ECOLOGIA BALKANICA

2025, Vol. 17, Issue 1 June 2025 pp. 151-163

Assessment of the quality of groundwater for irrigation in the municipality of Suharekë, Republic of Kosovo

Hazir Çadraku[1], Agron Shala[2], Sokol Xhafa[3*]

[1]University for Business and Technology, Faculty of Civil Engineering and Infrastructure, KOSOVO
[2]Hydro-meteorological Institute, Kosovo Environmental protection Agency, KOSOVO
[3]Budapest University of Technology and Economics, Budapest, HUNGARY
*Corresponding author: sokol.xhafa@gmail.com

Abstract. This study evaluates groundwater quality for irrigation in Suharekë, Kosovo. Sixteen well samples were analyzed for cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), anions (Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}), and irrigation quality indices (SAR, Na%, KR, MAR, PI, PS, RSC). Results indicate groundwater suitability for irrigation, with SAR (excellent), SP (excellent), KR (suitable), MAR (62.5% suitable, 37.5% unsuitable), PI (suitable), PS (excellent-good), and RSC supporting usability.

Key words: Groundwater, Irrigation, Quality, Suharekë.

Introduction

Water is essential for life and agricultural productivity. In Kosovo, agriculture contributes 13% of GDP and employs 25-35% of the population (MAFRD, 2020). Groundwater is a primary irrigation source, particularly in regions with limited surface water availability (Agrawal & Dohare, 2024). The increasing demand for water due to population growth, climate change, and industrialization necessitates continuous monitoring of water quality (Jasechko et al., 2024; Kartal et al., 2019).

Irrigation water quality is influenced by natural processes, such as mineral dissolution and precipitation, as well as human activities (Hounslow, 1995). Poor-quality irrigation water can impact soil health and agricultural productivity (Hegazi et al., 2018; Udom et al., 2019). The assessment of key water quality parameters and indices provides crucial information for sustainable agricultural practices (Ayers & Westcot, 1985; Twarakavi & Kaluarachchi, 2006).

This study assesses the quality of groundwater in Suharekë for irrigation use, addressing the lack of comprehensive regional data. By comparing measured parameters with international guidelines, it aims to provide insights for informed water management decisions in agriculture (Table 1). A comparison of values for pH, EC, TDS and for SAR, Na% and KR indices in the groundwater of the Blinajë River catchment and the study area-Suharekë are shown in Table 2.

Materials and Methods

Study area is located in the southern part of the territory of the Republic of Kosovo (Fig. 1). It lies at 42° 15' 00" north latitude and 42° 30' 00" and 20° 45' 00" and 21° 00' 00" east longitude. It has an area of 361.78 km2 (KAC, 2024) or constitutes 3.3% of the territory of Kosovo (KSA, 2013). The study area in the peripheral part is mainly surrounded by the elevated part of the terrain (mountainous part), while the plain part spreads in the southwest and west direction. The average altitude is 455 m; the highest peak is Dera e Pasha (2029 m) and Kryet e Ahishte peak (1677 m) (KCA, 2024). The study area is characterized by a continental-Mediterranean climate (Pllana, 2015). The average annual air temperature is 11ºC, while the average annual rainfall is 674 mm (KEPA-KHI, 2022). The hydrographic network is relatively developed. The main river is the Toplluha river, which represents the catchment area of the study area and has an area of 495 km^2 and a flow rate of 3.44 m^3/s (MESPI, 2020). Paleozoic, Mesozoic, Neogene and Quaternary rocks form part in the geological structure of the study area (ICMM, 2006). Agriculture is one of the economic development of the Municipality of Suhareka. According to the Development Plan of the Municipality of Suharekë, 41.7% of the surface is covered with forests, 53.7% is agricultural land and 4.6% are other surfaces (MS, 2020).

Table 1. Some of the works found related to the assessment of water for irrigation in the Republic of Kosovo.

Author	Name of the scientific article	Year of publication	Journal, DOI, ISSN
Pivić, R.; Maksimović, J.; Dinić, Z.; Jaramaz, D.; Majstorović, H.; Vidojević, D.; Stanojković-Sebić, A	Hydrochemical Assessment of Water Used for Agricultural Soil Irrigation in the Water Area of the Three Morava Rivers in the Republic of Serbia.	2022	Agronomy, 12(5), 1177. https://doi.org/10.3390/agronomy12051177
Çadraku, H.S.	Groundwater Quality Assessment for Irrigation: Case Study in the Blinajë River Basin, Kosovo.	2021	Civil Engineering Journal (E-ISSN: 2476-3055; ISSN: 2676-6957) Vol. 7, No. 09. Available online at www.CivileJournal.org
Rizani, S., & Laze, P.	Trace Elements Concentration in Surface Water Used for Irrigation in Kosovo.	2017	Environment and Ecology Research, 5(7), 500-509 doi: 10.13189/eer.2017.050706
Laze, P., Rizani, S., & Ibraliu.A.	Assessment of Irrigation Water Quality of Dukagjin Basin in Kosovo	2016	Journal of International Scientific Publications. Agriculture & Food. ISSN 1314-8591, Volume 4, 2016. www.scientific-publications.net
Rizani, S., Laze, P., & Ibraliu, A.	Assessment of Irrigation Water Quality of Kosovo Plain	2016	Agroknowledge Journal, 17, 3, 243-253 doi: 10.7251/AGREN1603243R

Table 2. A comparison of the values in the groundwater of Blinajë and Suharekë.

Study area	No. samples	pH			EC			TDS		
		Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.
Blinajë	28	5.92	8.03	7.12	167	1319	666	106.88	844.16	424.26
Suharekë	16	7.16	9.02	7.59	313	1180	627.6	165.8	706.7	146.15
Study area	**No. samples**	**SAR**			**Na%**			**KR**		
		Min	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**
Blinajë	28	0.024	0.73	0.29	1.35	30.15	14.35	0.01	0.18	0.08
Suharekë	16	0.04	0.86	0.25	1.08	18.78	7.01	0.01	0.22	0.07

Referring to the data from the Directorate for Agriculture, Rural Development and Forestry of the Municipality of Suharekë, it results that 4481 ha are planted with cereals, 949 ha are with grape vines, 646 ha with vegetables, and 279 ha with trees. Groundwater in the study area represents one of the main water resources. They are used for water supply, irrigation of agricultural crops, and other purposes.

To evaluate groundwater quality, 16 wells were identified across the study area (Fig. 1). Sampling was conducted at locations where groundwater is used for irrigating agricultural crops. Coordinates and altitudes were recorded using a Garmin handheld GPS (Table 3).

