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UNRAVELING THE FACTORS BEHIND WATER QUALITY VARIATIONS IN THE MOUNTAINOUS CORUH RIVER VALLEY, NORTHEASTERN TURKEY

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Abstract: Water pollution within mountainous watersheds is recognized as one of the foremost environmental challenges of our era. Extensive research has confirmed that major causes of this pollution are various human activities in natural areas, such as urban expansion, mining operations, and changes in land use. Similar human-induced impacts can be seen in the Coruh River Basin (CRB) as a result of the building of large dams and roads, mining operations, and urban growth. A thorough investigation is essential to determine the impact of these disturbances on the current surface water quality and to predict the level of water pollution. We chose three sub-watersheds, Murgul Creek Watershed (MCW), Fabrika Creek Watershed (FCW), and Hatila Creek Watershed (HCW), within the CRB to assess the effect of disturbances on surface water quality and forecast the level of water pollution. Since each sub-watershed has different land use types and human impacts on it, we expect a different level of water quality status in the three sub-watersheds. Overall, the results demonstrated that apart from the negative impacts of land use type differences on surface water resources, the human-induced degradation clearly has negative impact on the water quality, particularly for some sampling locations and times. In addition, the results revealed that most of the surface water quality parameters in the HCW (mostly forested land) were significantly better than those in the MCW and FCW (both affected by human-induced degradation). The average ammonium concentration were 1.15 mg/l, 0.15 mg/l, and 0.06 mg/l for Murgul, Fabrika, and Hatila Creeks, while the mean nitrate was 2.51 mg/l, 3, 25 mg/l, and 1.79 mg/l, respectively. Moreover, TDS and conductivity values were also measured significantly higher in Murgul (216 mg/l; 443.89 µS/cm) and Fabrika Creeks (175 mg/l; 205.64 µS/cm) than Hatila Creek (111 mg/l; 133.43 µS/cm). Given the identification of certain water quality parameters surpassing critical threshold values, it becomes evident that mitigating the impacts of anthropogenic factors and enhancing land management practices within the study area are imperative.

Keywords: Water quality, land use, mining, urbanization, anthropogenic

1. Introduction

Water is a crucial component of the ecosystem that supports the sustainability of all living organisms, including humans (Chaplin, 2001; Chang, 2006; Hatami, 2013). Recent literature confirms that the rapid growth of the global human population has led to an escalation in the consumption of goods and services, particularly water resources (Plummer and Baird 2021; Boyd, 2019). Human activities in natural areas and rising living standards have led to a continuous rise in production and consumption, resulting in a significant amount of industrial waste being deposited in environments like lakes and rivers. This has caused a notable increase in water pollution levels in these crucial ecosystems.

Water quality is a multifaceted topic that raises worldwide concerns across various crucial sectors such as agricultural and industrial water supply, fisheries and aquaculture, water-related recreation, and ecosystem health (Boyd, 2019; Schliemann, et al., 2021). Anthropogenic activities such as construction, urbanization, road building, mining, dam construction, agriculture, and livestock farming generate pollution through the disposal of agricultural, industrial, and municipal waste. This waste often ends up in creeks, lakes, and reservoirs (Lobato et al., 2015; Sánchez et al., 2007; Uddin et al., 2021). The reduced availability of clean water seems to be linked to the growing population (Schwartz & Randall, 2003; Hanjra & Qureshi, 2010). Water quality parameters such as dissolved oxygen, ammonium, and nitrate are influenced by various factors and are commonly utilized to assess water quality in watersheds. Consequently, the escalating pollution of surface water resources has necessitated the implementation of water quality monitoring and management research in Turkey and globally (Bartram and Ballance, 1996; Abdel-Dayem, 2011).

European Union countries have implemented the "integrated water resources management" approach to sustainably develop and manage ecosystems. The European Union has implemented the watershed-based management approach through the Water Framework Directive (WFD) to protect and enhance surface water resources in the EU since 2000. In Turkey, there is a regulation known as the Surface Water Quality Regulation (SWQR) that serves similar purposes. Surface waters are defined as all inland waters, transition waters, and coastal waters, excluding groundwater, according to this regulation (Gazete, 2012). The SWQR aims to maintain the current quality and quantity of water bodies, prevent pollution, and ensure suitable water conditions in all water bodies (Yetis and Akyuz, 2021).

The surface water resources in the Coruh River Basin (CRB) in northeastern Turkey are at risk of pollution due to human activities such as building large dams and roads, mining, and urban expansion. To determine how disturbances affected the water quality of certain streams, three sub-watersheds were chosen within the CRW - Murgul Creek Watershed (MCW), Fabrika Creek Watershed (FCW), and Hatila Creek Watershed (HCW). The watershed areas of certain creeks consist of diverse land use types and varying degrees of human influence. MCW has extensive areas designated for open-pit mining since the 1950s, FCW is heavily affected by pollution from the city center, and HCW experiences minimal human disturbances due to its national forest coverage.

This study aimed to assess the present water quality in the primary tributaries of the Murgul, Hatila, and Fabrika Sub-watersheds, analyze water quality parameters in relation to various land use features of the sub-watersheds, and compare parameter results based on water quality standards in Europe and Turkey. This study's results are expected to enhance comprehension of how different land uses impact surface water quality and aid in determining optimal management strategies for the sub-watersheds.

