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SEASONAL VARIATIONS AND EVALUATION OF DRINKING WATER QUALITY IN THE LALAPAŞA DISTRICT (EDIRNE/TÜRKIYE) USING SOME ECOLOGICAL – STATISTICAL INDICATORS

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ABSTRACT

Aim of the study

Although groundwater is a primary source of accessible freshwater, it is also particularly susceptible to contamination. Recognizing its importance is crucial for ensuring clean and sustainable drinking water on a global scale. The Thrace Region, renowned for its fertile agricultural lands, faces environmental pressures as agricultural and livestock activities pose a potential risk to local freshwater quality. This study aimed to assess the seasonal variation in drinking water quality in the Lalapaşa district of the Edirne province, within the Thrace Region, by analysing a range of physicochemical parameters.

Material and methods

A total of 28 drinking water samples were collected from various villages in Lalapaşa during the summer, autumn, and winter seasons of 2020–2021. Each sample was analysed for the following twelve parameters: dissolved oxygen (DO), oxygen saturation (O_2%), pH, electrical conductivity (EC), total dissolved solids (TDS), suspended solids (SS), salinity, turbidity, nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), and sulfate (SO_4^{2-}). The results were evaluated against national and international drinking water quality standards. Furthermore, ecological assessment was conducted using the water quality index (WQI), and statistical analyses were carried out using factor analysis (FA) and the pearson correlation index (PCI).

Results and conclusions

FA revealed three major factors – ‘salinity factor,’ ‘agricultural factor,’ and ‘oxygen factor’ – which together explained 74% of the total variance. Despite elevated concentrations of nitrogen and phosphorus in some samples, WQI values at all stations remained within acceptable limits. These findings highlight the essential role of sustainable polyculture agricultural practices in protecting the region’s groundwater resources.

Keywords: Lalapaşa district, drinking water quality, water quality index, statistical assessment

INTRODUCTION

Rapid population growth, technological advancements, and people’s indifference to environmental pollution and sustainability have unfortunately led to serious ecological problems worldwide (Muhammad et al., 2024). Freshwater pollution has become a global issue today, and access to clean drinking water sources is becoming increasingly difficult (Ustaoğlu and Tepe, 2019; Varol et al., 2022).

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Groundwater is one of the most critical natural resources for the socio-economic development (Zhou et al., 2025). The increasing severity of water scarcity (Yazman et al., 2024) and contamination represents a significant threat to human health and survival (Din et al., 2024). Groundwater plays a vital role in meeting human needs (Adimalla and Qian, 2023), supplying approximately 43% of agricultural water demands. Additionally, it serves as the primary source of domestic water supply in many regions across the globe (Wang et al., 2024; Salem et al., 2025).

Groundwater contamination arises from both geogenic and anthropogenic sources. In remote areas, geogenic factors are often the dominant contributors (Preethi et al., 2025), whereas in urban and industrialized regions, contamination typically results from a combination of geogenic and anthropogenic activities (Rehman et al., 2024). These include natural weathering and erosion of bedrock (Muhammad et al., 2024), as well as human-induced factors, such as industrial discharges, sewage infiltration, and agricultural runoff (Borah et al., 2025; Chaudhary et al., 2025).

Nitrate (NO_3^-) is among the most prevalent groundwater contaminants, originating from agrochemicals, crop residues, septic systems, and the decomposition of organic matter (Ather et al., 2024; Din et al., 2024). The World Health Organization (WHO, 2017) has established a guideline value of 50 mg/L for nitrate in drinking water. Exceeding this limit can lead to adverse health effects, including gastrointestinal issues, methemoglobinemia (blue baby syndrome), and an increased risk of miscarriage during early pregnancy (Mutlu et al., 2021; Din et al., 2024).

The availability of clean and safe drinking water is a major public health concern, particularly in rural areas where infrastructure may be limited, and routine monitoring is often inadequate. Lalapaşa, a district located in the northwestern part of Türkiye, is predominantly rural and relies heavily on local water sources for drinking and domestic use. Despite the significance of this issue, there is a notable lack of research specifically addressing the temporal variation in drinking water quality within the Lalapaşa district. Although several studies have addressed drinking water quality in the broader region, there has been no prior research focusing specifically on the seasonal variation of drinking water quality in the Lalapaşa district. This study aims to fill that gap by assessing the drinking water quality of Lalapaşa and its surrounding villages, benchmarking the findings against national and international water quality standards, and interpreting the results through water quality index (WQI) and factor analysis (FA) methodologies.

MATERIAL AND METHOD

Study area

Located in the northern part of Edirne province, the Lalapaşa district is bordered by Bulgaria to the west and the Süloğlu district to the east. The district covers an area of approximately 537 km² (536.788 km²) and has a population of around 7,000. The topography is largely flat, although slightly hilly formations can be observed along the border. Water bodies in the region are limited, with only a few seasonal streams that are primarily sustained by winter precipitation. One of the most notable hydrological features of the area is the Lalapaşa stream, which eventually discharges into the Tunca River and plays a crucial role in the region's hydrology. Lalapaşa has a continental climate, characterized by cold winters and hot summers, with annual precipitation typically ranging between 350 and 450 mm. In addition, a 55.5-kilometer segment of Türkiye's border with Bulgaria is located within the boundaries of the Lalapaşa district (Edirne, 2017).

The local economy in Lalapaşa is primarily driven by agriculture and livestock breeding, with the district hosting extensive arable lands. Sunflower and wheat are the main crops cultivated, while other important agricultural products include sugar beet, corn, vegetables, and various fruits. However, the region's water resources – both surface and groundwater – are subject to significant pollution pressures. This is mainly caused by the lack of proper domestic wastewater treatment systems in residential areas, poorly constructed septic tanks, uncontrolled disposal of septic waste collected by vacuum trucks, and the intensive use of chemical fertilizers and pesticides in agriculture. These challenges pose serious risks to the quality of drinking water. Furthermore, sociological studies conducted in the Thrace region have highlighted a general lack of public awareness and concern regarding environmental pollution and the long-term sustainability of agricultural practices (Helvacıoğlu et al., 2024).