Sixteen water samples were collected in 1000 ml polyethylene bottles, labeled (S1-Sn), and stored in a portable refrigerator until laboratory analysis. Field measurements included water temperature (DIN 38404-C4, WTW 3210), pH (ISO 10523:2008, WTW 3210), and electrical conductivity (EC) (ISO 7888:1985, WTW 315i).

Laboratory analyses followed standard methods (APHA, 1995), with total hardness (TH) calculated using Todd's (1980) formula (Table 4).

Calcium (Ca^{2+}) was determined by titrating 100 cm^3 of the sample with EDTA in a basic NaOH solution, using HSN indicator. Magnesium (Mg^{2+}) was calculated as the difference between total hardness and calcium concentration. Chloride (Cl^-) and sulfate (SO_4^{2-}) were analyzed using ISO 9297 and APHA 4500 methods, respectively, with concentrations converted from mg/l to meq/l.

Data were statistically analyzed for minimum, maximum, mean, and standard deviation using Past 4.03 software (Tables 2, 5, 6, 10, 11, 16) and for cluster hierarchy (Fig. 7). ArcGIS 10.5 was used for cartographic visualization (shape file format: point, polygon). Results were compared with WHO (2017, 2007) and FAO (2011, 2006) standards. Total hardness (TH) and irrigation indices (SAR, SP, KR, MAR, PI, PS, RSC) were calculated using equations in Table 4, with values expressed in meq/l.

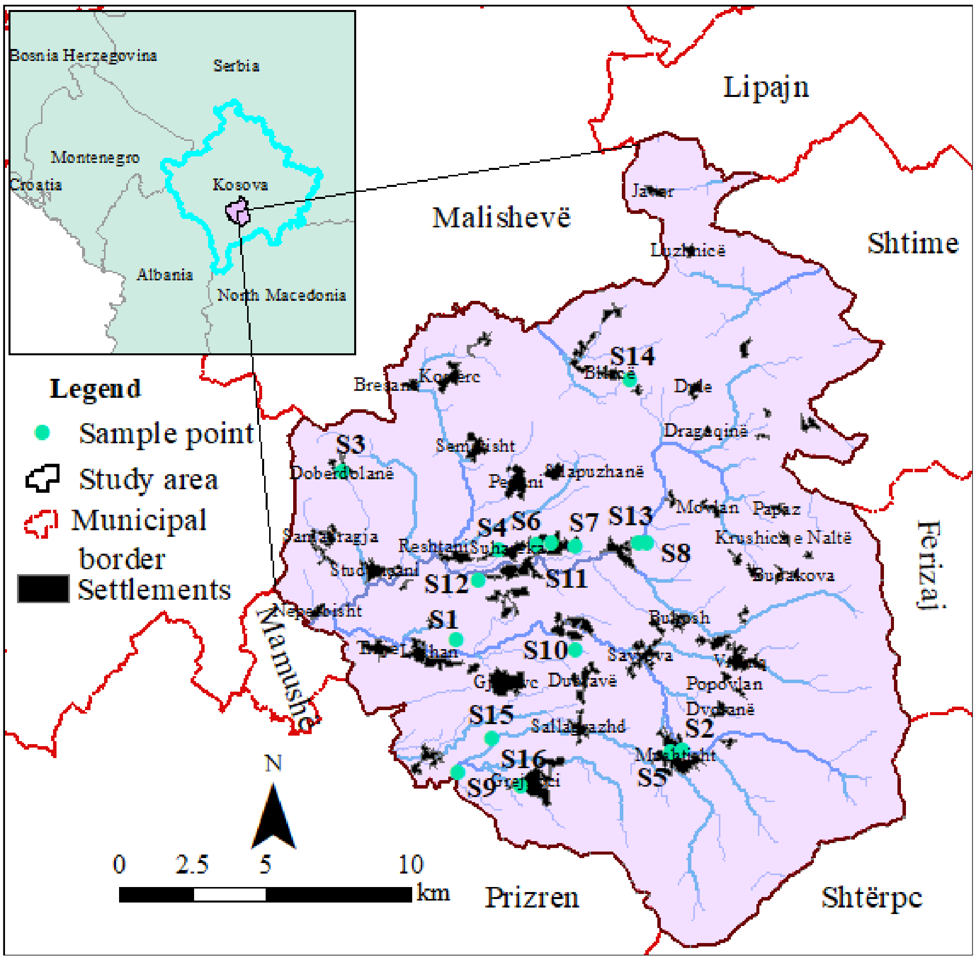

Fig. 1. Study area (Source: own study).

Table 3. Data on locations (wells) where water samples were taken for water quality assessment.

ID	Water Source	Geographic Coordinates		Height Above Sea Level (m)
S1	Well	42°20'0.09"N	20°51'22.13"E	458
S2	Well	42°17'55.45"N	20°53'29.74"E	587
S3	Well	42°23'5.73"N	20°44'59.12"E	543
S4	Well	42°21'4.63"N	20°48'25.12"E	382
S5	Well	42°17'53.33"N	20°53'11.16"E	587
S6	Well	42°21'37.20"N	20°48'55.19"E	388
S7	Well	42°21'45.14"N	20°49'50.18"E	402
S8	Well	42°21'42.63"N	20°50'50.41"E	412
S9	Well	42°17'15.77"N	20°49'27.73"E	462
S10	Well	42°19'46.48"N	20°50'49.62"E	467
S11	Well	42°21'46.18"N	20°50'14.07"E	409
S12	Well	42°22'9.21"N	20°52'36.39"E	449
S13	Well	42°21'45.39"N	20°52'22.61"E	429
S14	Well	42°24'45.52"N	20°52'12.79"E	656
S15	Well	42°18'8.85"N	20°48'43.16"E	409
S16	Well	42°17'31.52"N	20°47'53.74"E	383

Table 4. Equations used for calculation.

Parameters	Equation	No. equ.	Reference
TH	$TH = 2.5\ x\ Ca^{2+} + 4.1\ x\ Mg^{2+}$	1	Todd (1980)
SAR	$SAR = \dfrac{Na^{+}}{\sqrt{\dfrac{Ca^{2+} + Mg^{2+}}{2}}}$	2	Richards (1954)
SP	$SP = \dfrac{Na^{+} + K^{+}}{Na^{+} + Ca^{2+} + Mg^{2+}} * 100$	3	Wilcox (1955)
KR	$KR = \dfrac{Na^{+}}{Ca^{2+} + Mg^{2+}}$	4	Kelly (1940)
MAR	$MAR = \left(\dfrac{Mg^{2+}}{Ca^{2+} + Mg^{2+}}\right) * 100$	5	Paliwal (1972)
PI	$PI = \dfrac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}}$	6	Doneen (1964)
PS	$PS = Cl^{-} + \dfrac{SO_4^{2-}}{2}$	7	Doneen (1964)
RSC	$RSC\ (meql^{-1}) = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$	8	Eaton (1950)

(ion concentrations are expressed in meq/l)

Results and Discussions

The data for the physical and chemical parameters analyzed for the groundwater of the study area-Suharekë are shown in Table 5, while their correlation is shown in Table 6.

