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The impacts of human-induced disturbances on spatial and temporal stream water quality variations in mountainous terrain: A case study of Borcka Dam Watershed

Mehmet Özalp [a,*], Saim Yildirimer [b], Esin Erdoğan Yüksel [c]

[a] Dept. of Forest Engineering, Faculty of Forestry, Artvin Coruh University, Artvin, Turkey
[b] Karabuk University, Department of Forest Engineering, Karabuk, Turkey
[c] Bursa Technical University, Department of Forest Engineering, Bursa, Turkey

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ABSTRACT

Unaltered watersheds with natural vegetation cover (forest, grasslands, etc.) provide several ecological benefits in addition to providing freshwater, controlling water levels, and supporting flourishing streamside ecosystems. However, as in many watersheds in the World, the research area in this study, the Borcka Dam Watershed (BDW), has been affected by many human-induced disturbances affecting a wide area of forest and grassland areas as well as soil and water resources. Therefore, the objective of this study was to assess and evaluate the possible effects of anthropogenic disturbances, particularly on annual changes in water discharge, some water quality parameters, and total suspended sediment (TSS) amounts in the main streams of four sub-watersheds (Fabrika, Godrahav, Hatila, and Murgul) and the reservoir of the dam. In addition, we intend to confirm that land use change and/or transformation play a significant role in influencing stream water quality. The YSI/Professional-Plus, a portable water quality measurement device, was used to determine the amounts of pH, dissolved oxygen (DO), total dissolved substance (TDS), ammonium (NH_4–N), nitrate (NO_3–N), salinity, electrical conductivity (EC), and temperature besides measuring discharge and total suspended sediments (TSS) from a total of 27 sampling points in the field. Although the results revealed that the annual mean values of all water quality parameters for all four streams were mostly in good condition, for some time and points of the measurements, several parameters were found to be above the official water quality standards due to the intensive aforementioned anthropogenic activities, particularly in the stream waters of Murgul (e.g. pH and TSS being 10,84 and 236 mg/L, respectively) and Fabrika (e.g. EC of 412 μs/cm; DO of 4.44 mg/L; 14 ml of NO_3–N) sub-watersheds. These outcomes indicate that these two sub-watersheds have been impacted more severely by the human-induced disturbances compared to Hatila and Godrahav sub-watersheds.

1. Introduction

Watersheds play crucial roles in the hydrological cycle as they produce clean freshwater resources and also distribute them to the areas needed for domestic use (e.g., drinking water and daily usage, irrigation, energy generation, and healthy ecosystems [1–3]). In

* Corresponding author.
E-mail addresses: mozalp@artvin.edu.tr (M. Özalp), saimyildirimer@karabuk.edu.tr (S. Yildirimer), esin.yuksel@btu.edu.tr (E. Erdoğan Yüksel).