Sample collection

The map of Lalapaşa district, with the locations of the sampling stations, is presented in Figure 1. The geographic coordinates of all stations are detailed in Table 1. In this study, the drinking water samples were systematically collected from the tap water of residential houses located in the Lalapaşa district and its 27 surrounding villages. Sampling was carried out during three distinct seasons – July 2020 (summer), October 2020 (autumn), and February 2021 (winter) – in order to evaluate potential seasonal variations in water quality parameters across the region.

Physicochemical analysis

During the field studies, several in situ physicochemical parameters in the drinking water samples were measured, including dissolved oxygen (DO), percent oxygen saturation, pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity. These measurements were conducted using the Hach Lange multi-parameter measurement device (HQ40D). Turbidity was assessed separately using the Hach Lange turbidimeter (2100Q).

In subsequent laboratory analyses, additional parameters were evaluated, including suspended solids (SS), nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), and sulphate (SO_4^{2-}). These were determined using the Hach Lange colorimeter (DR 890).

Evaluation of data

The measured water quality parameters were compared against the threshold values specified in multiple national and international guidelines. These include the Water Pollution Control Regulation of Türkiye (SKKY, 2015), the Turkish Standards Institute's limits for drinking and utility water (TS266, 2005), the World Health Organization (WHO, 2011) guidelines for drinking water quality, and the European Commission (EC, 2007) standards for potable water.

Statistical analysis

To examine the relationships among the measured parameters, the Pearson correlation index (PCI) was employed. Additionally, factor analysis (FA) was conducted to identify and categorize the underlying pressure factors affecting the water system. Both statistical analyses were performed using the SPSS 17.0 software package.

Table 1. Location information of stations

	Location	North	East		Location	North	East
L1	Dombay Village	41.902	26.631	L15	Sinanköy Village	41.815	26.699
L2	Yünlüce Village	41.853	26.631	L16	Hüseyinpınar Village	41.900	26.596
L3	Hacılar Village	41.943	26.783	L17	Hanlıyenice Village	41.870	26.692
L4	Hacıdanişment Village	41.909	26.820	L18	Hamzabeyli Village	41.964	26.642
L5	Süleymandanişment Village	41.897	26.890	L19	Taşlımüsellim Village	41.823	26.767
L6	Büyünlü Village	41.892	26.731	L20	Çallıdere Village	41.940	26.725
L7	Vaysal Village	41.942	26.87	L21	Saksağan Village	41.877	26.605
L8	Çömlekköy Village	41.842	26.609	L22	Kavaklı Village	41.794	26.753
L9	Doğanköy Village	41.926	26.702	L23	Tuğlalık Village	41.924	26.614
L10	Küçünlü Village	41.934	26.765	L24	Çömlekpınar Village	41.837	26.645
L11	Lalapaşa İlçesi	41.838	26.735	L25	Demirköy Village	41.915	26.669
L12	Kalkansöğüt Village	41.971	26.814	L26	Çatma Village	41.884	26.637
L13	Uzunbayır Village	41.927	26.594	L27	Ömeroba Village	41.923	26.930
L14	Sarıdanişment Village	41.864	26.825	L28	Ortakçı Village	41.785	26.736

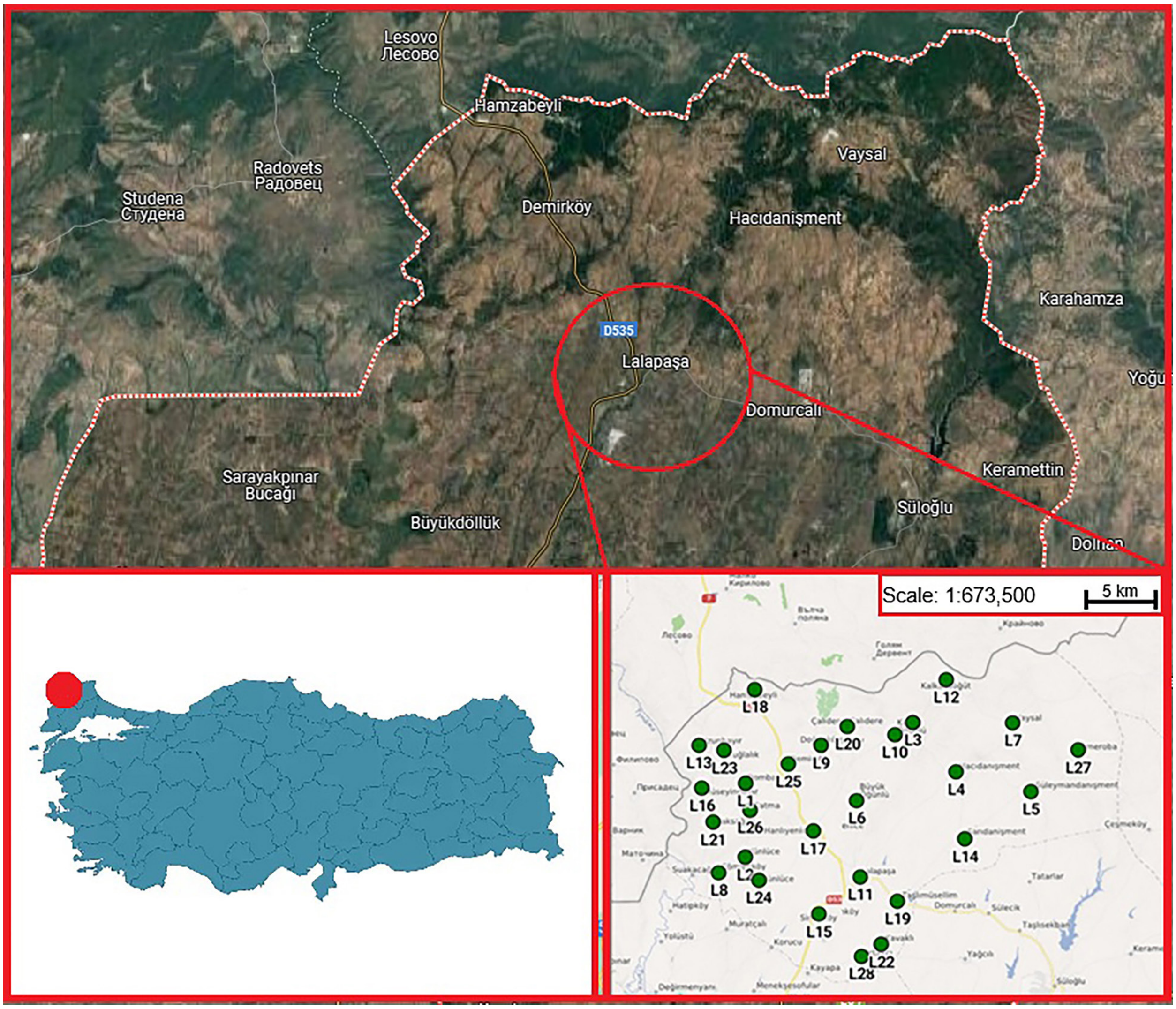

Fig. 1. Lalapaşa district map and selected stations (source: Authors' own elaboration)