The groundwater in the study area exhibited pH values ranging from 7.16 to 9.02, with an average of 7.59 ± 0.42 (Table 5). According to Dakoli (2007), 93.75% of the samples (15 samples) were classified as weakly alkaline (pH = 7-9), while one sample (S9) was alkaline (pH > 9). When compared to FAO (2011, 2006) irrigation standards (pH = 6.5-8.4), 93.75% of samples fell within the acceptable range, with only S9 exceeding the limit. All samples were within the pH range (6-8.5) recommended by Ayers & Westcot (1985) for irrigation.

Table 5. Results of groundwater samples in the study area.

ID	EC	TDS	TH	pH	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	CO_3^{2-}
	μScm^{-1}	mg/L	mg/L	0-14	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
S1	313.00	166.50	130.00	7.50	9.23	8.60	39.70	7.50	4.77	0.72	146.40	23.20
S2	681.00	468.60	379.60	7.37	17.75	24.70	68.20	51.00	3.64	11.69	384.30	45.20
S3	879.00	237.40	474.91	7.26	11.36	28.60	111.90	47.60	6.04	8.92	542.90	49.50
S4	720.00	484.00	439.66	7.50	12.78	34.80	81.40	57.60	2.81	0.97	445.00	65.90
S5	693.00	432.00	328.01	7.61	32.40	45.00	80.20	31.10	23.70	1.77	305.00	62.30
S6	693.00	432.00	328.01	7.61	32.40	45.00	80.20	31.10	23.70	1.77	305.00	62.30
S7	452.00	344.40	328.41	7.25	17.75	13.70	53.30	47.60	7.26	0.74	384.30	34.30
S8	1026.00	564.30	466.03	7.16	31.24	115.00	119.50	40.80	21.90	0.42	457.50	33.10
S9	599.00	346.50	369.46	9.02	7.10	0.90	36.10	68.10	1.66	0.35	439.20	23.05
S10	431.00	232.40	213.08	7.33	16.33	8.80	58.50	16.30	3.88	0.93	232.00	26.10
S11	1180.00	706.70	607.09	7.59	48.28	127.00	152.80	54.90	30.17	1.27	585.60	114.20
S12	588.00	325.00	309.24	7.51	11.36	28.60	88.60	21.40	4.51	1.68	353.80	57.40
S13	848.00	446.10	384.81	7.61	23.43	62.60	73.40	49.10	39.00	3.27	469.70	95.90
S14	313.00	165.80	130.00	7.50	9.23	8.60	39.70	7.50	4.77	0.72	146.40	23.20
S15	720.00	484.00	439.66	7.80	12.78	34.80	81.40	57.60	2.81	0.97	445.00	65.90
S16	627.00	335.60	349.31	7.81	4.97	8.80	46.90	56.60	2.88	0.73	439.20	142.10
Min	313.00	165.80	130.00	7.16	4.97	0.90	36.10	7.50	1.66	0.35	146.40	23.05
Max	1180.00	706.70	607.09	9.02	48.28	127.00	152.80	68.10	39.00	11.69	585.60	142.10
Avg.	672.69	385.71	354.83	7.59	18.65	37.22	75.74	40.36	11.47	2.31	380.08	57.73
SD	236.84	146.15	124.36	0.42	11.88	36.80	31.93	18.98	11.94	3.24	126.84	34.55

Table 6. Correlation matrix of physical and chemical parameters.

	EC	TDS	TH	pH	Cl-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	CO_3^{2-}
EC	1.00											
TDS	0.83	1.00										
TH	0.93	0.83	1.00									
pH	-0.08	0.00	0.03	1.00								
Cl^-	0.67	0.74	0.51	-0.25	1.00							
SO_4^{2-}	0.86	0.82	0.69	-0.27	0.85	1.00						
Ca^{2+}	0.89	0.71	0.79	-0.36	0.72	0.87	1.00					
Mg^{2+}	0.57	0.59	0.78	0.43	0.07	0.21	0.24	1.00				
Na^+	0.61	0.56	0.37	-0.15	0.81	0.75	0.52	0.05	1.00			
K^+	0.20	0.01	0.22	-0.27	-0.04	-0.06	0.18	0.18	-0.06	1.00		
HCO_3^-	0.85	0.68	0.95	0.12	0.31	0.54	0.66	0.85	0.29	0.24	1.00	
CO_3^{2-}	0.51	0.48	0.50	0.04	0.27	0.35	0.34	0.45	0.38	-0.03	0.54	1.00

Electrical conductivity (EC) values ranged from 313.00 to 1180 µS/cm, averaging 627.56 ± 236.84 µS/cm (Table 5). Based on USSL Staff (1954) classifications, 75% of samples (12 samples) fell within the medium salinity class (C2, EC = 250-750 µS/cm), while 25% (4 samples) were in the high salinity class (C3, EC = 750-2250 µS/cm) (Table 7, Fig. 2a).

Total dissolved solids (TDS) ranged from 165.80 to 706.70 mg/l, with an average of 385.71 ± 146.15 mg/l (Table 5). All samples were classified as fresh water (C1, TDS < 1000 mg/l) according to Carroll (1962) (Table 8, Fig. 2b).

Total hardness (TH) values ranged from 130.00 to 607.09 mg/l, averaging 354.83 ± 124.36 mg/l (Table 5). Based on U.S. EPA (1986) classifications, 87.5% of samples (14 samples) were very hard (TH > 180 mg/l), while 12.5% (2 samples) were hard (TH = 120-180 mg/l) (Fig. 3a). Chloride (Cl-) concentrations ranged from 0.14 to 1.36 meq/l, with an average of 0.53 ± 0.33 meq/l (Table 5). All samples were safe for crops (Cl < 70 mg/l) (Table 9, Fig. 3b).

Table 7. Water quality based on EC value.

EC (μScm^{-1})	Salinity class	Salinity hazard	No. of sample	%
100-250	C1	Low	-	
250-750	C2	Medium	12	75
750-2250	C3	High	4	25
> 2250	C4	Very high	-	

Table 8. Water quality based on TDS value.