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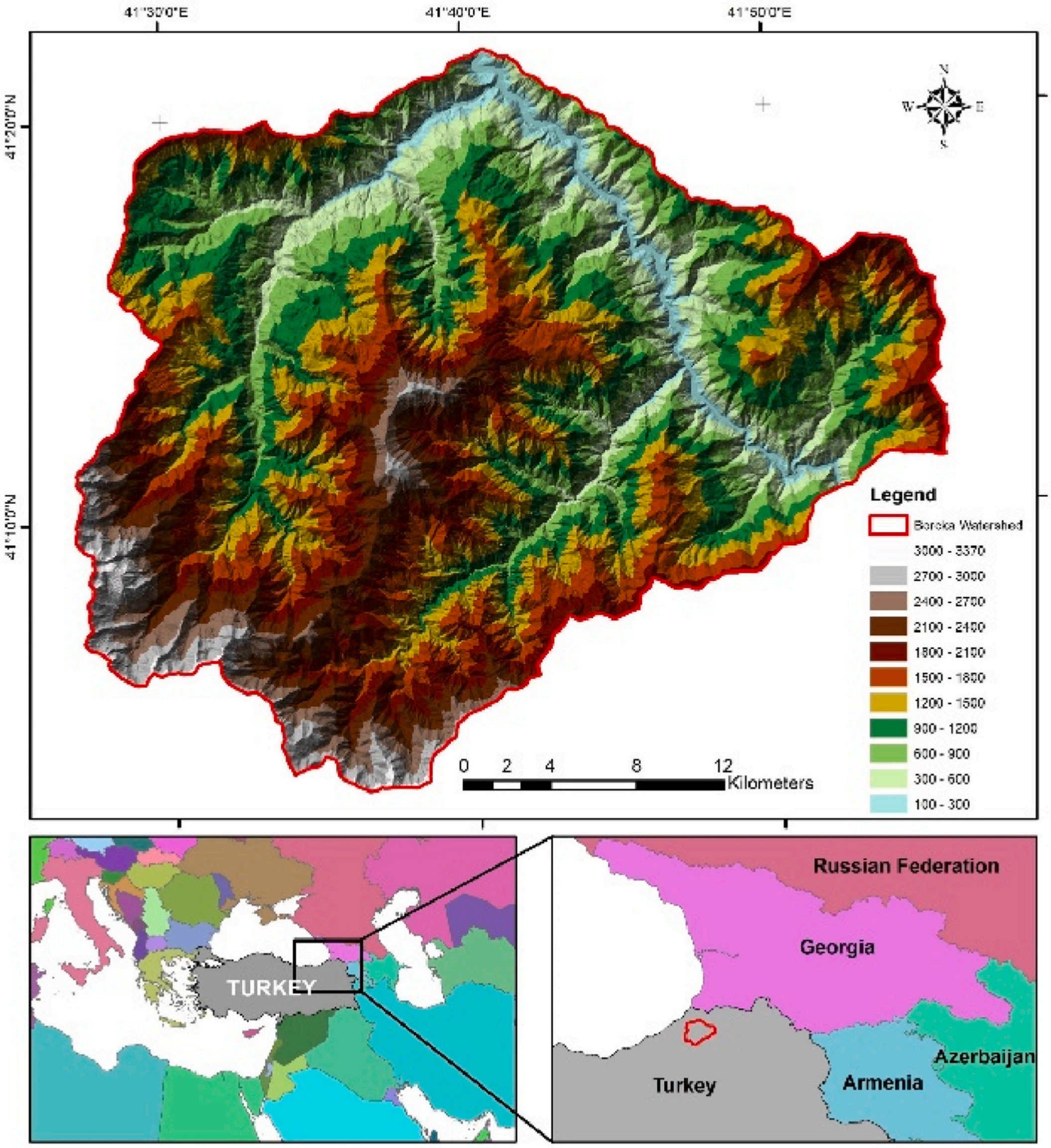

Fig. 1. The location, geographical coordinates, and elevation distribution map of the study area.

this respect, especially mountainous watersheds with some type of vegetation cover (e.g., dense forests, woodlands, grasslands, meadows) are particularly important as they -along with soil-act as natural filters to transform precipitation water into clean fresh water. According to Bakker [4], the importance and value of mountainous forested watersheds will be in the trend of a significant rise in the near future since recent reports showed that the freshwater resources in the World are continuously lacking. Therefore, the management of watersheds, most importantly the decisions on changing and/or narrowing natural land use, especially in the middle/upper part of the watershed may cause important outcomes; not only for water resources but also for people, the economy, and the environment in distant locations (e.g., lower sections or deltas) [5].

In undisturbed nature, the main factor determining the quality of stream water is closely related to the dissolution of rocks, the amount of precipitation, and the type and density of vegetation within the watershed area [6]. Therefore, it is extremely important to protect the natural structure of watersheds -especially concerning their vegetation cover and natural land use-to preserve and sustain their function of producing clean water. However, in recent years, a large number of human-induced interventions interrupting this important yet fragile function of watersheds, which, in turn, may adversely affect both the quality and quantity of freshwater resources such as lakes and streams [1]. It is known that both anthropogenic disturbances (land use change, urbanization, agricultural activities) [7–11] and natural processes (varying precipitation patterns, weathering, and erosion) in watersheds stand as fundamentally important for the water quality of streams. For example, Camara et al. [12] reported that about 87% and 82% of the studies completed