Water quality index (WQI)

The water quality index (WQI) is a tool widely used for the classification of surface water that relies on standardized parameters to characterize overall water quality (Mutlu et al., 2021). In recent years, WQI has gained considerable prominence as a reliable method for evaluating the suitability of water for drinking purposes (Ustaoğlu et al., 2020; Ali et al., 2025). In this study, the WQI was calculated using the standard formula presented below:

$$WQI = \sum \left[W_i \times \left(\frac{C_i}{S_i} \right) \times 100 \right] \qquad (1)$$

$$W_i = \frac{W_i}{\Sigma W_i} \qquad (2)$$

In this formula, Wi denotes the relative weight assigned to each parameter, with values ranging from 1 to 5 based on the relative significance of toxic substances to human health and their overall impact. The measured concentration of the parameter in the water sample is represented by Ci, while Si corresponds to the standard drinking water quality limits established by TS266 (2005), EC (2007), and WHO (2011). The classification scale for the water quality index (WQI) used in this study is provided in Table 2 (Xiao et al., 2019).

Table 2. Water quality rating for WQI

Value	Water quality	Usage possibilities	Rating
< 50	Perfect water quality	Drinking, irrigation, industrial	A
50–100	Good water quality	Drinking, irrigation, industrial	B
100–200	Poor water quality	Irrigation, industrial	C
200–300	Very poor water quality	Irrigation	D

RESULTS

Physicochemical values determined in drinking water of the Lalapaşa district

The values of water quality that were measured at all sampling stations in the Lalapaşa district during the summer season are summarized in Table 3. Those obtained in the autumn season are presented in Table 4, and the winter season values are detailed in Table 5.

In the summer season, pH values range from 6.41 to 8.18, indicating slightly alkaline conditions. Electrical conductivity (EC) and total dissolved solids (TDS) show considerable variation across stations. For instance, station L10 has an EC of 1234 µS/cm and TDS of 545 mg/L, while station L2 shows an EC of 691 µS/cm and TDS of 301 mg/L. Dissolved oxygen saturation (%O) is generally above 90%, although lower values are observed at some stations (e.g., 86.2% at L14). Nitrate (NO_3^-) concentrations are indicated as '>24.300' mg/L at several stations (L3, L8, L11, L12, L19, L20, L23, L25), suggesting that the parameter levels have exceeded the measurement limit. Similarly, phosphate (PO_4^{3-}) and sulphate (SO_4^{2-}) values vary between the stations. Turbidity and suspended solids (SS) values are generally low, though some stations like L17 show relatively higher turbidity (5.46 NTU) and suspended solids (2 mg/L) compared to others.

In the autumn season, pH values generally indicate neutral to slightly alkaline conditions, ranging from 7.4 at station L25 to 8.86 at station L18. Electrical conductivity (EC) and total dissolved solids (TDS) vary significantly across stations, with the highest EC (1055 µS/cm) and TDS (518 mg/L) observed at station L10, and the lowest EC (357 µS/cm) and TDS (220 mg/L) at station L5. Dissolved oxygen saturation (%O) is mostly high, generally above 90%, with station L6 showing the highest at 106.7%. Nitrate (NO_3^-) concentrations are frequently above the detection limit of 24.300 mg/L at multiple stations (L3, L11, L12, L16, L19, L20, L21, L25, L26). Phosphate (PO_4^{3-}) levels are generally low, though station L19 shows a notably higher value of 1.02 mg/L. Sulphate (SO_4^{2-}) concentrations also vary, with the highest (119 mg/L) at station L16. Turbidity and suspended solids (SS) are generally low, with some exceptions like station L4 (turbidity 3.78 NTU) and station L7 (SS 27 mg/L).

In the winter season, the pH levels are generally neutral to slightly alkaline, ranging from 7.4 (L12) to 8.67 (L4). Electrical conductivity (EC) and total dissolved solids (TDS) show considerable variability For example, station L20 has high EC (956 µS/cm) and TDS (533 mg/L), while station L24 shows lower values (EC 441 µS/cm, TDS 240 mg/L). Dissolved oxygen saturation (%O) remains largely high, typically above 90%, with station L6 recording the highest at 101.3%. Several stations (L3, L10, L13, L19, L20, L23, L25) report Nitrate (NO_3^-) concentrations exceeding the 24.300 mg/L detection limit. Phosphate (PO_4^{3-}) levels vary, with notable peaks observed at several stations such as L3 (2.75 mg/L), L6 (2.75 mg/L), L10 (2.75 mg/L), L17 (2.75 mg/L), and L24 (2.75 mg/L). Sulphate (SO_4^{2-}) concentrations also differ across stations, with L18 showing a high of 170 mg/L. Turbidity and suspended solids (SS) are generally low, though station L5 has a relatively higher SS value of 15 mg/L, and station L8 shows a turbidity of 2.2 NTU.