TDS (mg/l)	Salinity hazard	Remark on quality	Study area	
			No. of sample	%
0-1000	C1	Fresh water	16	100
1000-10000	C2	Brackish water		
10000-100000	C3	Saline water		
> 100000	C4	Brine		

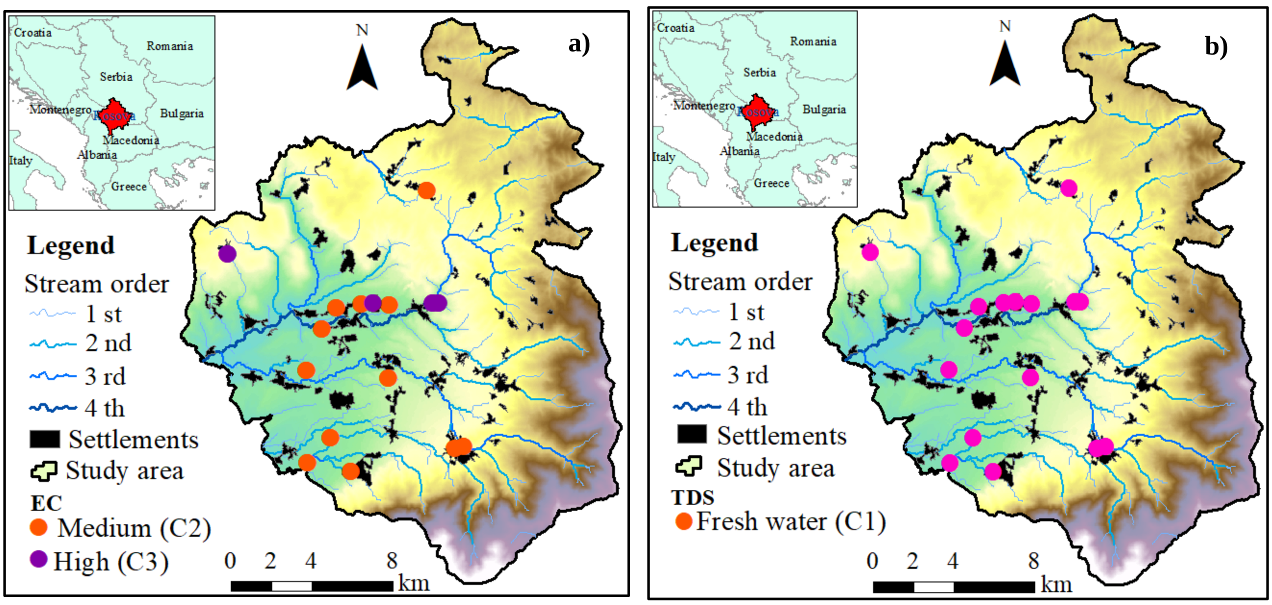

Fig. 2. Spatial distribution of EC (a) and TDS (b) in groundwater in the study area (Source: own study).

Table 9. Water quality based on the Cl^- value.

Cl^- concentration		Effect on crops	Study area	
meq/l	**mg/l**		**No. of sample**	**%**
< 2	< 70	Generally safe for all plants	16	100
2 - 4	70 -140	Sensitive plants usually show slight to moderate injury		
4 - 10	141-350	Moderately tolerant plants usually show slight to substantial injury		
> 10	> 350	Can cause severe problems		

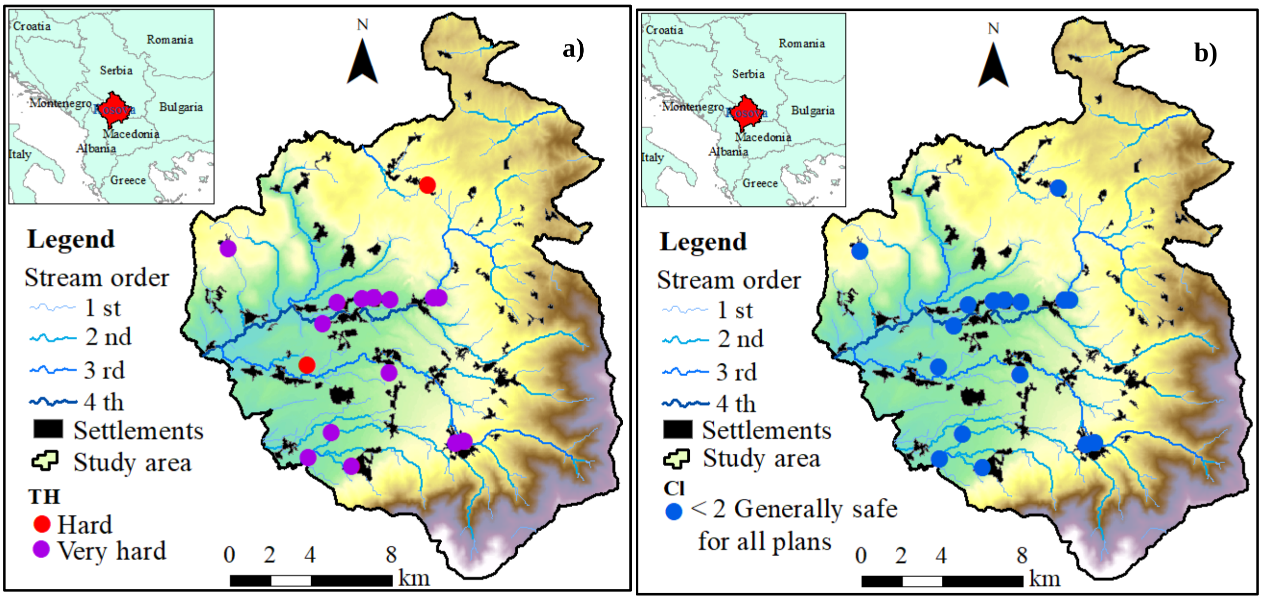

Fig. 3. Spatial distribution of TH (a) and Cl^- (b) in groundwater in the study area (Source: own study).

Irrigation water quality indices (SAR, %Na, KR, MAR, PI, PS, RSC) were calculated and analyzed (Tables 10-11) According to Al-Saffawi et al. (2020) water indices such as: SAR, SP, KR, MAR, PI, PS are the important tools for assessing the pollution and suitability of water for irrigation purposes.

SAR (sodium adsorption ratio) is the ratio of the concentration of Na^+ divided by the square root of half the concentration of Ca^{2+} and Mg^{2+} (U.S. DANRCS, 2012) and is expressed by Equation (2) (Richards, 1954) (Table 4). It is an important parameter and helps to categorize any water source for irrigation uses (Çadraku, 2021, 2022). The values of the SAR index (sodium adsorption ratio) in the groundwater of the study area showed a value from 0.04 (S9) to 0.86 (S13) with an average value of 0.26 ± 0.25 (Table 11).

The values obtained for the SAR index in the groundwater of the study area were compared with the values given by Richards (1954) and it turned out that all the water samples or 100% of them are within the limit (SAR = 0 to 10) thus indicating that these waters are of class C1 (according to sodium hazard class) and excellent (Table 12 and Fig. 4a).