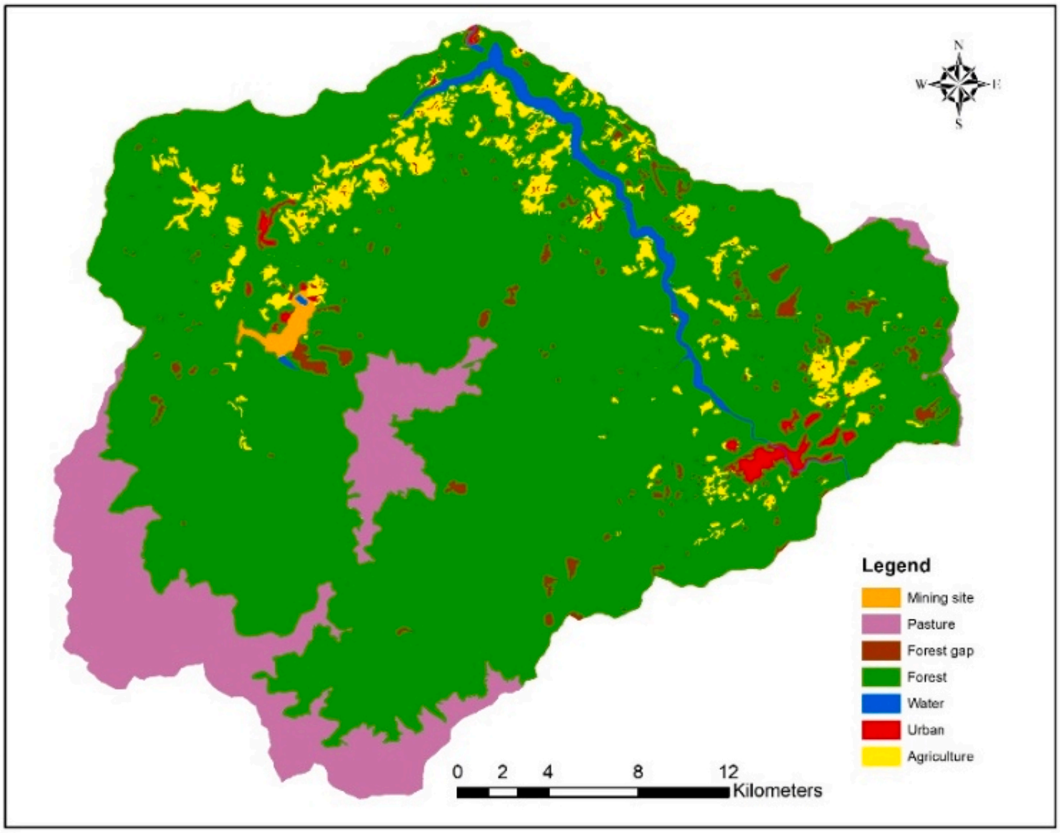

Fig. 2. The land use map of the Borcka Dam Reservoir Watershed (BDRW).

in Malaysia between 2015 and 2017 pointed out urban land use and agricultural activities, respectively, as the main factors in lowering the water quality in the country. Thus, when human-induced interferences reinforce their impact on watersheds, they may lower the quality of surface water and accordingly impair their use for drinking, industrial, agricultural, recreation, or other purposes [13–15]. As the 2018 World Water Development Report [5] indicated, many watersheds around the World, have been increasingly affected by deforestation, land use change, intensive agriculture, mining, population growth, and climate change.

Since the late 1990s, a substantial part of the Coruh River Watershed (CRW) has also been facing various human interventions including; (a) building several large dams on the main branch of Coruh River, (b) conversion of forest areas into settlements, and agriculture, (c) construction of new access roads, (d) mining operations and (e) allowing dozens of run-of-river hydroelectric power plants (RoR-HEPPs) on streams [16–18]. In this regard, it is vital to determine how these negative disturbances have influenced the quantity and quality of surface waters (especially streams). The primarily steep and mountainous watershed area feeding the reservoir of the Borcka Dam, which has been constructed and operational since 2007, was chosen as the research area for this purpose. Furthermore, in studies aimed at determining stream water quality/quantity, both spatial and temporal variations are typically taken into account because the water quality of a stream varies depending on location and time. While most water quality parameters may change spatially depending on incoming tributaries, longitudinal changes in the watershed, land use/change, certain soil properties, and geology, temporal fluctuations in streams are heavily reliant on seasonal shifts in watersheds (e.g., changes in precipitation, hydrological pathways, and runoff) [15,19].