Table 3. Values obtained from drinking water of Lalapaşa district in summer

Station	ÇO	%O	pH	EC	TDS	Salinity	Turbidity	SS	NO_3^-	NO_2^-	PO_4^{3-}	SO_4^{2-}
	mg/L	%		µS/cm	mg/L	‰	NTU	mg/L	mg/L	mg/L	mg/L	mg/L
L1	7.130	97.300	8.180	681.000	293.000	0.290	1.580	20.000	10.500	0.050	0.660	35.000
L2	7.310	98.300	8.080	691.000	301.000	0.300	0.530	1.000	24.300<	0.004	0.410	10.000
L3	7.430	99.000	7.890	1208.000	540.000	0.540	0.610	9.000	24.300<	0.016	0.650	80.000
L4	7.200	95.800	8.060	845.000	373.000	0.370	0.620	8.000	6.100	0.022	0.370	21.000
L5	7.280	97.000	7.750	504.000	220.000	0.220	0.440	7.000	20.900	0.018	0.690	66.000
L6	7.450	99.300	7.670	872.000	385.000	0.410	0.630	9.000	17.900	0.054	0.670	80.000
L7	7.280	97.000	7.830	928.000	411.000	0.410	0.660	0.000	3.900	0.024	0.520	12.000
L8	7.000	95.200	7.600	687.000	296.000	0.290	2.380	4.000	24.300<	0.000	0.670	11.000
L9	7.230	97.000	7.930	1189.000	528.000	0.530	0.510	2.000	24.300<	0.025	0.500	77.000
L10	7.330	98.300	7.980	1234.000	545.000	0.550	1.340	15.000	24.300<	0.003	0.480	7.000
L11	7.390	99.000	8.000	641.000	280.000	0.280	0.500	2.000	21.300<	0.084	0.180	80.000
L12	6.860	93.900	7.470	962.000	414.000	0.410	0.290	9.000	24.300<	0.000	0.740	16.000
L13	6.690	94.700	7.760	720.000	311.000	0.310	0.720	11.000	15.000	0.006	0.390	13.000
L14	6.700	90.800	7.790	725.000	313.000	0.310	0.550	9.000	7.300	0.032	0.510	11.000
L15	6.410	86.200	7.790	726.000	317.000	0.320	0.620	5.000	7.200	0.034	0.400	18.000
L16	7.120	96.100	7.880	721.000	312.000	0.310	0.580	7.000	13.000	0.018	0.400	16.000
L17	6.870	93.000	8.100	1125.000	491.000	0.490	5.460	2.000	1.600	0.048	0.540	80.000
L18	7.370	100.500	7.930	843.000	362.000	0.360	0.970	4.000	6.300	0.039	0.090	18.000
L19	7.020	95.900	7.550	1057.000	457.000	0.460	0.410	1.000	24.300<	0.045	0.780	22.000
L20	7.140	97.200	7.890	1248.000	545.000	0.550	0.480	0.000	24.300<	0.000	0.260	39.000
L21	6.530	88.200	7.500	682.000	296.000	0.290	0.510	12.000	15.100	0.048	0.840	10.000
L22	7.140	95.700	7.960	639.000	280.000	0.280	0.550	9.000	18.000	0.056	0.010	16.000
L23	6.650	89.600	7.660	1066.000	467.000	0.470	1.340	0.000	24.300<	0.032	0.300	80.000
L24	6.880	92.800	7.900	580.000	251.000	0.250	0.250	4.000	11.600	0.000	0.160	80.000
L25	7.190	96.300	7.850	1211.000	538.000	0.540	0.590	7.000	24.300<	0.010	0.100	16.000
L26	7.150	96.000	7.900	719.000	314.000	0.310	0.820	14.000	17.400	0.018	0.070	33.000
L27	6.350	85.100	7.530	981.000	434.000	0.430	0.390	11.000	1.700	0.000	0.280	15.000
L28	7.080	94.300	7.900	637.000	280.000	0.280	0.400	6.000	17.100	0.000	0.200	4.000

Table 4. Values obtained from drinking water of Lalapaşa district in autumn

Station	ÇO	%O	pH	EC	TDS	Salinity	Turbidity	SS	NO_3^-	NO_2^-	PO_4^{3-}	SO_4^{2-}
	mg/L	%		µS/cm	mg/L	‰	NTU	mg/L	mg/L	mg/L	mg/L	mg/L
L1	8.430	98.200	7.870	580.000	297.000	0.290	0.580	12.000	21.100	0.033	0.120	15.000
L2	8.560	98.900	8.270	578.000	285.000	0.230	0.940	17.000	24.300<	0.019	0.100	18.000
L3	8.440	97.600	7.750	1014.000	523.000	0.520	0.430	1.000	24.300<	0.035	0.140	80.000
L4	8.660	99.600	8.320	697.000	357.000	0.360	3.780	6.000	5.500	0.036	0.120	18.000
L5	8.440	97.400	8.260	436.000	220.000	0.220	0.970	7.000	11.700	0.049	0.270	25.000
L6	8.440	97.400	7.910	793.000	407.000	0.410	0.570	4.000	8.900	0.072	0.070	28.000
L7	9.230	106.700	8.030	780.000	399.000	0.400	20.000	27.000	4.700	1.120	0.240	18.000
L8	8.280	95.600	7.500	544.000	277.000	0.270	1.680	0.000	18.400	0.044	0.190	11.000
L9	8.380	96.700	7.740	984.000	507.000	0.510	0.720	1.000	24.300<	0.030	0.210	80.000
L10	8.340	96.400	7.830	1055.000	518.000	0.520	2.020	7.000	24.300<	0.031	0.090	72.000
L11	8.430	97.200	8.290	548.000	279.000	0.280	0.600	0.000	24.300<	0.027	0.220	10.000
L12	8.380	96.700	7.690	733.000	374.000	0.370	0.270	4.000	24.300<	0.021	0.410	22.000
L13	8.410	97.000	7.700	630.000	310.000	0.310	0.390	7.000	20.500	0.030	0.220	8.000
L14	8.310	95.300	7.730	641.000	327.000	0.330	0.350	5.000	10.600	0.041	0.210	3.000
L15	8.230	94.900	7.770	617.000	315.000	0.310	0.420	2.000	11.100	0.018	0.190	25.000
L16	8.470	97.500	7.920	604.000	308.000	0.310	0.370	4.000	23.200	0.038	0.090	11.000
L17	8.170	94.100	7.850	950.000	491.000	0.490	1.100	0.000	4.200	0.074	0.350	80.000
L18	8.790	101.300	8.860	695.000	356.000	0.350	0.660	2.000	8.800	0.026	0.190	18.000
L19	8.610	99.100	7.780	913.000	471.000	0.470	0.610	0.000	24.300<	0.030	1.020	75.000
L20	8.340	95.800	7.350	1000.000	519.000	0.520	0.250	2.000	24.300<	0.027	0.150	69.000
L21	8.380	96.300	8.050	607.000	311.000	0.310	0.440	7.000	19.200	0.065	0.170	11.000
L22	8.430	96.800	8.110	586.000	299.000	0.300	0.520	2.000	23.900	0.020	0.120	5.000
L23	7.980	91.500	7.960	591.000	303.000	0.300	0.730	1.000	20.500	0.046	0.250	13.000
L24	8.140	93.200	8.110	482.000	247.000	0.250	0.390	0.000	18.600	0.036	0.140	4.000
L25	8.270	94.300	8.010	763.000	397.000	0.400	1.390	4.000	24.300<	0.043	0.280	46.000
L26	8.310	94.700	7.400	598.000	309.000	0.310	0.700	7.000	24.300<	0.043	0.210	6.000
L27	8.010	94.800	7.980	640.000	334.000	0.330	0.630	9.000	6.000	0.049	0.060	10.000
L28	8.510	96.300	7.820	573.000	298.000	0.300	0.390	6.000	23.100	0.048	0.140	9.000