SP (sodium percentage) - According to Wilcox (1955, 1958), sodium percentage is also widely used for assessing the suitability of water quality for irrigation. The calculation of the SP index was made with Equation (3) (Table 4). SP values in the groundwater of the study area showed values from 1.08 (S9) to 18.78 (S13) with an average value of 7.01 ± 5.18 (Table 11).

The SP values in the groundwater of the study area were compared with the values given by Wilcox (1955) and Khopdapanah et al. (2009) (Table 13) and showed that they meet the limit (SP < 20), ranking these waters in the class excellent (Table 13 and Fig. 4b).

Table 10. Index values.

Sample ID	SAR	% Na	KR	MAR	PI	PS	RSC
S1	0.18	0.08	0.08	0.24	0.62	0.35	0.57
S2	0.08	0.06	0.02	0.55	0.33	0.76	0.21
S3	0.12	0.05	0.03	0.41	0.32	0.62	1.05
S4	0.06	0.02	0.01	0.54	0.32	0.72	0.69
S5	0.57	0.14	0.16	0.39	0.43	1.38	0.52
S6	0.57	0.14	0.16	0.39	0.43	1.38	0.52
S7	0.17	0.05	0.05	0.6	0.41	0.64	0.87
S8	0.44	0.09	0.1	0.36	0.36	2.08	-0.72
S9	0.04	0.01	0.01	0.76	0.37	0.21	0.57
S10	0.12	0.04	0.04	0.31	0.48	0.55	0.41
S11	0.53	0.1	0.11	0.37	0.33	2.68	1.26
S12	0.11	0.04	0.03	0.28	0.41	0.62	1.53
S13	0.86	0.19	0.22	0.52	0.47	1.31	3.19
S14	0.18	0.08	0.08	0.24	0.62	0.35	0.57
S15	0.06	0.02	0.01	0.54	0.32	0.72	0.69
S16	0.07	0.02	0.02	0.67	0.39	0.23	4.94

Table 11. Descriptive statistics of irrigation water quality indices.

	SAR	% Na	KR	MAR	PI	PS	RSC
N	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Min	**0.04**	**0.01**	**0.01**	**0.24**	**0.32**	**0.21**	**-0.72**
Max	**0.86**	**0.19**	**0.22**	**0.76**	**0.62**	**2.68**	**4.94**
Sum	4.16	1.13	1.13	7.17	6.61	14.60	16.87
Mean	**0.26**	**0.07**	**0.07**	**0.45**	**0.41**	**0.91**	**1.05**
Std. error	0.06	0.01	0.02	0.04	0.02	0.17	0.33
Variance	0.06	0.00	0.00	0.02	0.01	0.48	1.72
Stand. dev	0.25	0.05	0.06	0.15	0.10	0.69	1.31
Median	0.15	0.06	0.05	0.40	0.40	0.68	0.63
25 prcntil	0.07	0.03	0.02	0.32	0.33	0.40	0.52
75 prcntil	0.51	0.10	0.11	0.55	0.46	1.36	1.21
Skewness	1.23	0.97	1.08	0.43	1.23	1.44	2.07
Kurtosis	0.47	0.40	0.35	-0.61	0.97	1.75	5.05
Geom. mean	0.17	0.05	0.05	0.42	0.40	0.71	0.00
Coeff. var	**96.13**	**72.65**	**90.81**	**34.48**	**23.30**	**75.65**	**124.33**

Table 12. Water quality based on the SAR value.

SAR (meq/l)	Sodium hazard class	Remark	Study area	
			No. of sample	%
0 - 10	C1	Excellent (little or no hazard)	16	100
10 - 18	C2	Good (appreciable hazard but can be used with appropirate management	-	-
18 - 26	C3	Doubtful (unsatisfactory for most of the crops)	-	-
> 26	C4	Unsuitable (unsatisfactory for all the crops)	-	-

Table 13. Water quality based on the SP value.

% Na	Class	Study area	
		No.of samples	%
< 20	Excellent	16	100
20 - 40	Good	-	-
40 - 60	Permissible	-	-
60 - 80	Doubtfull	-	-
> 80	Unsuitable	-	-

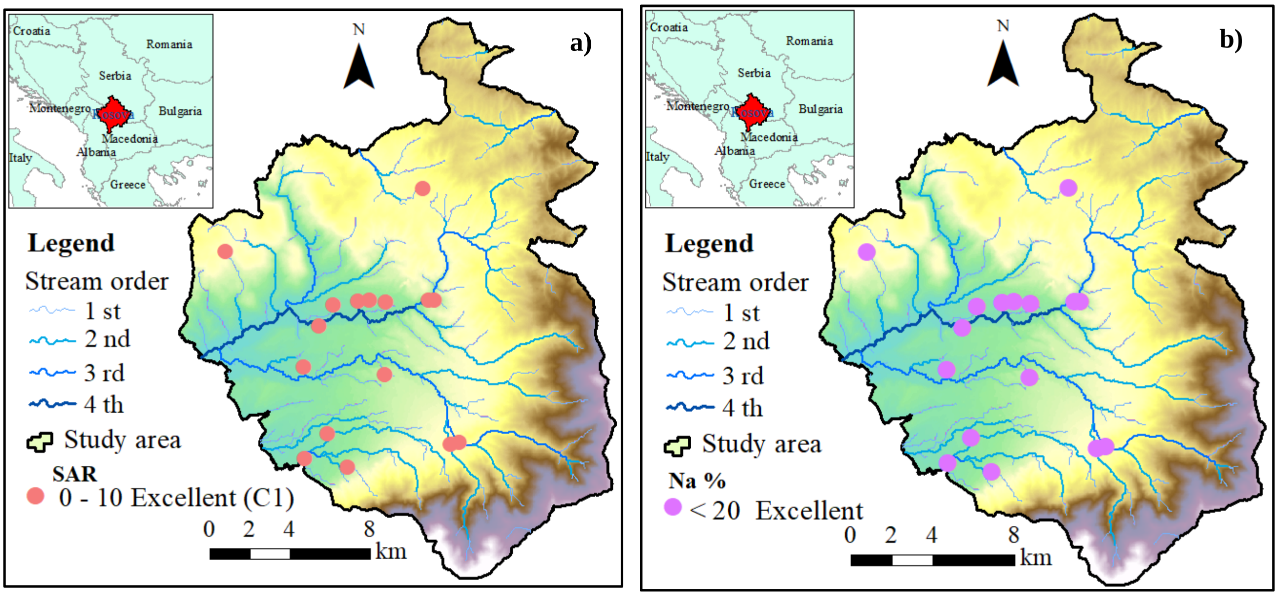

Fig. 4. Spatial distribution of SAR (a) and % Na (b) (Source: own study).