For the rational and efficient use of surface water resources generated by the mountainous watersheds of the study area, it is crucial to detect the current condition and/or changes (both geographical and temporal) of streams based on scientific data. As a consequence, the primary objective of this study was to determine and evaluate how the anthropogenic interventions described above affect the quantity, flow, and quality of stream water, as well as the amount of transported sediment. In addition, because the watersheds of the study area differ in land use type/cover, we intended to confirm that land use change and/or transformation play a significant role in influencing stream water quality.

2. Materials and methods

2.1. Study area

Borcka Dam Reservoir Watershed (BDRW) is located in the Eastern Black Sea Region of Turkey between 41° 03′ 00″-41° 21′ 10″

Table 1
Land use distributions of the study area classified according to satellite imagery.

Land use	MSC		HSC		FSC		GSC	
	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
Forest	27398.4	75.6	18477.9	79.2	2109.74	86.71	4480.89	84.38
Forest gap	562.6	1.6	149.7	0.6	36.22	1.49	153.75	2.9
Pasture	5996.2	16.6	4674.1	20	0	0	194.5	3.66
Urban	194.2	0.5	0.3	0	161.69	6.65	93.92	1.77
Agriculture	1586.9	4.4	30.5	0.1	124.99	5.14	387.07	7.29
Mining site	324.5	0.9	0	0	0	0	0	0
Water	160.9	0.4	7.4	0	0.36	0.01	0	0
Total	36223.8	100	23339.9	100	2433.01	100	5310.12	100