Materials and Methods

Study area

The study focused on the sub-watersheds of Hatila, Fabrika, and Murgul Creeks within the Coruh River Basin (CRB), which is one of Turkey's 25 primary basins. The sub-watershed sizes of Hatila, Fabrika, and Murgul Streams are 233 km², 24 km², and 362 km², respectively (Yıldırım, 2018).

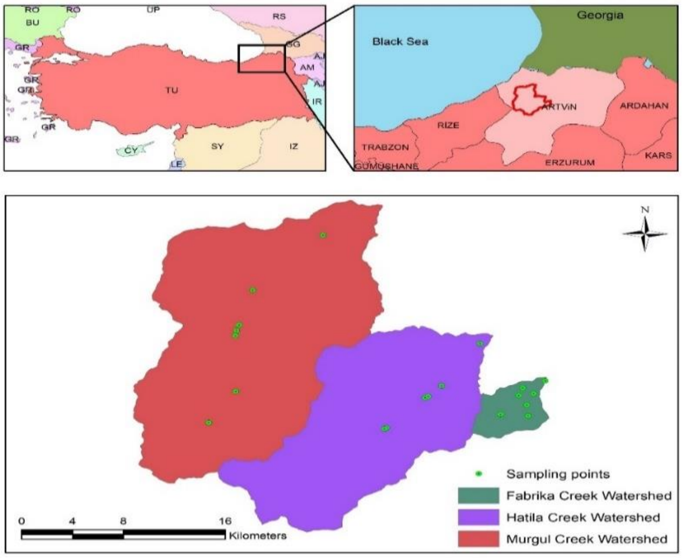

Fig 1. Boundaries and geographical locations of the sub-watersheds of Hatila, Fabrika and Murgul Creeks

The creeks of Hatila, Fabrika, and Murgul originate from peaks measuring 3224 m, 1970 m, and 3371 m, respectively, according to Yıldırımer (2018), before merging with the main branch of the Coruh River downstream. Artvin province's location between the Black Sea coast and East Black Sea Mountains results in varying climates due to elevation differences. The coastal areas experience a Black Sea climate with more than 2000 mm/year of precipitation throughout the year, while the inland areas are influenced by a colder, less rainy, and more terrestrial climate (Mızrak, 1983). MCW, FCW, and HCW comprise distinct land use zones. MCW is a watershed impacted by six run-of-river hydroelectric facilities and mining activities since 1951. FCW is a watershed that encompasses a significant portion of the Artvin City center, characterized by numerous impermeable surfaces and continuous construction activities. Urbanization occupies 6.65% of the watershed, beginning from downstream and reaching up to an altitude of approximately 800 meters. The agricultural area covers 5.14% (Yıldırımer, 2018). HCW comprises in Hatila National Park, which encompasses 70% of the sub-watershed and approximately 38% of it is natural old forests, resulting in minimal human activities. (Turgut, et al., 2021). Fig 2 displays maps of land use (a), elevation (b), and slope (c).

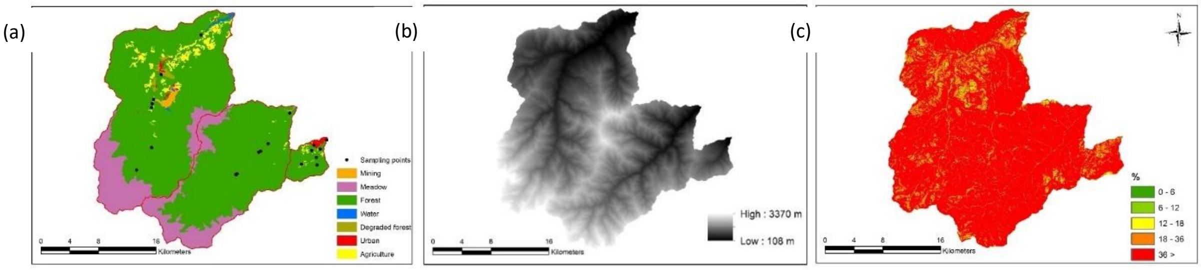

Fig 2. Maps of land use (a), elevation (b) and slope (c)

The sampling locations were selected to assess the influence of various land uses at specific intervals, beginning from high altitudes devoid of human activity and progressing towards the outlets of the three sub-basins.

Table 1. Dominant land use types associated with the surface water sampling locations along the creeks

Sampling Locations	Fabrika Creek	Hatila Creek	Murgul Creek
1st	Forest	Forest	Forest
2nd	Forest	Forest	Forest
3rd	Agriculture	Forest	Mining
4th	Agriculture	Forest	Mining
5th	Agriculture	Forest	Mining
6th	Urban	Forest	Urban
7th	Urban	Forest	Urban

Measurement and Analysis of Water Quality Parameters

Samples were collected in May, August, November (2017), and February (2018) to cover all four seasons. A total of 21 sampling points were used, with 7 samples taken from each creek. The "YSI/Professional-Plus" portable water quality device from Yellow Springs Instrument Company in the USA was utilized in the field to measure various parameters including dissolved oxygen (DO), total dissolved solids (TDS), ammonium (NH_4-N), nitrate (NO_3-N), salinity, conductivity, and temperature. The pH parameter was directly measured at 21 points using a Hach-Lange HQ40D device. Water samples for total suspended solids (TSS) analysis were collected using 1 L amber polyethylene bottles from the end of each creek before it enters Borçka Dam reservoir. Samples were taken to the laboratory and analyzed using the gravimetric method with a vacuum filtration set, following the process described. The formula from Clesceri et al. (1998) was utilized to calculate the concentration of Total Suspended Solids (TSS) in milligrams per liter (mg/l). The water discharge was measured using the portable FLOWATCH 2 JDC device, which was transported to each sampling location. The monthly discharge measurements at the sampling points were determined using the velocity-area method as described by Turnipseed and Sauer in 2010.