KR (Kelly's ratio) - in (1940) Kelly determined the dangerous effect of sodium on the quality of water used for irrigation. Kelly's ratio is calculated with Equation (4) (Table 4). This index is considered suitable for irrigation at the limit of KR values < 1 and not adapted at the limit of values for KR > 1 (Akoachere et al., 2019; Karakus & Yildiz, 2020). The values of the KR ratio in the groundwater of the study area showed values from 0.01 to 0.22 with an average value of 0.07 ± 0.06 (Table 11). The groundwater values were compared with the values given in (Table 14 and Fig. 5a) and it turned out that the groundwater of the study area belongs to the KR limit (< 1), respectively the Suitable class. According to Karakus & Yidiz (2020), the KR values lower than 1 indicates that water is suitable for irrigation and values higher than 1 indicate that water is unsuitable for irrigation purposes.

Magnesium adsorption ratio (MAR) ranged from 0.24 to 0.76, averaging 0.45 ± 0.15, falling within the suitable range (MAR < 50) (Fig. 5b). Permeability index (PI) ranged from 0.32 to 0.62, averaging 0.41 ± 0.10, classifying all samples as good (PI < 80) (Fig. 6a). Potential salinity (PS) ranged from 0.21 to 2.68, averaging 0.91 ± 0.69, with all samples in the low permeability class (PS < 3) (Table 15, Fig. 6b). Residual sodium carbonate (RSC) ranged from -0.72 to 4.94, averaging 1.05 ± 1.31.

RSC (residual sodium carbonate) is used to determine the dangerous effects of carbonate and bicarbonate on the quality of irrigation water (Udom et al., 2019). According to Taqueen & Abbasi (2013) water containing more than 2.5 meq/L RSC is not suitable for irrigation, while those with less than 1.25 meq/L are good for irrigation. Mainly this parameter is important to evaluate the quality of irrigation water in clay soils that have a high cation exchange capacity. Equation (8) was used for its calculation (Table 4). RSC values in the groundwater of the study area showed values from -0.72 to 4.94 with an average value of 1.05 ± 1.31 (Table 11).

Table 14. Water quality based on the KR value.

KR	Class	Study area	
		No.of samples	%
< 1	Suitable	16	100
1 - 2	Marginal	-	-
> 2	Unsuitable	-	-

Table 15. Water quality based on the PS value.

Soil Characteristics	Water Class			Study area	
	Class I	Class II	Class III	No. of sample	%
Low permeability	< 3	3 up to 5	> 5	16	100
Medium permeability	< 5	5 up to 10	> 10	-	-
High permeability	< 7	7 up to 15	> 15	-	-

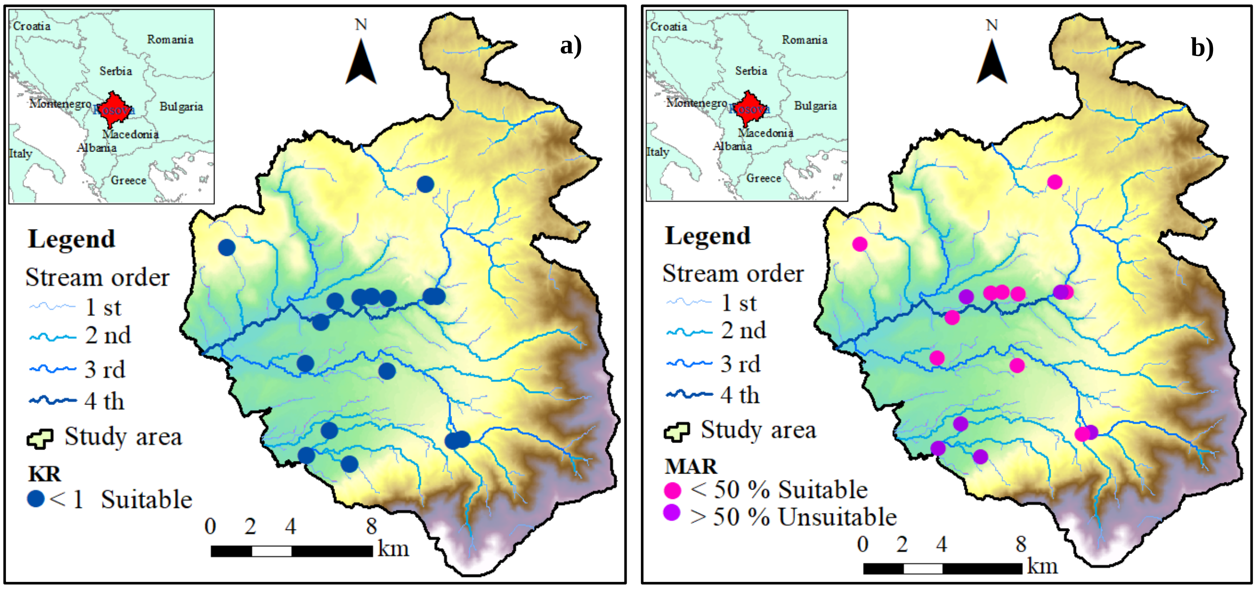

Fig. 5. Spatial distribution of KR (a) and MAR (b) (Source: own study).

