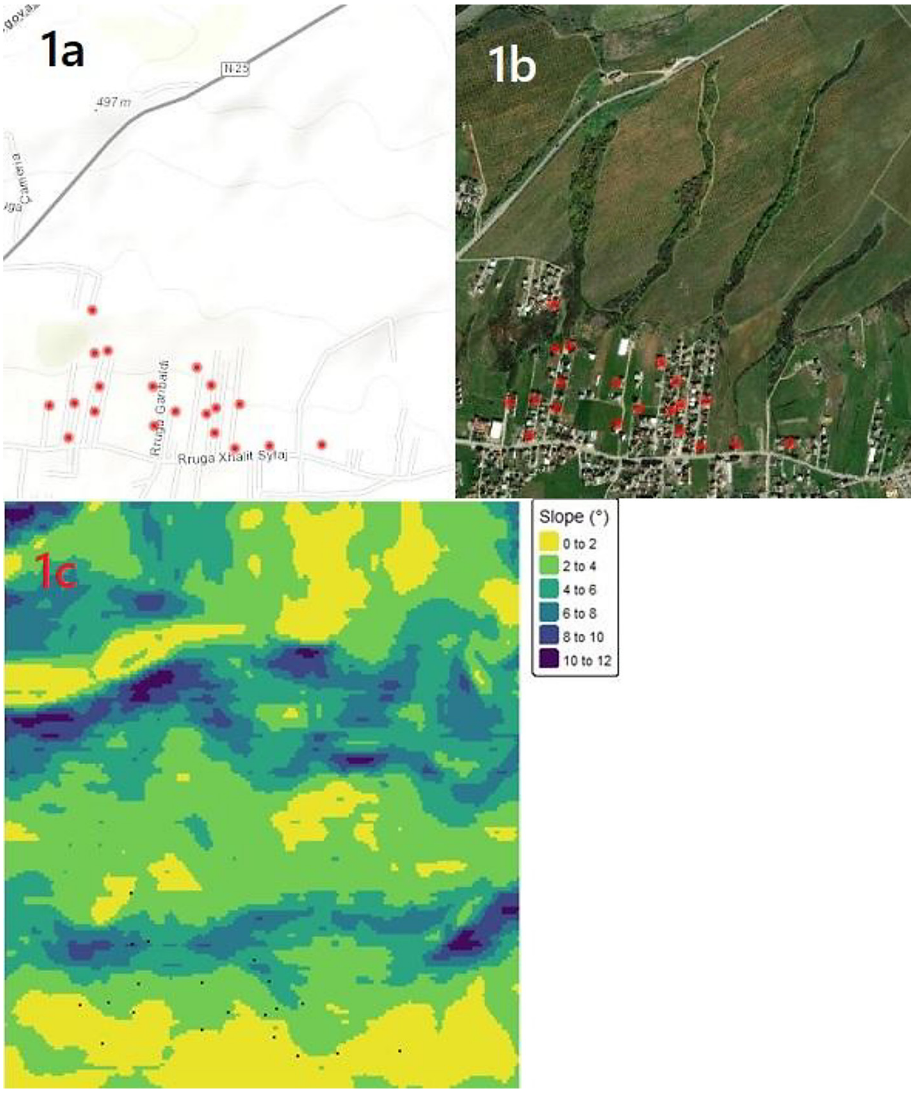

Figure 1. Map of the location of the sample collection (1a Terrain view, 1b Satellite view and 1c Terrain-slope view)

The area chosen in this study includes areas that are under the influence of vineyards which is directly related to the authors' interest to see the possibility of pollution from vineyard runoff.

Methodology

Sampling locations were pre-identified using a map-based approach, ensuring a wider spatial distribution across the area influenced by runoff patterns from surrounding vineyards. In total 20 wells or 14% (142 in total) of all private wells were part of the study. The wells selected in this study are the wells privately built by the residents and are not under the supervision of the water supply authority or the Institute of Public Health (Figure 2).