Statistical Methods

An ANOVA test was conducted to determine if the data from field and laboratory studies exhibit variations based on sampling time, sampling points, and land use. The Tukey test was employed following the ANOVA test to identify significant variations in sampling time, sampling points, land use, and watershed-based distinctions. Regression analysis demonstrated the relationship between flow and total suspended solids, while correlation analysis identified possible linear relationships among the quality parameters. Statistical analysis of the collected data was conducted using JMP Pro (JMP Version 12.0.1, SAS Institute Inc., Cary, NC, USA) software package.

2. Results and Discussion

Measurements were taken in the creek for the following parameters: pH, dissolved oxygen (DO), total dissolved solids (TDS), ammonium (NH_4-N), nitrate (NO_3-N), salinity, conductivity, temperature, and total suspended solids (TSS) values were analyzed using ANOVA. The results are presented in Table 2. The relevant regression and correlation analysis are shown in Table 4, and the water quality limit values are displayed in Table 3.

Table 2. The limit values for the measured water quality parameters according to the Surface Water Quality Regulation (SWQR) and Water Framework Directive (WFD)

Water quality parameters	Surface Water Quality Regulation (2016) (SWQR)				Water Framework Directive (2000) (EU)
	I.	II.	III.	IV.	
Salinity (ppt)	-	-	-	-	-
Temperature (°C)	≤25	≤25	≤30	>30	12-25
Conductivity (µS/cm)	<400	1000	3000	>3000	400
DO (mg/l)	> 8	6	3	<3	7
TDS (mg/l)	-	-	-	-	-
pH	6.5-8.5	6.5-8.5	6.0-9.0	<6.0 or > 9.0	6.5-8.5
Ammonium (mg/l)	<0,2	1	2	> 2	0.3
Nitrate (mg/l)	<5	10	20	> 20	-

Table 3. Minimum, maximum, and mean values of the water quality parameters measured in the Fabrika, Hatila, and Murgul Creeks

Watersheds	Fabrika			Hatila			Murgul		
Parameters	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Salinity (ppt)	0.05	0.37	0.13	0.04	0.9	0.14	0.02	0.9	0.24
Temperature (°C)	1.1	22.1	10.2	1.1	22.1	10.21	2.8	27	12.25
Conductivity (µS/cm)	65	750	205.64	54	308	133.43	20	1638	443.89

DO (mg/l)	7.45	14.47	11	1.52	13	10.18	6.74	12.13	10.20
TDS (mg/l)	65	495	175	50	215.2	111.35	40.3	877.5	216.40
pH	7.2	8.6	8.06	7.3	8.9	7.96	3.26	9.32	7.32
Ammonium (mg/l)	0.02	0.75	0.15	0.01	0.3	0.06	0.01	1.21	1.15
Nitrate (mg/l)	0.7	12.5	3.25	0.3	5.4	1.79	0.1	8.1	2.51

Table 4. The correlation matrix of water quality parameters for the Fabrika, Hatila, and Murgul Creek Sub-watersheds

	Conductivity	Salinity	TDS	DO	NH4	NO3	Temperature
Salinity	0,5657						
TDS	0,3825	0,3313					
DO	-0,3713	-0,4537	-0,3056				
NH4	0,3801	0,3263	0,5937	-0,1723			
NO3	0,1983	0,2726	0,1929	0,1650	0,1018		
Temperature	0,4138	0,2502	0,3058	-0,7403	0,2157	-0,2975	
pH	-0,3450	-0,3310	-0,5410	0,1500	-0,2367	-0,1533	-0,0269

Salinity

The results of variance analysis showed statistically significant difference in salinity values among FCW, MCW, and HCW based on land use, sampling points, and time. When comparing land uses, the highest salinity was observed in mining and urban areas (Fig 3 / a). Among the sampling points, the highest value was found at M5 and downstream of Fabrika Creek (Fig 3 / b). As for the sampling time, the months with the highest salinity levels were observed in November, August, and May, respectively (Fig. 3/c).