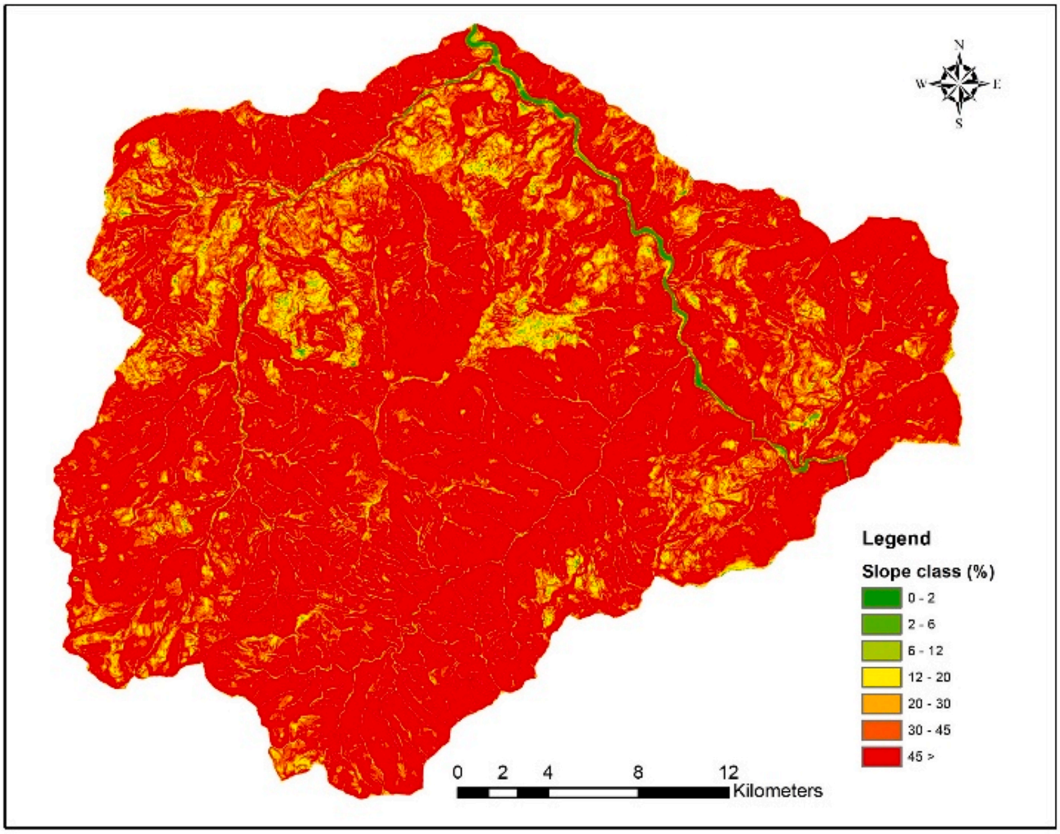

Fig. 3. The map showing the slope classes within the BDRW.

Northern Latitudes and 41° 26′ 57″-41° 55′ 26″ Eastern Longitudes in the Lower Coruh Watershed (Fig. 1). The total area of the watershed is 86.5 km^2 and it extends in the North-Southwestern direction, covering the districts of Borcka, Murgul, and central counties of the city of Artvin. The topographic structure of the study area can be described as quite steep, mostly caused by the radical elevation changes ranging between 100 m and 3370 m. Since Artvin Province is situated between the Eastern Black Sea and Eastern Anatolia, its climatic characteristics are transitional. According to the Koppen-Geiger climate classification, the Cfa and Cfb sub-climate types correspond to the wet Black Sea climate region and are distributed throughout the Black Sea belt, including the Coruh River Valley, where the four selected catchments are located. Artvin's annual average temperature is 12.48 °C, according to the province's meteorological data archive from 1989 to 2018. Moreover, from the same data, the annual average precipitation is estimated to be 670.5 mm. August has the lowest average annual precipitation with 27.1 mm, while January has the highest average annual precipitation (mostly snow) with 87.62 mm [20].

Artvin is located in the North Anatolian Orogenic Belt. Basalt, rhyodacite, andesite, and granite bedrocks in the study area belong to the eruptive (volcanic) bedrock group, and claystone and limestone belong to the sedimentary (sediment) bedrock group. A total of 70.91% of the area is forestland (14.49% National Park), 19.31% is pastureland, and 7.71% is agricultural land within BDRW (Fig. 2, Table 1).