Table 5. Values obtained from drinking water of Lalapaşa district in winter

Station	ÇO	%O	pH	EC	TDS	Salinity	Turbidity	SS	NO_3^-	NO_2^-	PO_4^{3-}	SO_4^{2-}
	mg/L	%		µS/cm	mg/L	‰	NTU	mg/L	mg/L	mg/L	mg/L	mg/L
L1	7.200	78.500	7.840	608.000	330.000	0.330	0.700	1.000	15.800	0.023	1.140	21.000
L2	8.930	96.700	8.090	534.000	290.000	0.230	0.730	0.000	24.300<	0.022	0.530	12.000
L3	9.080	98.400	7.770	735.000	401.000	0.400	0.680	4.000	24.300<	0.006	2.750	49.000
L4	8.840	95.600	8.670	723.000	396.000	0.400	1.720	1.000	3.400	0.025	0.700	11.000
L5	8.900	96.200	8.130	406.000	213.000	0.220	0.480	15.000	11.800	0.047	0.930	24.000
L6	8.770	95.600	7.680	723.000	393.000	0.390	1.160	0.000	10.800	0.021	2.750	35.000
L7	9.230	101.300	8.430	842.000	387.000	0.370	0.920	7.000	2.000	0.037	0.990	16.000
L8	8.680	94.600	7.870	529.000	286.000	0.280	2.200	9.000	12.600	0.019	0.840	50.000
L9	8.780	96.200	7.900	673.000	363.000	0.360	0.910	2.000	7.000	0.022	0.470	14.000
L10	9.020	98.200	7.720	842.000	446.000	0.420	0.810	7.000	24.300<	0.003	2.750	46.000
L11	8.700	95.100	7.730	512.000	276.000	0.270	0.690	7.000	17.100	0.020	1.280	14.000
L12	8.590	94.100	7.500	640.000	346.000	0.340	2.430	9.000	21.400	0.020	1.580	20.000
L13	8.600	93.100	7.440	651.000	355.000	0.350	0.360	4.000	24.300<	0.023	1.320	23.000
L14	8.680	93.600	7.650	593.000	323.000	0.320	0.800	1.000	4.700	0.018	0.320	5.000
L15	8.120	90.200	8.620	619.000	329.000	0.330	0.660	2.000	4.100	0.013	2.250	35.000
L16	8.630	93.200	8.720	652.000	355.000	0.350	0.640	4.000	16.700	0.031	2.750	23.000
L17	8.660	93.100	8.390	917.000	505.000	0.510	0.840	2.000	2.000	0.006	2.750	80.000
L18	9.330	100.000	8.520	630.000	344.000	0.340	1.270	1.000	4.200	0.049	2.750	17.000
L19	8.880	94.900	7.570	848.000	468.000	0.470	0.510	3.000	24.300<	0.020	1.360	78.000
L20	7.930	84.100	7.810	956.000	533.000	0.530	0.750	6.000	9.200	0.022	0.840	77.000
L21	8.560	91.500	8.060	635.000	347.000	0.350	0.540	1.000	17.800	0.028	2.750	22.000
L22	9.000	95.900	8.130	510.000	278.000	0.280	0.560	20.000	8.500	0.033	0.700	6.000
L23	7.480	82.000	7.870	618.000	334.000	0.330	2.760	6.000	24.300<	0.007	2.750	20.000
L24	8.430	90.300	8.230	441.000	240.000	0.240	0.520	0.000	19.200	0.026	2.750	6.000
L25	9.220	99.000	8.690	635.000	348.000	0.350	0.440	1.000	15.100	0.014	1.030	37.000
L26	8.780	95.000	7.810	655.000	357.000	0.360	0.400	8.000	15.300	0.039	2.350	23.000
L27	8.940	96.800	8.520	710.000	388.000	0.390	0.270	0.000	2.500	0.013	1.100	11.000
L28	8.640	93.500	7.920	514.000	279.000	0.280	0.350	3.000	11.400	0.032	2.750	9.000

Statistical analysis

In this study, Pearson correlation analysis (PCA) was conducted to identify statistically significant relationships among the physicochemical parameters ($n = 84$) at significance levels of $p < 0.05$ and $p < 0.01$. The significant correlations and their respective coefficients are summarized in Figure 2.

To identify the key factors that affect the drinking water quality in the Lalapaşa district, ten measured parameters were included in the analysis. The Kaiser-Meyer-Olkin (KMO) sample adequacy test yielded a value of 0.507, indicating that the sample size was adequate for factor analysis. Principal components with eigenvalues greater than one were retained as criteria to explain the variance within the dataset (Fig. 2).

The percentage of variance explained by each factor, cumulative variance, and component loadings before and after rotation are summarized in Figure 2. After rotation, three factors accounted for 74% of the total variance. The parameter loadings for these three factors (component matrix) are illustrated in Figure 3, while the component plot depicting the relationships among the identified factors is presented in Figure 2.