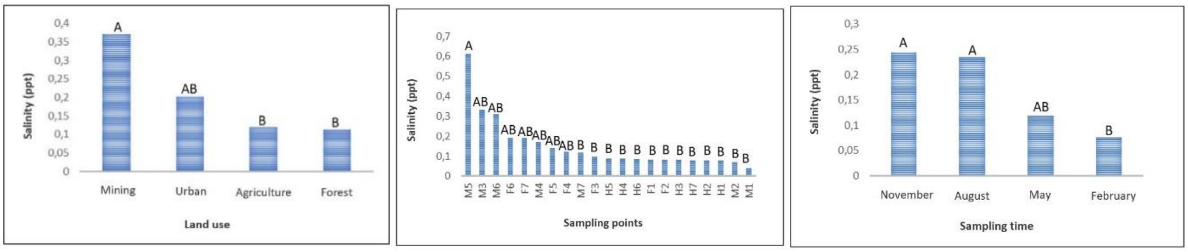

Fig 3. Change of salinity parameters according to land use, sampling points, and time

The high salinity in the urban land use area of the FCW may be attributed to the mixing of waste from domestic and small industrial facilities with water, leading to an increase in salinity in the creek. McGrane (2016) highlighted that urbanization can significantly degrade the chemical quality of urban creeks through both point and non-point source contaminants. The salinity level in natural waters fluctuates based on land use (such as forest, agriculture, settlement, mineral extraction) and geological composition (Ayers and Wescot, 1985). The high salinity in MCW is attributed to an increase in the salinity parameter value caused by water pollution and a decrease in water quality due to mining activities. Zgórska et al. (2016) conducted a study demonstrating that the river with the highest salinity levels is the one most impacted by mine water discharges. The peak values in November and August decrease when snow melts in spring and rain increases the flow of fresh water from creeks and groundwater. In summer, higher temperatures lead to increased evaporation downstream.

In a similar study conducted by Yıldırımer (2019) to determine the water quality in Murgul, Hatila, Fabrika, Godrahav Watershed, and Borçka dam reservoir, the mean salinity values in FCW and MCW were found to be 0.13 and 0.15 ppt, respectively, which is similar to the results of our study. Çiftçi (2015) conducted a study to assess water quality in the Seydisuyu (Eskişehir) Watershed. The study found mean salinity values of 0.28 g/L in autumn, 0.24 ppt in winter, 0.27 ppt in spring, and 0.3 ppt in summer. It is evident from the results that salinity rates in Seydisuyu Watershed remain relatively constant throughout the seasons, whereas statistically significant differences have been observed in the FCW and MCW. Correlation analysis indicates a significant positive relationship between salinity and conductivity ($p < 0.01$).

Temperature

The variance analysis results showed statistically significant differences in temperature values among FCW, MCW, and HCW at different sampling times. The highest temperature was observed in August, as anticipated.

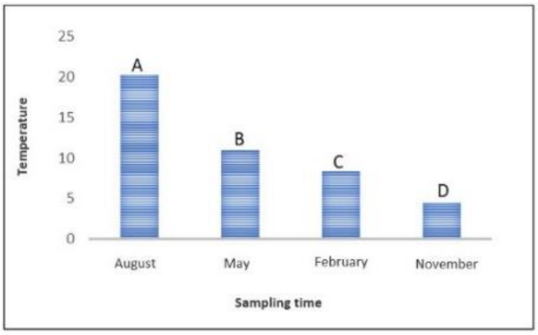

Fig 4. Change of temperature parameters according to sampling time

Referring to the Yıldırımer (2019) study to assess water quality in various locations. The mean temperatures recorded were 9.8, 9.4, and 9.3 for different areas. The findings were similar to our study in terms of FCW, HCW, and MCW. Serdar (2015) conducted a study to assess the seasonal variation of water quality in the Eastern Black Sea Watershed. The study measured the annual temperatures of 11 different creeks downstream: Melet 15.98 °C, Pazarsuyu 16.83 °C, Aksu 16.73 °C, Harşit 14.99 °C, Değirmendere 15.06 °C, Left-handed 14.64 °C, İyidere 14.02 °C, Büyükdere 15.42 °C, Storm 13.95 °C, Çağlayan 15.39 °C, and Capistre 15.50 °C. These values closely align with the findings of our study. Correlation analysis indicates a statistically significant positive relationship between temperature and conductivity ($p < 0.01$), salinity ($p < 0.05$), TDS ($p < 0.01$), and ammonium ($p < 0.05$). A negative correlation ($p < 0.01$) between nitrate and dissolved oxygen (DO) was found.

Conductivity

Results of variance analysis revealed a statistically significant difference in conductivity values among FCW, MCW, and HCW based on land use, watershed, sampling points, and sampling time. The mining site (Fig 5/a) exhibited the highest conductivity as per the land use analysis. The high conductivity is likely due to the substances mixed with the city water, which elevates the concentration of dissolved substances in the water, thereby increasing conductivity. Rusydi (2018) demonstrated the strongest correlation between TDS and conductivity, which aligns with our study. Conductivity was highest in MCW compared to other watersheds in the study (Fig 5/b). The highest salinity values were recorded at sampling points M5, M3, and M4 (Fig 5/c). There is a detrimental effect on the water quality of the mining enterprise due to land use, inter-watershed, and sampling points. The months with high conductivity were identified as August and November based on time (Fig 5/d).