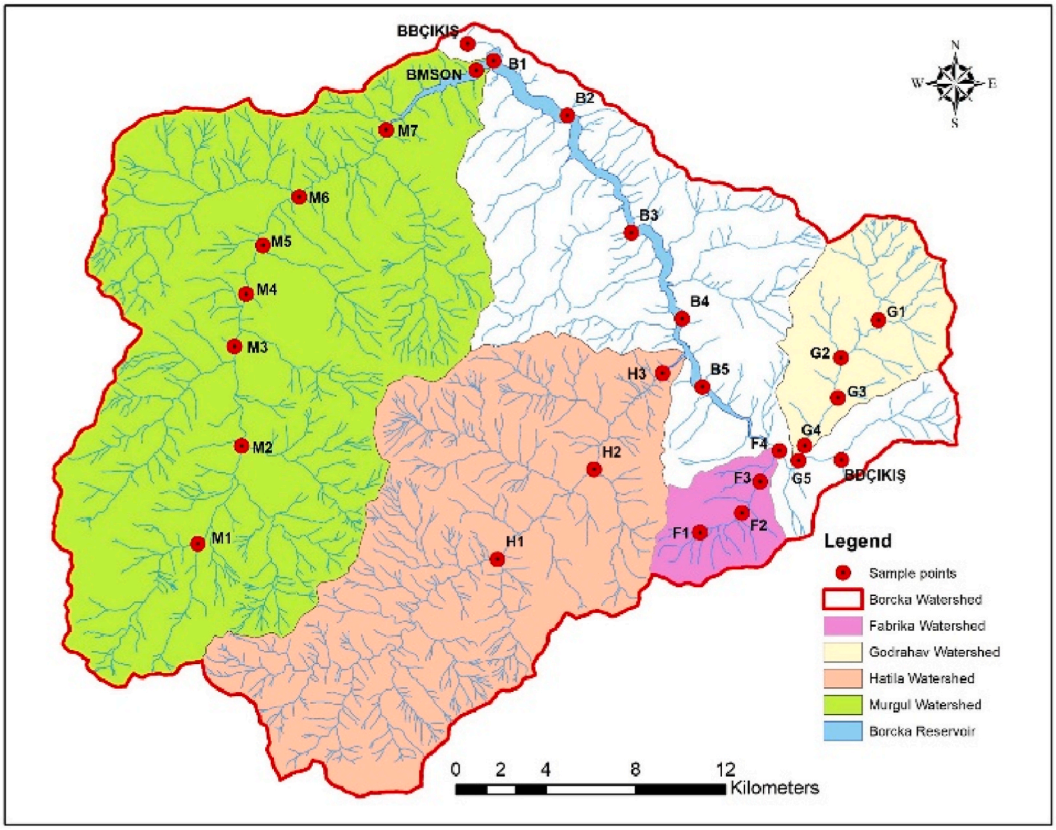

Fig. 4. The locations and distributions of all 27 sampling points in each of the four catchments of Fabrika, Godrahav, Hatila, and Murgul Streams.

It is well-known fact that the slope as a topographic feature is a factor having a great impact in terms of hydrology and water erosion of a watershed. A slope map of the study area was created using GIS according to the Soil Classification System [21] (Fig. 3). As seen in Fig. 3, when the BDRW is examined in terms of the land classification system [22] regarding its slope status, it was detected that the majority of the watershed (94.91% of the area) had a slope of 20% and above, while only 5.09% of the entire research area has a slope of 20% or less (Fig. 3), a clear indication that a very steep land structure is dominant in the study area.

BDRW consists of four catchments (sub-watersheds) named Fabrika, Godrahav, Hatila, and Murgul Stream Catchments, all of which vary in size and have different land use and/or cover (Table 1). For example, Fabrika Stream Catchment (FSC) consists of a large portion of Artvin's city center, thus; many settlement areas and some agricultural lands are common in this catchment. On the other hand, compared to FSC, in Godrahav Stream Catchment (GSC), there are more agricultural areas, but some rural settlements as well as an industrial zone close to its river mouth (outlet of the catchment).

Out of all four catchments, the watershed area of Murgul Stream Catchment (MSC) has the most variations with respect to land use types as well as human disturbances considered as potential causes for pollution of water resources. Besides large settlement areas, mining facilities, and some agricultural activities, there are six Run-of-River Hydroelectric Power Plants (RoR-HEPPs) established -one after the other-on Murgul Stream. Lastly, there is a protected national park with mostly dense forests constituting a very large part of Hatila Stream Catchment (HSC), where we expect limited pollution compared to other catchments.

Therefore, all the catchments, except HSC, suffer from the impacts caused by some degree of various human-induced disturbances, affecting land use and consequently the quantity and quality of water in the streams.

2.2. Determining sampling points

A total of 27 sampling points were identified along the streams of four catchments and on the surface of the reservoir to both determine and monitor the water quality, water amount, and suspended sediment data of BDRW (Fig. 4). Representing the entire watershed and not causing unnecessary loss of time and labor were the most important factors in the selection of sampling points [23].

2.3. Collecting water samples

Monthly measurements (once per month) were taken at 27 sample stations in the streams of the four catchments and in the reservoir of the Borcka dam between March 2018 and February 2019 to measure and/or calculate certain water quality parameters, as