The first factor, designated as the 'Salinity Factor,' accounts for 33.6% of the total variance. It includes salinity, total dissolved solids (TDS), electrical conductivity (EC), and sulphate. Salinity, TDS, and EC show strong positive loadings (> 0.75) on this factor, whereas sulphate demonstrates a moderate positive loading (0.50–0.75).

The second factor, termed the 'Agricultural Factor,' explains 23.1% of the total variance. It comprises nitrite, turbidity, and suspended solids (SS). Both nitrite and turbidity show strong positive loadings (0.50–0.75), while suspended solids are moderately positively loaded within the same range.

The third factor, labelled the 'Oxygen Factor,' accounts for 17.3% of the total variance. It consists of dissolved oxygen, pH, and oxygen saturation. Dissolved oxygen shows a strong positive loading (> 0.75), whereas pH and oxygen saturation are moderately positively loaded (0.50–0.75).

Water quality index (WQI)

To determine the synergistic effects of the measured parameters, the water quality index (WQI) was calculated using the values of pH, electrical conductivity, turbidity, nitrate, and nitrite obtained across all seasons and sampling stations (for nitrate concentrations exceeding the analytical detection limit, the upper detection limit value of 24.3 mg/L was used in the WQI calculations to maintain a conservative esti-

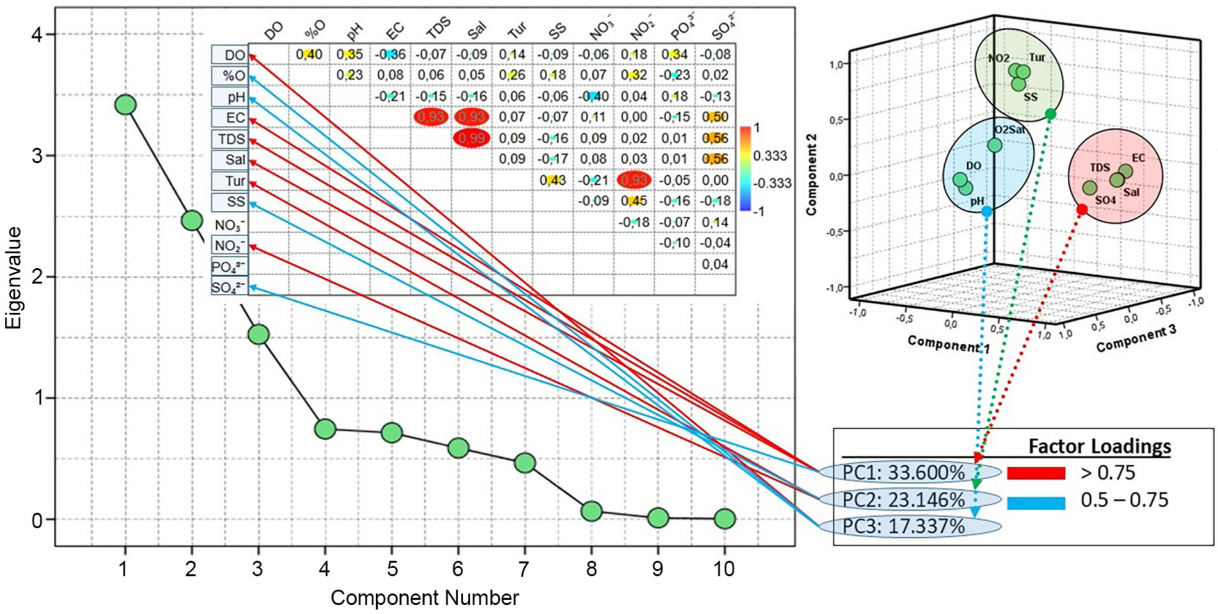

Fig. 2. PCI coefficients, scree plot, component matrix and diagram after rotation (source: Authors' own elaboration)

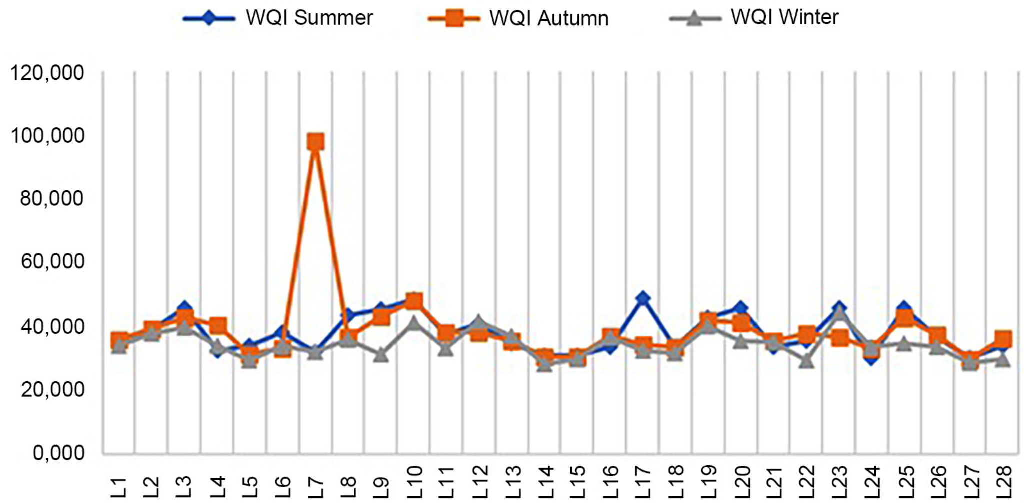

Fig. 3. Seasonal variation of WQI values calculated in drinking water (source: Authors' own elaboration)

mate). The seasonal variation of the WQI values for drinking water from the villages in the Lalapaşa district during summer, autumn, and winter is illustrated in Figure 3. The WQI results indicate that water quality in the Lalapaşa district generally falls within acceptable limits (<100). Notably, during the autumn season, all sampling sites exhibited 'Class A – Excellent' water quality across the three seasons, except for Vaysal village (L7 station) in the northern part of the district, which was classified as 'Class B – Good' for that season. The average water quality index (WQI) values measured during the study were 38.13 in summer (July 2020), 39.30 in autumn (October 2020), and 34.46 in winter (February 2021), corresponding to the three sampling seasons.