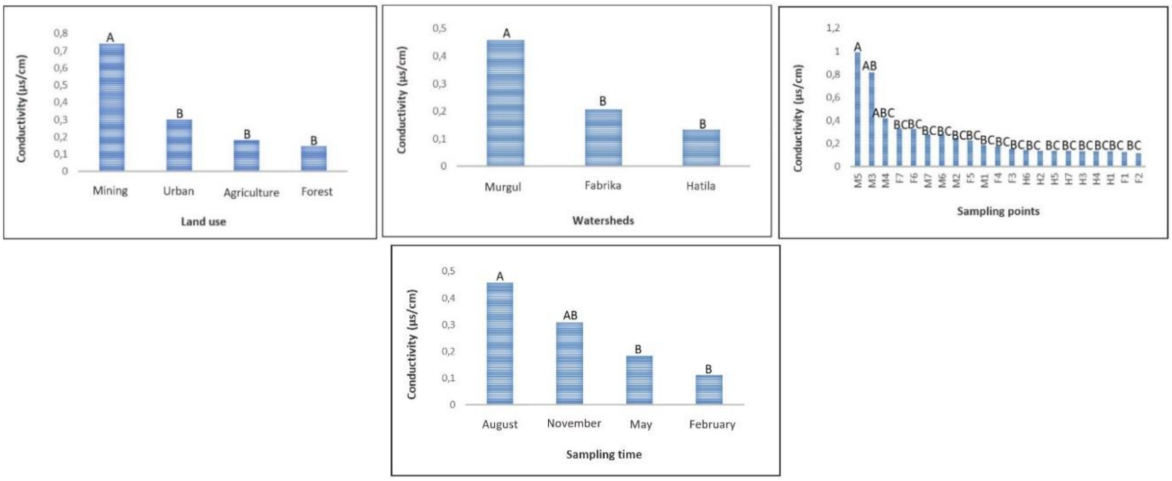

Fig 5. Change of the conductivity parameters according to land use, sub-watersheds, sampling points, and time

Similar studies conducted by Çiftçi (2015) in Seydisuyu Watershed found mean conductivity values of 534 µs/cm at Çatören and 573 µs/cm at Kunduzlar dam lakes in the Seydisuyu Watershed. Turan and Ülkü (2013) reported conductivity values ranging from 663 to 3313 µs/cm in Gökpınar and Çürüksu streams. Tunca et al. (2012) measured a conductivity value of 439 µs/cm in Yeniçağa Lake, while Elmaci et al. (2010) recorded a value of 555.75 µs/cm in Uluabat Lake. The parameters obtained from these studies closely matched the maximum and average parameters found in FCW and MCW of the present study.

Dissolved Oxygen (DO)

The results of variance analysis revealed a statistically significant difference in DO values among FCW, MCW, and HCW based on sampling time. The highest DO values were observed in February and November (Fig. 6). The seasonal variation observed can be attributed to the relationship between DO levels, pressure, and temperature as explained by Rounds et al. (2013).

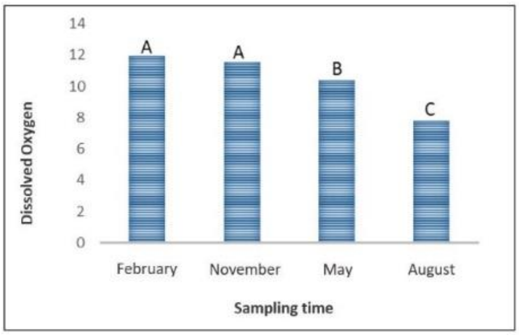

Fig 6. Change of DO values according to sampling times

In other similar studies, Zhang et al. (2021) studied water quality in the Taihu Lake Watershed in China and found mean DO values of 6.76 mg/l between dry and wet seasons. Serdar (2015) examined seasonal variations in water quality in the Eastern Black Sea Watershed, reporting annual DO levels between 7.8 and 11.44 mg/l from 11 different streams. Yıldırım (2015) investigated water quality in Karmuç Creek, finding DO values ranging from 7.02 to 9.77 mg/l. Our study's mean DO value aligns closely with these findings. Another study in Mediterranean reservoirs by Fadel et al. (2021) demonstrated water quality indexes, with a mean dissolved oxygen (DO) value of

6.12 mg/l. Correlation analysis indicates that Dissolved Oxygen (DO) is negatively correlated with conductivity, salinity, and Total Dissolved Solids (TDS) at a significance level of $p < 0.01$.

Total Dissolved Solids (TDS)

Analysis of variance showed a significant difference in TDS values across various land uses, watersheds, sampling points, and sampling times. Figure 7a displays the highest TDS levels in mining, urban, and agriculture areas. The values were the highest within Murgul Creek, as shown in Figure 7b. The peak sampling point value was identified at point M5 (Fig. 7/c), with peak values recorded in August, November, and May according to the sampling time (Fig. 7/d).