All the researched wells were also selected based on their usability, that is, only those that are used as a primary or alternative source of water. For the collection and storage during transportation of well water samples, the water sampling procedure was followed in accordance with the standard methods for water examination according to EPA 2016, and ISO 5667-1:2010, ISO 5667-3:2010.

The water sampling was carried out in 1L glass bottles, pre-sterilized in an autoclave at 121 °C for 20 minutes (Borrell Fontelles and Winkler, 2006), wrapped in aluminum foil to prevent contamination after sterilization. Water extraction was carried out by submersible pumps that were installed in the wells by their owners, the pipe from which the water flowed was disinfected, then the water flow was released for 2–3 minutes (EPA 2016). Transport of the sample to

Figure 2. A sampling private built well (photo by Kukalaj)

the laboratory was made in ice packs to maintain a temperature lower than 10 °C (EPA 2016).

Chemical parameters, such as the temperature and conductivity were measured at the sampling site, the measurements were taken with the relevant equipment (Seven Compact S210, Toledo, USA), in a separate glass from the bottles where the samples were taken (ISO 5667-3:2010).

The samples were analyzed on the same day they were taken (Figueras and Borrego, 2000). The analysis of the samples for chemical indicators was carried out no later than 24 hours after their collection.

The analysis of the iron parameter was performed in the laboratory with the UV-VIS Spectrophotometry equipment type UV/1800, using the standard methods recommended for analyzing drinking water. Lead tracer analyses were performed in the Laboratory with AAS 7000 type Atomic Absorber equipment using standard methods. The determination of the Total Microbial Load was carried out with the vacuum pressure equipment of the type: Vacuum PR, pump 4 bar, using the filtration method, where from each sample, 100 ml of water was filtered individually through the 0.47μm pore diameter sterile membrane filters using the vacuum pressure pump. For the TAMC identification, the used filters were each placed in R2A media plates of the BioMérieux manufacturer. The samples were incubated at 35 °C ≤ 5 days.

For the determination of the Total Load of Coliform Bacteria from each sample, 100 ml of water was filtered individually through the 0.47 μm pore diameter sterile membrane filters using the vacuum pressure pump. The used filters were each placed in VRBA (Violet Red Bile Glucos Agar-Figure 3) media plates. The samples were incubated at 35 °C for 24 h.

For the *E. coli* identification, from each sample, 100 ml of water was filtered individually through the 0.47 μm pore diameter sterile membrane filters using the vacuum pressure pump. The used filters were each placed in MCA

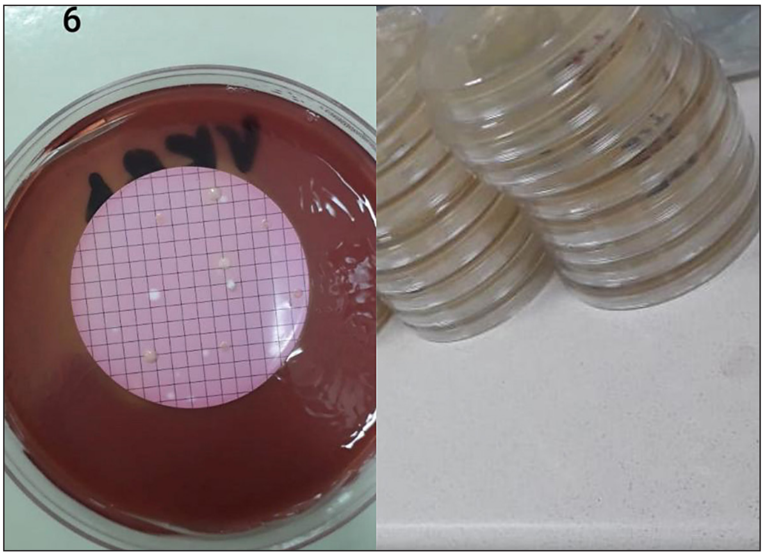

Figure 3. Violet red bile glucose agar (left) and MacConkey Agar (right)-(Photo by Kukalaj)

(MacConkey Agar) media plates. The samples were incubated at 35 °C for 24 h.