DISCUSSION

The dissolved oxygen (DO) content of water fluctuates depending on factors such as water temperature, treatment processes, and conditions within the distribution network. Generally, the DO concentration in drinking water is adequate. However, oxygen levels can decrease when water is sourced from deep reservoirs, microbial growth occurs in the network, or water is exposed to elevated temperatures for prolonged periods (Tokatlı et al., 2022). Reduced DO concentrations may facilitate the proliferation of undesirable anaerobic microorganisms, adversely affecting the aesthetic qualities of the water and promoting corrosion in pipes and installations. Although low dissolved oxygen levels do not pose direct health risks, they can impair the taste and odor of drinking water (Çavuş et al., 2017). According to the Water Pollution Control Regulation (SKKY, 2015), all sampling stations were classified as Class 2 for DO parameters during the summer season. In autumn, the L23 station was classified as Class 2, while all other stations achieved Class 1 status. During winter, stations L1, L20, and L23 were identified as Class 2, with the remaining stations classified as Class 1.

The pH values of drinking water vary significantly depending on its chemical composition. Drinking water standards set by TS266 (2005) and the European Commission (EC, 2007) consider a pH range of 6.5 to 9.5 acceptable. Our findings indicate that drinking water in the Lalapaşa district is generally slightly alkaline, remaining within the prescribed limits across all three seasons (TS266, 2005; EC, 2007). Regarding pH classifications based on SKKY (2015), all stations were rated as Class 1–2 during summer; in autumn, the L18 station was classified as Class 3, while the others remained within Class 1–2; and in winter, stations L4, L15, L16, L18, and L25 were assigned Class 3, with the rest categorized as Class 1–2.

Electrical conductivity (EC) and total dissolved solids (TDS) are critical parameters for assessing drinking water quality, as they typically increase proportionally with salinity (Tokatlı et al., 2022). The strong positive correlations observed in this study between EC, salinity, and TDS ($p < 0.01$) corroborate existing literature. According to the standards set by TS266 (2005) and the European Commission (EC, 2007), the EC value in drinking water should not exceed 2500 µS/cm. EC reflects the ability of water to conduct electric current, which rises with increasing ion concentration. Our results indicate that EC levels in the drinking water samples from the Lalapaşa district remained within acceptable limits across all seasons (TS266, 2005; EC, 2007). Furthermore, water quality classification based on EC showed that samples were generally categorized as Class 1–2 during autumn and winter, while in summer, classifications shifted to Class 2–3 (SKKY, 2015).

Total dissolved solids (TDS) is a general indicator of the total concentration of dissolved ions in water. In this study, drinking water in the Lalapaşa district was classified as Class 1–2 during the summer and autumn seasons, and Class 1 during the winter season according to SKKY (2015) standards.

Turbidity, measured in nephelometric turbidity units (NTU), is an important parameter reflecting water clarity. According to TS266 (2005) and WHO (2011) guidelines, turbidity in drinking water should not exceed 5 NTU. Except for two instances – a turbidity value of 5.46 NTU at the L17 station during summer and 20.0 NTU at the L7 station during autumn – all sampling locations remained below this threshold.

Sulphate is a naturally occurring ion in drinking water, with the WHO (2011) establishing a guideline value of 250 mg/L. Throughout the summer, autumn, and winter sampling periods, sulphate concentrations in the Lalapaşa district did not exceed this limit, and all stations were classified as Class 1 in terms of sulphate quality (WHO, 2011; SKKY, 2015).

Nitrate is a naturally occurring nutrient essential for plant growth. However, it can contaminate drinking water through oxidation of nitrogenous waste originating from agricultural activities, leachate from solid waste, industrial effluents, and wastewater discharges, including septic systems (Ather et al., 2024). According to the data obtained in this study, drinking water samples were generally classified as Class 2–3 during the summer season, with approximately 35% of sampling sites exceeding the measurement limit of 24.3 mg/L set by the colorimetric nitrate kit used in the laboratory. As a result, the water quality was classified as Class 4. Similarly, in the autumn season, 35% of stations also surpassed the limit values, indicating Class 4 water quality. In winter, around 20% of the stations were reported above this threshold, also classifying the water as Class 4 for nitrate concentration (SKKY, 2015). The elevated nitrate levels detected in drinking water of the Lalapaşa district are attributed primarily to the extensive use of fertilizers in livestock and agricultural practices.

Certain soil bacteria naturally facilitate the oxidation of ammonium by first converting it into nitrite, which is then transformed into nitrate. Nitrite is a nitrogen compound with low oxygen content that can partially bind to hemoglobin in the human bloodstream, reducing oxygen transport and posing particular health risks to infants. Consequently, the permissible nitrite concentration in drinking water is regulated at 0.5 mg/L by TS266, whereas the World Health Organization (WHO) recommends a stricter limit of 0.2 mg/L. In this study, nitrite concentrations in drinking water samples were consistently below these thresholds at all sampling sites during the summer and winter seasons, and at all stations except for L7 during the autumn season. Furthermore, according to the Water Pollution Control Regulation, drinking water in the Lalapaşa district was generally classified as Class 1–2 for nitrite across all seasons (SKKY, 2015).

Phosphate naturally occurs in phosphate rocks and is widely utilized not only in chemical fertilizer production but also in the manufacturing of specialty glass, porcelain, baking powder, and detergents. Hence, phosphate presence in drinking water can arise from natural mineral dissolution or anthropogenic sources such as fertilizer application, sewage discharge, and industrial effluents. Phosphorus is also an essential nutrient for humans, serving as a vital inorganic component of bones and teeth. Analysis revealed that approximately 75% of stations in summer, 60% in autumn, and 100% in winter exhibited Class 3–4 water quality with respect to phosphate levels (Uslu and Türkman, 1987). The elevated phosphate concentrations in the Lalapaşa District's drinking water are likely attributable to intensive agricultural and livestock activities, as well as widespread septic tank usage in the region's villages.