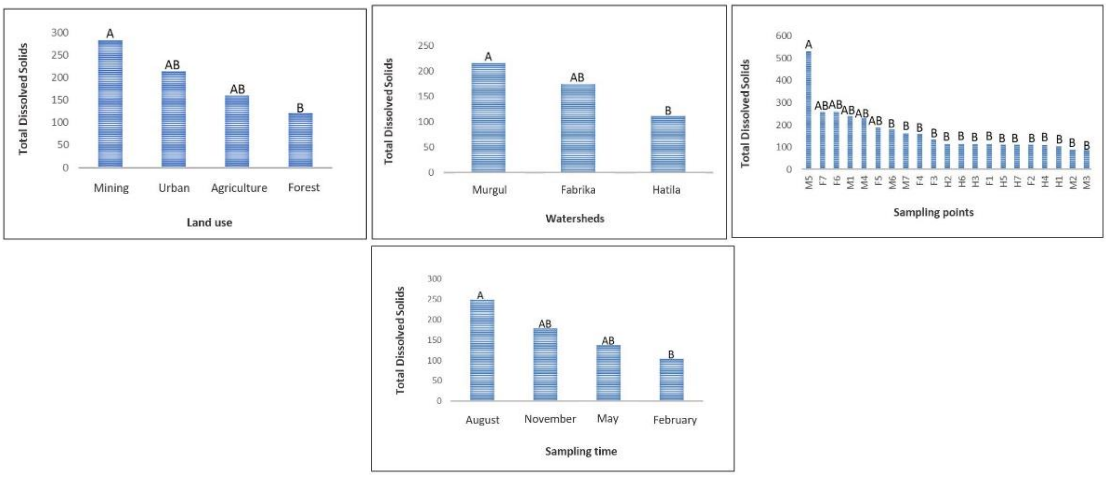

Fig 7. Change of TOD values according to land uses, sub-watersheds, sampling points and time

No limit values have been established for TDS within both the Surface Water Quality Regulations (SWQR) and Water Framework Directive (WFD). Belitz (2004) found that the TDS concentration in streams in mountainous areas was 200 mg/l. The maximum and mean TDS values found in this study exceeded that limit value. The highest TDS rate observed in the mining area can be attributed to the elevated TDS values resulting from mining activities, as well as the combination of domestic wastes and water from agricultural areas and lands, which may contribute to the TDS concentration. The peak values were recorded in August and November, as shown in Figure 24. The seasonal variation is due to the rise in dissolved organic and inorganic substances in the water during high temperatures. Yıldırımer (2019) measured the mean Total Dissolved Solids (TDS) values in the Borcka Dam watershed as 177 mg/l in FCW and 209 mg/l in MCW to assess water and sediment quality, which closely aligns with our results. TDS values ranged from 21-319 mg/L in rivers in Trabzon province in a study by Gültekin et al. (2012). Another study by Turan and Ülkü (2013) found TDS concentrations between 305-1682 mg/L in Gökpınar and Çürüksu to assess water quality. Our study observed that the TDS values were significantly high. This is due to the impact of mining and urbanization on water quality. TDS is positively correlated with conductivity and salinity based on the correlation analysis ($p < 0.01$).

pH

The results of variance analysis revealed a statistically significant difference for pH values in the creeks based on land use, sub-watersheds, sampling points, and sampling time (Fig. 8). As might be predicted, the mining area had the lowest pH level while the agricultural parts had the highest. Furthermore, the MCW has the lowest mean pH level of all the watersheds, primarily as a result of acid mine drainage from the Murgul Copper Plant, which is now operating inside this watershed. Therefore, both the land use and sampling points in the mining area show the lowest pH values, indicating acidity issues for the creek waters. The sampling point with the highest pH value was F6 point (Fig. 8 / c) while as for the sampling time, the highest pH values were recorded in February (Fig. 8 / d).

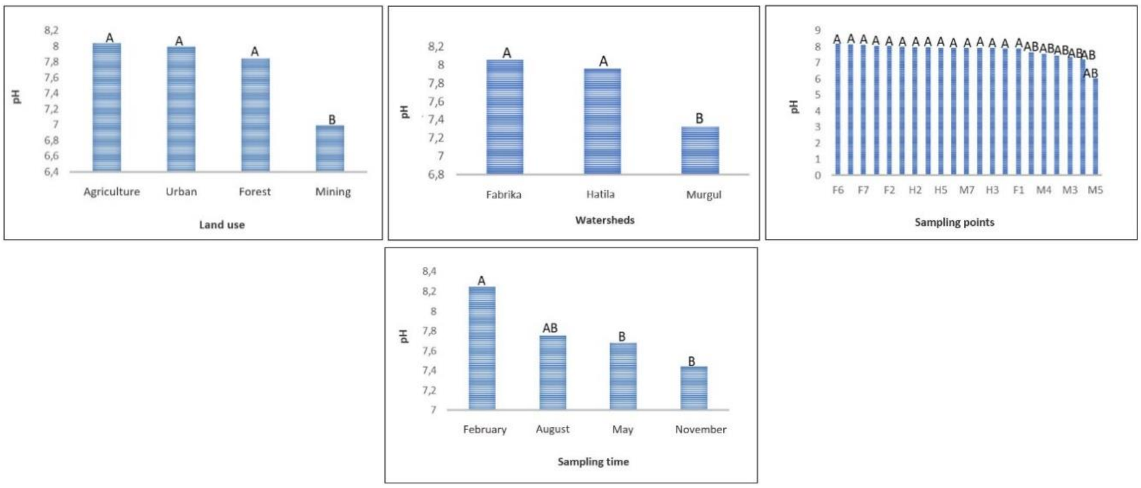

Fig 8. Change of pH values according to land use, sub-watersheds, sampling points, and time

In similar studies, Zeybek and Kalyoncu (2016) found mean pH values ranging from 7.87 to 8.26 in Kargı Stream in Antalya. Taş and Çetin (2011) reported mean pH values between 6 and 6.31 in Gökgöl. Akçay et al. (2003) determined pH values between 7.9-8.2 and 8-8.3 in water samples from Gediz and Büyük Menderes rivers, respectively. In comparison to other studies, the average pH values of FCW and HCW closely align with those found in the literature while the average values of MCW similarly align with the literature, though the minimum values notably below the parameters established in existing literature.