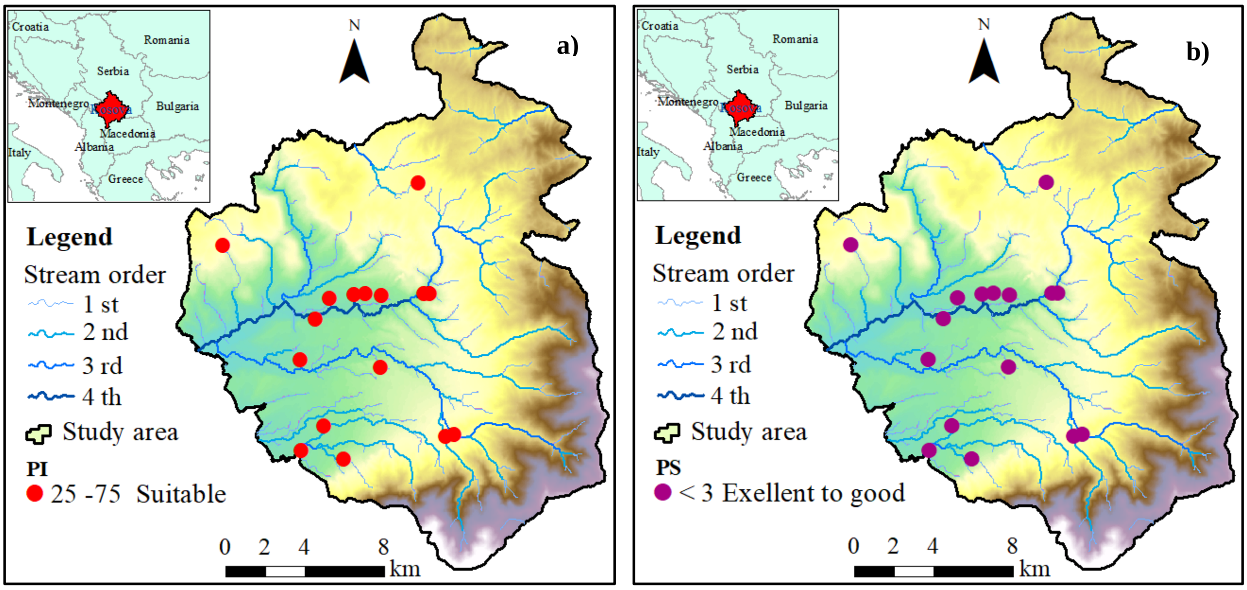

Fig. 6. Spatial distribution of PI (a) and PS (b) (Source: own study).

Correlation analysis was conducted to assess relationships between variables, with coefficients of 1 and -1 indicating functional dependence and 0 indicating no relationship. The correlation matrix of the values of the water quality indices for irrigation are shown in Table 16.

Hierarchical clustering, also known as hierarchical cluster analysis, offers a different method for grouping objects based on their similarities.

Fig. 7. illustrates the hierarchical grouping of water quality indices for irrigation in the study area.

Table 16. Correlation matrix for irrigation indices (linear Pearson).

	SAR	% Na	KR	MAR	PI	PS	RSC
SAR	1						
% Na	0.95	1					
KR	0.97	0.98	1				
MAR	-0.22	-0.34	-0.31	1			
PI	0.14	0.32	0.34	-0.55	1		
PS	0.72	0.58	0.58	-0.24	-0.30	1	
RSC	0.09	0.03	0.07	0.36	0.00	-0.20	1

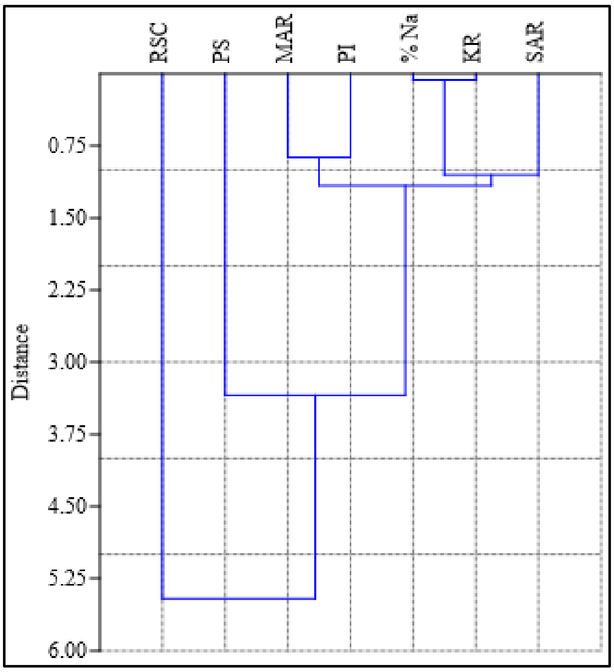

Fig. 7. Hierarchical clustering (Source: own study).

Conclusions

The study area is located in the southern part of the Republic of Kosovo and has 53.7% agricultural land. Groundwater in the study area represents one of the main water resources. The pH in 93.75% of the samples showed a value within the standard for water that can be used for irrigation. The EC parameter showed that the groundwater belongs to class C2 and C3. The groundwater of the study area was shown to be very strong. According to the Cl- parameter, these waters are generally safe for watering all plants. All water samples showed values for the SAR index in the range of 0 to 10, weighing these waters in class C1 (excellent).

In general, physical-chemical parameters and indices of water for irrigation showed that the groundwater in this study area is within the standard values and is of good quality for irrigation.

Acknowledgments

We thank all colleagues who support our work from a logistical, laboratory and advisory perspective.

References

Agrawal, A., & Dohare, D. (2024). Assessment of Groundwater Suitability for Drinking and Irrigation Purpose Using Statistical and Geospatial Techniques: A Review. *Holistic Approach of the Environment*, 14(1), 27–39. doi: 10.33765/thate.14.1.4.

Akoachere, R.A. II, Eyong, T.A., Egbe, S.E., Wotany, R.E., Nwude, M.O., & Yaya, O.O. (2019). Geogenic Imprint on Groundwater and Its Quality in Parts of the Mamfe Basin, Manyu Division, Cameroon. *Journal of Geoscience and Environment Protection*, 7, 184-211. doi: 10.4236/gep.2019.75016

Al-Saffawi, A.Y., Ibn Abubakar, B.Sh.U., & Abbass, L.Y. (2020). Assessment of groundwater quality for irrigation using water quality index (IWQ Index) in Al-Kasik Subdistrict North-western, Iraq. *Nigerian Journal of Technology*, 39 (2), 632-638. doi: 10.431/njt.v.39i2.35

APHA. (1995). *Standard Methods for the Examina-tion of Water and Wastewater*. 19th Edition, American Public Health Association Inc., New York.

Ayers, R.S., & Westcot, D.W. (1985). Water quality for agriculture. *FAO irrigation and drainage paper*, 29 (Rev. 1), 1–144.

Carroll, D. (1962). *Rain water is a chemical agent of geological process: a review*. US Geological survey water supply paper, 1535-G. doi: 10.3133/wsp1535G

Doneen, L.D. (1964). *Notes on Water Quality in Agriculture*. Department of Water Science and Engineering, University of California, Davis.

Dakoli, H. (2007). *Hydrogeology*. Library of FGJM, Tirana. (in Albanian)

Eaton, E.M. (1950). Significance of Carbonate in Irrigation Water. *Soil Science*, 69, 123-134. doi: 10.1097/00010694-195002000-00004

Food and Agriculture Organization (FAO). (2011). *Water Reports Irrigation in Southern and Eastern Asia in Figures*. AQUASTAT Survey. ISBN 978-92-5-107282-0, Rome, Itay

Food and Agriculture Organization (FAO). (2006). *Prospects for Food, Nutrition, Agriculture, and Major Commodity Groups*. World agriculture: toward 2030-2050, Intern report. Global Perspective Studies Unit. FAO, Rome.

Hegazi, I.M., Abbas, M.H.H., Ismail, A.O.A., & Abdel-Kader, Gh.A. (2018). Groundwater Quality Assessment for Irrigation Purposes in the West of Minia, Governorate, South Egypt. *Journal of Soil Science and Agricultural Engi-neering, Mansoura Univ*., 9(12), 809 – 816.