Consistent with the findings of the present study, an investigation conducted in the Meriç River Basin evaluated drinking water samples from 22 villages in the Enez and Süloğlu districts. The results indicated that none of the analysed parameters exceeded the permissible limits for drinking water quality (Onur and Tokatlı, 2020). Similarly, a separate study conducted in the İpsala district examined the drinking water quality of the district centre and its surrounding villages. In line with the current study, nitrate concentrations were found to be notably high, significantly influencing the overall drinking water quality in the region (Tokatlı, 2014). Furthermore, another study assessed the drinking water quality in the İpsala district using the water quality index (WQI). Although elevated nutrient levels were observed in some samples, the WQI values generally remained within acceptable limits (<100). The findings further revealed that the drinking waters of the İpsala district and its affiliated villages were classified as 'Class A – Excellent' in terms of overall quality (Tokatlı et al., 2022).

The sampling stations included in this study are located in villages with broadly similar environmental and socio-economic characteristics. None of the sites are directly influenced by identifiable sources of pollution such as mining operations, industrial facilities, or large-scale agricultural enterprises like dairies or production plants. Consequently, the variations observed in water quality parameters across the stations are likely attributable to diffuse pollution sources, including seasonal agricultural activities, variable sanitation infrastructure, and natural environmental fluctuations. These factors collectively contribute to spatial and temporal differences in water quality, underscoring the complexity of managing drinking water resources in rural settings without prominent localized contamination sources.

CONCLUSION

This study comprehensively assessed the drinking water quality of the Lalapaşa district in the Edirne province by analysing a range of physicochemical parameters, supplemented with an ecological evaluation using the water quality index (WQI). The results indicate that drinking water in the Lalapaşa district maintains in general a very high quality, with WQI values predominantly within the 'Class A – Excellent' category across all seasons. Parameters such as pH, electrical conductivity, sulphate, and dissolved oxygen mostly complied with national and international standards, reflecting a sound baseline for water safety.

However, despite the overall positive water quality status, the study revealed concerningly elevated concentrations of nitrogenous compounds, particularly nitrate and phosphate, in many stations and across seasons. These elevated nutrient levels, largely attributed to intensive agricultural practices – including the extensive use of chemical fertilizers, livestock waste, and improper septic tank management – pose a clear risk of eutrophication and potential contamination of both groundwater and surface water resources. Such nutrient pollution not only threatens aquatic ecosystems but may also compromise drinking water safety over time if left unaddressed.

The findings underscore the urgent necessity for implementing sustainable agricultural practices within the region. Promoting polyculture and crop rotation can reduce dependency on chemical inputs, mitigate nutrient runoff, and improve soil and water health synergistically. Furthermore, raising awareness among local communities about the environmental impacts of monoculture farming and the benefits of sustainable land management is essential. Educational programs and community engagement initiatives should be prioritized to encourage behavioural changes that support environmental sustainability and water quality preservation.

In parallel with these local efforts, continued seasonal monitoring and more extensive research are recommended to track temporal variations in water quality and identify emerging threats promptly. Strengthening wastewater treatment infrastructure and regulating septic tank usage will also play critical roles in safeguarding the district's vital water resources.

Overall, while drinking water in the Lalapaşa district is currently high quality, proactive, integrated, and sustainable management strategies are vital to ensure the long-term protection of the region's water resources in the face of growing agricultural pressures.

This study is derived from the master's thesis of Can Canbaz.

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ZMIANY SEZONOWE I OCENA JAKOŚCI WODY PITNEJ W OKRĘGU LALAPAŞA (EDIRNE/TURCJA) PRZY UŻYCIU NIEKTÓRYCH WSKAŹNIKÓW EKOLOGICZNO-STATYSTYCZNYCH

ABSTRAKT

Cel badania

Wprawdzie wody gruntowe stanowią główne źródło dostępnej wody słodkiej, są one jednak szczególnie podatne na zanieczyszczenia. Uświadomienie sobie ich znaczenia odgrywa kluczową rolę w zapewnieniu czystej i zrównoważonej wody pitnej w skali globalnej. Region Tracji, znany z żyznych gruntów rolnych, stoi w obliczu zagrożeń środowiskowych, ponieważ rolnictwo i hodowla zwierząt stanowią potencjalne ryzyko dla jakości lokalnej wody słodkiej. Celem niniejszego badania była ocena sezonowych zmian jakości wody pitnej w okręgu Lalapaşa w prowincji Edirne w regionie Tracji poprzez analizę szeregu parametrów fizykochemicznych.

Materiały i metody

W sezonach letnim, jesiennym i zimowym w latach 2020–2021 pobrano łącznie 28 próbek wody pitnej z różnych wsi w regionie Lalapaşa. Każda próbka została poddana analizie pod kątem następujących dwunastu parametrów: tlenu rozpuszczonego (DO), nasycenia tlenem (O_2%), pH, przewodnictwa elektrycznego (EC), całkowitej ilości substancji rozpuszczonych (TDS), zawiesin (SS), zasolenia, mętności, azotanów (NO_3^-), azotynów (NO_2^-), fosforanów (PO_4^{3-}) i siarczanów (SO_4^{2-}). Uzyskane dane poddano ocenie w stosunku do krajowych i międzynarodowych norm jakości wody pitnej. Ponadto przeprowadzono ocenę ekologiczną przy użyciu wskaźnika jakości wody (WQI) oraz analizy statystyczne z wykorzystaniem analizy czynnikowej (FA) i wskaźnika korelacji Pearsona (PCI).

Rezultaty i wnioski

Analiza składu chemicznego wykazała trzy główne czynniki – ‘czynnik zasolenia’, ‘czynnik rolniczy’ i ‘czynnik tlenowy’, które łącznie uzasadniły 74% całkowitej wariancji. Pomimo podwyższonego stężenia azotu i fosforu w niektórych próbkach wartości wskaźnika jakości wody (WQI) we wszystkich stacjach pozostały w dopuszczalnych granicach. Wyniki te wskazują na istotną rolę zrównoważonych praktyk rolniczych opartych na uprawie wielogatunkowej w ochronie zasobów wód gruntowych regionu.

Słowa kluczowe: Lalapaşa, jakość wody pitnej, wskaźnik jakości wody, ocena statystyczna