Ammonium (NH_4-N)

The results of variance analysis revealed a statistically significant difference in ammonium values among FCW, MCW, and HCW based on land use, sampling points, and sampling time. Ammonium levels were highest in areas with mining, urban, and agricultural land use (Fig. 9 / a). The highest levels were found at sampling points M5, F7, and F6 (Fig. 9 / b) and the peak values for ammonium were recorded in May, August, and November (Fig. 9 / c).

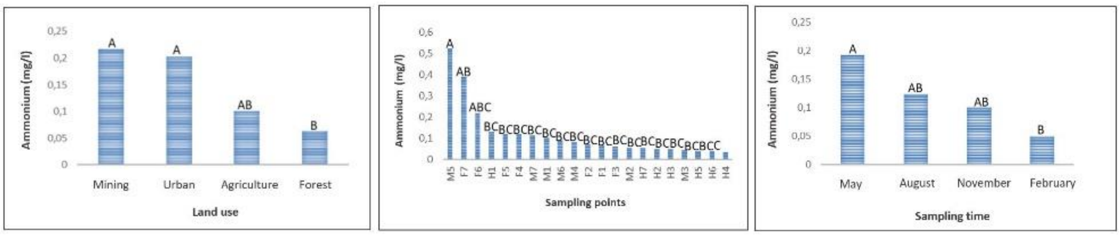

Fig 9. Change of Ammonium values according to land use, sampling points, and time

In terms of sampling points, the highest concentration of ammonium was detected at M5 due to the convergence of water from the mining facility and the main creek, resulting in an excess of ammonium in the water. The highest level of ammonium at the F7 point, where the last sample in FCW was taken, is due to the convergence of water from urban and agricultural areas at the final sampling location of the river. Yıldırımer (2019) measured values to assess water and sediment quality in the Borcka Dam watershed. The mean ammonium levels were 0.23 mg/l in FCW and 0.11 mg/l in MCW. Our study found similar results in FCW, but higher ammonium levels in MCW. Ammonium concentrations in Gökgöl, as reported by Taş and Çetin (2011), ranged from 0.22 to 1.2 mg/L in previous research. Elmaci et al. (2010) reported a concentration of 0.56 mg/L in Uluabat Lake, while Akçay et al. (2003) found a range of 0.05-0.55 mg/L for NH3+ (ammonia) in Büyük Menderes River, which closely aligns with our study results. Correlation analysis indicates that there is a significant positive relationship between ammonium and conductivity, salinity, and TDS ($p < 0.01$).

Nitrate (NO_3-N)

Statistically significant differences in nitrate values were observed among the FCW, MCW, and HCW sub-watersheds based on various sampling times, as confirmed by the variance analysis findings. The highest values of nitrate between watersheds were observed in FCW and MCW (Fig. 10 / a) and the highest values according to sampling time were observed in November (Fig. 10 / b). Agricultural areas are recognized as the main origin of nitrates in the FCW and MCW land use. Excessive nitrate in these watersheds is thought to be caused by agricultural pollution. Agriculture in the upper regions of the MCW and FCW creeks is mainly a combination of water from agricultural areas. The surplus of nitrate could have resulted from the precipitation transporting it to the impacted regions.

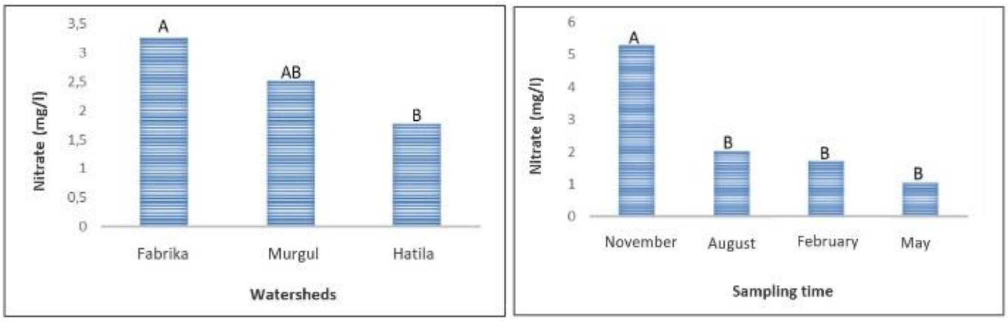

Fig 10. Change of nitrate parameters according to sub-watersheds, and sampling times

In a similar study, Serdar (2015) conducted a study in the Eastern Black Sea region, finding NO3-N values ranging from 0.094 to 2.396 mg/l. Kibena et al. (2013) also conducted a study, reporting nitrate levels between 0.020 and 1.890 mg/l during precipitation and between 0.006 and 2.870 mg/l during the dry period. In addition, Lalchhingpuii et al. (2011) conducted research in the Tlawng River in India and found that the nitrate levels ranged from 0.02-0.32 mg/l. Our study revealed that the nitrate levels in FCW were higher than these values, while the levels in MCW were similar to them. Nitrate and salinity are positively correlated ($p < 0.05$) based on the analysis.