For the determination of Pseudomonas, from each sample, 100 ml of water was filtered individually through the 0.47 µm pore diameter sterile membrane filters using the vacuum pressure pump. The used filters were each placed in CA (Cetrimide Agar) media plates of the BioLife Manufacturer. The samples were incubated at 35 °C for 24 h.

RESULTS

The study of physical parameters over the 20 examined wells reveals a stable groundwater system with little environmental stress. The average depth of the wells was 16.2 ± 3.2 meters. With a mean of 15.54 °C and a relative standard deviation (RSD%) of 5.86, water temperature measurements varied from 14.10 °C to 18.60 °C. These small differences in temperature range indicate that the groundwater is drawn from deep or well protected aquifers, less affected by seasonal changes or atmospheric temperature variations. Stable temperatures during seasons are also good for maintaining consistent chemical and biological water quality throughout time.

With an average of 1691.75 µS/cm, electrical conductivity, a measurement of the capacity of water to conduct electricity from dissolved ions. Though the conductivity measurements differed slightly (RSD% = 16.99), but all were below the upper limit of 2.500 U.S. EPA. This suggests absence of salinity-related to pollution from industrial discharge, agriculture, or seawater incursion. Typical of groundwater with considerable mineral concentration, the conductivity values are probably the result of natural geochemical interactions between water and subsurface rock formations.

Ranging from 7.05 to 7.47 (mean = 7.22), the groundwater pH was typically slightly alkaline. These figures fit both WHO and EPA suggested values, implying that the water is chemically balanced and does not risk metal leaching or corrosion in distribution systems. The low RSD% of 1.72 for pH strengthens the consistency and stability of groundwater chemistry in the research region (Table 1).

Some of the main toxic chemical components were also measured. Chemical analysis showed notable contamination, especially with lead (Pb) and iron (Fe). Nineteen of the twenty analyzed wells had lead levels over the U.S. EPA standard of 0.015 mg/L; the average was 0.0359 mg/L (RSD% = 45.6). The noted high lead levels are troubling given that lead is a well-known neurotoxic with notably strong negative effects in children. Historical usage of pesticides and fertilizers in surrounding vineyards, which sometimes include lead-based chemicals, may explain the higher lead levels. Especially in the areas where farming operations include the use of such chemicals, these pollutants can seep over time into groundwater supplies. The great variation in lead levels among the wells supports the idea that the problem may be caused by localized sources of pollution or changes in aquifer conditions.

Groundwater iron levels were also an issue, as every well surpassed the World Health Organization (WHO) standard of 0.03 mg/L. Ranging from 0.0381 mg/L to a worrisome maximum of 0.755 mg/L, the average iron content was 0.093 mg/L with a considerable degree of variability (RSD% = 110.37). Extreme fluctuations in iron levels point to major geochemical interactions, perhaps caused by geological leaching from neighboring rock formations or agricultural runoff. Though not directly harmful, high iron levels can cause cosmetic problems like laundry and plumbing stains and change water flavor. Furthermore, high iron levels in groundwater can indicate a more general problem with the chemical quality of the aquifer, which might potentially affect other water characteristics (Table 2).

The distance from closest point of vineyard and wells was calculated using data from ArcGIS Online software. It was found that there is a high correlation (-0.81) between distance from the vineyard and the concentration of lead in water.

Table 1. Physical parameters summary

Parameter	Mean	SD	RSD%	Min	Max	Exceedances (EPA/WHO)
Temperature (°C)	15.54	0.91	5.86	14.10	18.60	None
Conductivity (µS/cm)	1691.7	287.34	16.99	1059	2000	None
pH	7.22	0.12	1.72	7.05	7.47	None

Table 2. Summary of chemical contaminants detected in well water samples

Parameter	Mean (mg/L)	SD	RSD%	Min	Max	Exceedances (EPA/WHO)
Lead (Pb)	0.0359	0.0163	45.46	0.0115	0.0633	19 wells* > 0.015 mg/L
Iron (Fe)	0.093	0.052	110.37	0.0381	0.755	All wells** > 0.03 mg/L

The slope in degree between the closest point of vineyard and wells was calculated and found that mean slope value 4.16° ± 2.05°. When the correlation analyses between slope and lead concentration were performed, weak positive values were found (0.35). We can conclude that the distance is better predictor of contamination compared to slope of the terrain.