Hounslow, A. (1995). *Water Quality Data, Analysis and Interpretation*. Lewis Publishers, 381 p.

Independent Commission for Mines and Minerals. 2006. Geological Map of Kosovo. Available at: https://kosovo-mining.org/?lang=en

Jasechko, S., Seybold, H., Perrone, D., Fan, Y., Shamsudduha, M., Taylor, R.G., Fallatah, O., & Kirchner, J.W. (2024). Rapid groundwater decline and some cases of recovery in aquifers globally. *Nature*, 625, 715–721. doi: 10.1038/s41586-023-06879-8

Karakus, C.B., & Yildiz, S. (2020). Evaluation for Irrigation Water Purposes of Groundwater Quality in the Vicinity of Sivas City Centre (Turkey) by Using Gis and an Irrigation Water Quality Index. Irrigation and Drainage, 69(1), 121-137. doi: 10.1002/ird.2386

Kartal, S., Değirmenci, H., & Arslan, F. (2019). Ranking irrigation schemes based on principle component analysis in the arid regions of Turkey. *Agronomy Research*, 17(2), 456–465. doi: 10.15159/AR.19.053

Kelly, W.P. (1940). Permissible Composition and Concentration of Irrigated Waters. *Proceedings of the American Society of Civil Engineers*, 66, 607-613.

Khodapanah, L., Sulaiman, W.N.A., & Khodapanah, D.N. (2009). Groundwater quality assessment for diferent purposes in Eshtehard District, Tehran, Iran. Eur J Sci Res 36 (4):543–553

Kosovo Cadastral Agency. (2024). State Geoportal, Topographic Map. Republic of Kosovo. Available at: https://geoportal.rks-gov.net/en/filimi

Kosovo Agency of Statistics. (2013). Të përgjithshme /General/ Available at: https://ask.rks-gov.net/Themes/Others

Kosovo Environmental Protection Agency-Kosovo Hydrometeorological Institute. (2022). Meteo-rological Data, Monthly Average 2001-2019, V.3.1., Prishtinë. Available at: https://www.ammk-rks.net/en/al

Laze, P., Rizani, S., & Ibraliu, A. (2016) Assessment Of Irrigation Water Quality of Dukagjin Basin in Kosovo. *Journal of International Scientific Publications: Agriculture & Food*, 4, 544-551.

Ministry of Agriculture Forestry and Rural Development. (2020). Kosovo Irrigation Master Plan, Stage IV-Completion Report, September 2020. Available at: https://www.mbpzhr-ks.net/

Ministry of Environment, Spatial Planning and Infrastructure. (2020). Report on the state of water in Kosovo 2020. Available at: https://www.ammk-rks.net/

Municipality of Suhareka. (2024). Draft Plani Zhvillimor Komunal Suharekë 2020-2028. Municipal Development Plan 2021-2029. Available at: https://kk.rks-gov.net/

Offical Gazette of The Republic of Kosova. (2013). Law No. 04/L-147 On Water of Kosovo. Available at: https://gzk.rks-gov.net/

Offical Gazette of The Republic of Kosova. (2007). Law No. 02/L-9 For The Irrigation of Agricultural Lands. Available at: https://gzk.rks-gov.net/

Paliwal, K.V. (1972). *Irrigation with Saline Water*. New Delhi: Water Technology Centre, Indian Agricultural Research Institute, 198 p.

Pivić, R., Maksimović, J., Dinić, Z., Jaramaz, D., Majstorović, H., Vidojević, D., & Stanojković-Sebić, A. (2022). Hydrochemical Assessment of Water Used for Agricultural Soil Irrigation in the Water Area of the Three Morava Rivers in the Republic of Serbia. *Agronomy*, 12(5), 1177. doi: 10.3390/agronomy12051177

Pllana, R. (2015). *Klima e Kosovës*. ASHAK, Prishtinë. (in Albanian)

Çadraku, H. (2021). Groundwater Quality Assessment for Irrigation: Case Study in the Blinaja River Basin, Kosovo. *Civil Engineering Journal*, 7(09), 1515-1528. doi: 10.28991/cej-2021-03091740

Çadraku, H. (2022). Quantitative and Qualitative Characterization of the Curreli Spring Groundwater, Golesh Massif, Kosovo. *IFAC-PapersOnLine*, 55(39), 36-41. doi: 10.1016/j.ifacol.2022.12.007

Rizani, S., & Laze, P. (2017). Trace Elements Concentration in Surface Water Used for Irrigation in Kosovo. *Environment and Ecology Research*, 5(7), 500-509. doi: 10.13189/eer.2017.050706

Richards, L.A. (1954). *Diagnosis and Improvement of Saline and Alkali Soils*. US Salinity Laboratory Staff, US Department of Agriculture, Washington DC.

Todd, D.K. (1980). *Groundwater hydrology*, 2nd ed. Wiley & Sons, New York, 535 p.

Taqueem, A. K., & Abbasi, A. M. (2013). Synthesis of Parameters Used to Check the Suitability of Water for Irrigation Purposes. International J. of Environmental Science, Vol.3 No.6, 2030-2039.

Twarakavi, N.K., & Kaluarachchi, J. (2006). Sustainability of ground water quality considering land use changes and public health risks. *Journal of Environmental Management*, 81(4), 405-19. doi: 10.1016/j.jenvman.2005.11.008

Udom, E.A., Ekpo, A.E., & Oluka, S.I. (2019). Assessment of Irrigation Water Qualities of Abak River, Abak, Akwa Ibom State, Nigeria. *Global Journal of Pure and Applied Sciences*, 25, 135-144. doi: 10.4314/gjpas.v25i2.2

USSL Staff. (1954). *Diagnosis and improvement of saline and alkali soils*. USDA Handbook No 60. Washington DC, USA, 160 p.

United States Environmental Protection Agency (U.S. EPA). (1986). *Quality Criteria for Water*, 1 May 1986, EPA 440/5-86-001

World Health Organization (WHO). 2017. *Guidelines for Drinking-Water Quality*: *4th Edition, Incorporating the 1st Addendum*. Geneva: World Health Organization

World Health Organization (WHO). (2007). *pH in Drinking-water Revised background document for development of WHO Guidelines for Drinking-water Quality*. WHO/SDE/WSH/07.01/1.

Wilcox, L.V. (1955). *Classification and Use of Irrigation Water*. U.S. Dept. of Agr. Circular 969, United States Department of Agriculture Washington, D.C.

Wilcox, L.V. (1958). *Determining the quality of irrigation water*. United States Department of Agriculture, Washington.

Received: 18.01.2025
Accepted: 28.04.2025