Total Suspended Solids (TSS)

Table 5 presents the regression analysis of the relationship between TSS and water discharge in the Hatila, Fabrika, and Murgul creeks within their sub-watersheds.

Table 5. The Coefficient of Detection (R^2) explaining the relationship between TSS and water discharge in sub- watersheds

Watersheds	R^2	%
MCW	0,031008	3.1
FCW	0,504532	50.5
HCW	0,847284	85

Table 5 indicates the percentage of the variance for the linear regression between the TSS and water discharge values in sub- watersheds with the help of the Coefficient of Detection (R^2). As seen from Table 5, the lowest relation ratio (0.031) between the TSS and water discharge was detected for the MCW. On the other hand, while the highest relation was found for the HCW with 0.847, it was in between with 0,504 for the FCW. The main reason for detecting almost no linear relation between the TSS and water discharge for the MCW can be mostly associated with two major human interferences along Murgul Creek. One of them is the fact that the local hydraulic state officials have been building water retaining walls along both sides of the creek for flood control and the other one was the construction of several run-of-river hydropower plants within the MCW. Both human-caused disturbances have been causing disruption for the natural connectivity between hillsides and the creek, resulting in unnatural and unpredicted water flow and consequently the sediment flow and distribution. As for the FCW, somewhat similar reasons (except hydropower plants) have taken effect along with the watershed consisting of urban and agricultural land uses, keeping the relation relatively low. On the other hand, the HCW, having mostly forested national park and almost no human disturbances, resulted in the highest R² between the TSS and water discharge, as expected. The regression analysis in this study confirms the findings of the previous literature regarding the relationship between water discharge and TSS. Vaughan (2016) discovered that land use in watersheds, specifically agriculture and forest land use, played a crucial role in determining the TSS-water discharge. In addition, a study by Chen and Chang (2014) found that urban land use has the highest levels of Total Suspended Solids (TSS).

Water quality parameters according to the standards set by SWQR and WFD

The final chapter of the data processed by the YSI device according to SWQR and WFD does not include the limit values for salinity and TDS parameters. The average values of temperature, dissolved oxygen (DO), pH, ammonium, and nitrate parameters were presented in Table 6 for comparison with the specified limits of both the Water Quality Directive (SWQR) and Water Framework Directive (WFD).

Table 6. Comparison of water quality parameters according to SWQR and WFD limit values

Water Quality Parameters	Surface Water Quality Regulation (2016) (SWQR)			Water Framework Directive (2000) (EU)		
	Fabrika	Hatila	Murgul	Fabrika	Hatila	Murgul
Salinity (ppt)	+	+	+	+	+	+
Conductivity (µS/cm)	+	+	-	+	+	-
DO (mg/l)	+	+	+	-	-	-
pH	+	+	+	+	+	+
Ammonium (mg/l)	-	+	-	-	+	-
Nitrate (mg/l)	+	+	+	No value		

* "+" symbol stated here indicates that the limit values are below the specified limit values.
** "-" symbol stated here indicates that the limit values are above the specified limit values.

Table 6 displays that conductivity and ammonium levels in MCW, associated with mining activities, exceeded the limit values set by both SWQR and WFD. Meanwhile, DO levels surpassed the limit values set by WFD only. In FCW, linked mainly to urban and agricultural land use, different results were observed. The ammonium concentration exceeded the limit values set by SWQR and WFD, whereas the DO levels only surpassed the limit values established by WFD.

3. Conclusions

Our findings provide a comprehensive assessment of the current water quality status in the creeks flowing within the Fabrika, Hatila, and Murgul sub-watersheds. Surface waters were meticulously compared across these sub-watersheds, revealing stark differences in land-use patterns and the array of human-induced disturbances affecting each area. The Fabrika Creek Watershed (FCW) is characterized by dense urban and agricultural activities, particularly in its lower reaches, while the Murgul Creek Watershed (MCW) grapples with the enduring impacts of extensive mining operations, urban expansion, and agriculture. In contrast, the majority of the Hatila Creek Watershed (HCW) is enveloped by a national park, predominantly comprised of forested land.

Urgent actions are needed to tackle water pollution in these creeks, following suggestions from Wikurendra et al. (2022) on improving waste management in urban areas, and from Kumar et al. (2022) on adopting sustainable pollution control methods in mining operations. While it may not be possible to completely eliminate pollution in mining-affected regions, it is crucial to focus carefully on waste storage, disposal, and drainage to reduce its negative impacts.

Our research enhances the comprehension of mining and urban area administration in the study regions and is also applicable to similar environments. Continuous monitoring of water quality is crucial due to the initiation of underground mining activities in the untouched old-growth forest regions, especially in the upper parts of the HCW (Cerattepe area). This study provides a fundamental reference for upcoming evaluations and actions designed to maintain water quality in the face of changing environmental conditions.

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DECLARATIONS

All authors declare that there are no financial or non-financial conflicts of interest in this manuscript.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are openly available upon request.

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