Significant pollution (Figure 4) was found in the groundwater of the study area by microbiological examination, which raises concerns about water safety and public health. Averaging 1.314 CFU/100 mL, the Total Aerobic Microbial Count (TAMC) ranged from 24 to 2.922 CFU/100 mL. These high values point to significant organic pollution and imply that the groundwater is tainted with a wide range of bacteria. Although TAMC is not officially controlled, high numbers may indicate the presence of additional dangerous microorganisms such coliforms and fecal bacteria.

With an average concentration of 220.45 CFU/100 mL, total coliforms were found in all 20 wells, well over the U.S. EPA and WHO standards for drinking water (which call for 0 CFU/100 mL). Often connected to defective sanitation infrastructure or direct pollution from agricultural runoff, the presence of total coliforms is a significant signal of fecal contamination. Given that these bacteria are frequently employed as a broad indicator of water quality, particularly for evaluating possible health concerns, the widespread finding of total coliforms in all investigated wells is concerning.

Seventy percent of the wells had *E. coli*, a more particular marker of fecal contamination, with an average concentration of 13.55 CFU/100 mL. Although E. coli levels in several wells were rather low in comparison to total coliforms, its presence in more than two-thirds of the wells is quite troubling. Finding *E. coli* directly correlates to a higher chance of waterborne diseases like diarrhea, gastroenteritis, and other gastrointestinal infections.

The presence of Pseudomonas aeruginosa, a bacterium often associated with environmental pollution and poor sanitation, was also noted in 65% of the wells, with an average of 7.60 CFU/100mL. Pseudomonas species are opportunistic pathogens, particularly dangerous for individuals with compromised immune systems (Gellatly and Hancock, 2013). Its presence further underscores the environmental pollution risks, potentially exacerbated by agricultural runoff or inadequate wastewater treatment.

DISCUSSION

The results from this study demonstrate significant contamination of groundwater, with concerning levels of both chemical and microbiological pollutants across the 20 sampled wells. These findings underscore the need for urgent intervention to safeguard public health and improve water quality management in the region.

Chemical contamination

Lead (Pb) concentrations exceeded the U.S. EPA's limit of 0.015 mg/L (also WHO limit of 0.01 mg/L) in 19 of the 20 wells, with an average concentration of 0.0359 mg/L (RSD% = 45.46). The presence of lead in groundwater at these levels is alarming due to its neurotoxic effects, particularly in children (Lidsky and Schneider, 2003). Neurodevelopmental impairments in children, even at low exposure levels, are strongly linked to lead contamination in drinking water, with population and toxicokinetic studies confirming a direct correlation between waterborne lead concentrations and elevated blood lead levels, though targeted mitigation strategies can effectively reduce the exposure risks (Lanphear et al., 2005). Lead is known to have toxic effects in multiple organ systems like liver, spleen, pancreas, brain, etc., by increasing oxidative stress (Mazreku, 2017). Lead contamination in agricultural regions is often linked to historical pesticide and fertilizer use (Alloway, 2013). Lead has also a very high translocation factor in the plants exposed to the contamination (Bici, 2021). Lead is found in vegetables

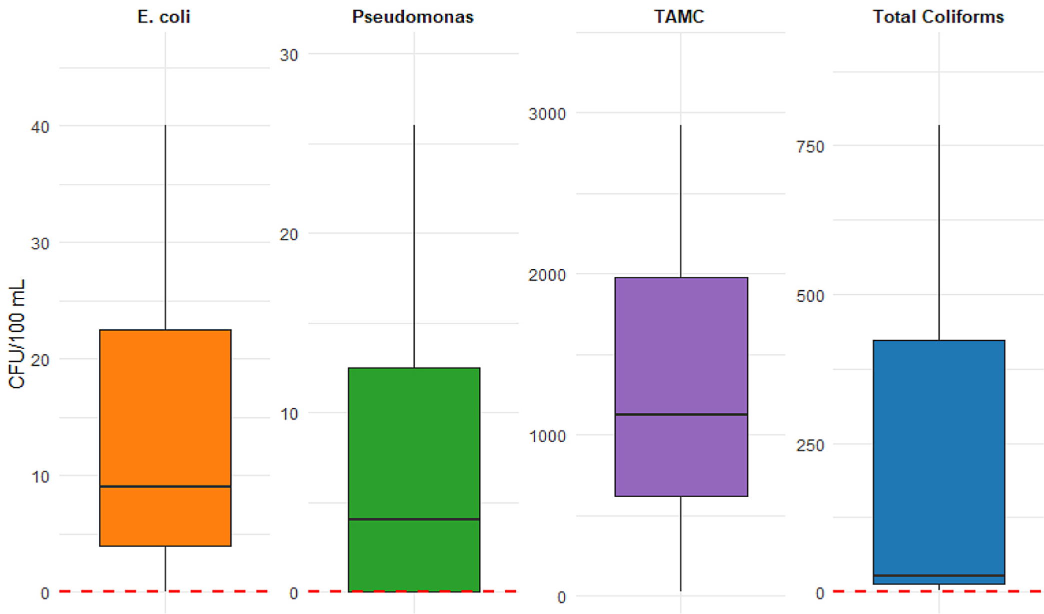

Figure 4. Summary of microbiological parameters detected in well water samples and their exceedances based on EPA/WHO standards

farmed in regions with contaminated water with lead (Ngoc, 2020). Elevated iron (Fe) concentrations (mean = 0.093 mg/L) exceeded the WHO limit (0.03 mg/L) in all wells. High iron levels in groundwater are frequently associated with geological leaching processes or anthropogenic activities such as agricultural runoff (Neidhardt et al., 2013). The findings of these measurements show that the water from these sources should not be used as a drinking water for humans or animals. Usage of these water sources for watering plants should also reconsidered, because of the biomagnification effect of lead.

Microbiological contamination

Mean values 1.314 CFU/100 mL of total aerobic microbial count (TAMC) showed general organic contamination. The WHO standards (2017) potentiate that high TAMC values (> 500 CFU/mL) suggest organic contamination and possible biofilm development in water systems, thereby corresponding with the obtained TAMC = 1.314 CFU/100 mL results, organic contamination of groundwater can be concluded. Total coliforms in all wells (mean = 220.45 CFU/100 mL) and E. coli in 70% of wells (mean = 13.55 CFU/100 mL) indicate fecal contamination, hence increasing the possibility of waterborne illnesses (Cabral, 2010). Total coliforms in groundwater (mean = 220.45 CFU/100 mL) are consistent indications of fecal contamination even in the absence of E. coli, according to this study (Edberg, 2000). Pseudomonas (mean = 6.8 CFU/100 mL) in 65% of wells draws even more attention to environmental contamination probably connected to biofilm development in water systems (Kämpfer et al., 2010).

The pollution detected in the conducted study underlines the need for better land-use practices since it fits with the trends of agricultural runoff reported by Schipper et al. (2010). Groundwater monitoring should follow WHO (2017) recommendations to reduce hazards; infrastructure improvements such as well sealing, and disinfection systems should be given priority.

CONCLUSIONS

Al measurements indicate that water source from private wells near vineyards in Rrezina, Suhareka, is significantly polluted. Chemical and microbiological measurements show that these sources of water should not be used for drinking or watering. The limitation of the study is the size of the area, which limits the possibility to make a direct connection between the vineyard agriculture activity and groundwater pollution. The studies that will measure the possible pollution of water near vineyard cultivation should be carried throughout the territory of the country, to monitor and to measure the effects of the agriculture activities in groundwater.

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