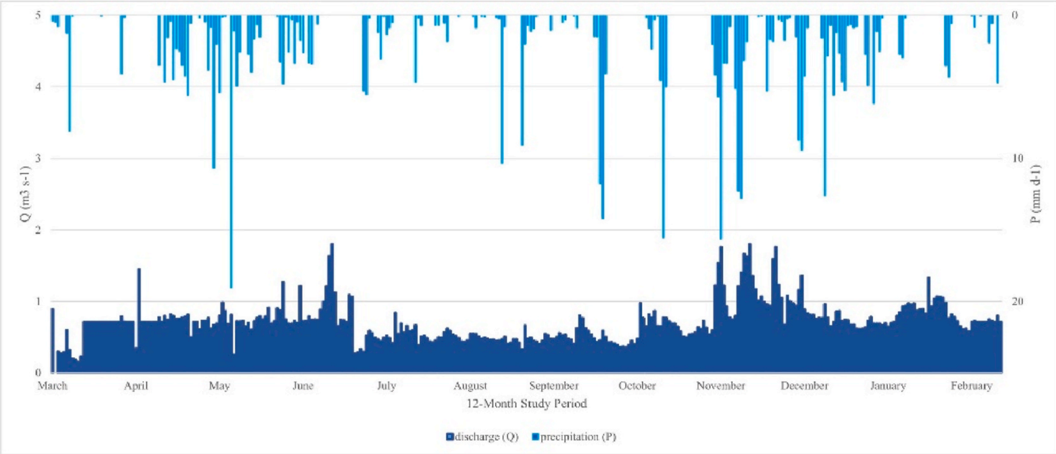

Fig. 5. The relationship between the precipitation within the Borcka Watershed and its effect on the average discharge level of all the streams combined.

well as discharge rates and sediment yields. To collect the samples, 1-L amber-color polyethylene containers were used to grab water samples for the measurements of TSS. The container was filled at least 20–30 cm below the water surface after was rinsed at least twice in the process of taking water samples from both the streams and the dam reservoir. The samples were kept in a cold transport bag with ice to keep the biochemical reactions at minimum levels and not exposed to sunlight in hot weather during the transfer process until placed in a refrigerator in the laboratory.

2.4. Measuring water quality parameters

While the pH values were determined at the measuring points with Hach-Lange HQ40D measuring device, monthly measurements for the parameters of dissolved oxygen (DO), total dissolved substance (TDS), ammonium (NH_4–N), nitrate (NO_3–N), salinity, electrical conductivity (EC), and temperature were made in the field using the YSI/Professional-Plus multi-parameter, a portable water quality measurement device calibrated before each sampling day. Recently, such devices' use in water quality research has been rising [24–29] with the development of the technology advancing in producing more accurate sensors for measurements of water quality parameters.

2.5. Measuring discharge and its relationship with the precipitation

Fig. 5 depicts the link between the average precipitation in the study area and the discharge of all streams during a 12-month period. The water flow (discharge) was computed using the relationships between the speed of water flow (m/s) recorded by the portable "FLOWATCH 2 JDC" brand equipment and the area (m^2) of the stream bed for each unit area at all measurement stations of the catchments' streams. The precipitation data were collected from both the regional weather stations in Artvin (which provide climatological data to the Turkish State Meteorological Service) and the four automated pluviographs (funded by the Turkish Scientific and Technological Research Council - TUBITAK) installed at various points throughout the project area.

2.6. Determination of suspended solids

The filtration method mentioned in the "Standard Method for Examination of Water and Wastewater" published by the American Public Health Association (APHA) was used to determine the amount of total suspended sediments (TSS) in the streams [30]. The water samples were brought to constant weight with the Suspended Solid Vacuum Filtration Device (six sets) and were then filtered by using 47-mm diameter Whatman-brand glass wool fiber filters with a pore diameter of 0.8 μm. After the filtering process, the filters were dried at 105 °C in an oven for 1 h, taken to a desiccator, brought to room temperature, and weighed with a Radwag-brand scale with an accuracy of 0.0001 g precision. The amount of TSS after filtering and drying processes was calculated as mg/L according to the below Eq. (1) given in the section "2540 D. Total Suspended Solids Dried at 103–105 °C" within the Standard Method for Examination of Water and Wastewater [30]:

$$TSS = \frac{(\mathrm{A} - \mathrm{B})\ \mathrm{x}\ 100}{\mathrm{Sample\ Volume\ (mL)}} \tag{1}$$

where; A = weight of filter paper + dry residue (mg), B = weight of filter paper (mg), V = known sample volume (ml).

To create various maps of the study area (e.g., land use, slope, and elevation), a SPOT 7 satellite image taken in September 2015 (with 1.5 m terrestrial resolution) covering the watershed area was classified (Fig. 6) with the help of ArcGIS 10.3.1 Software. In

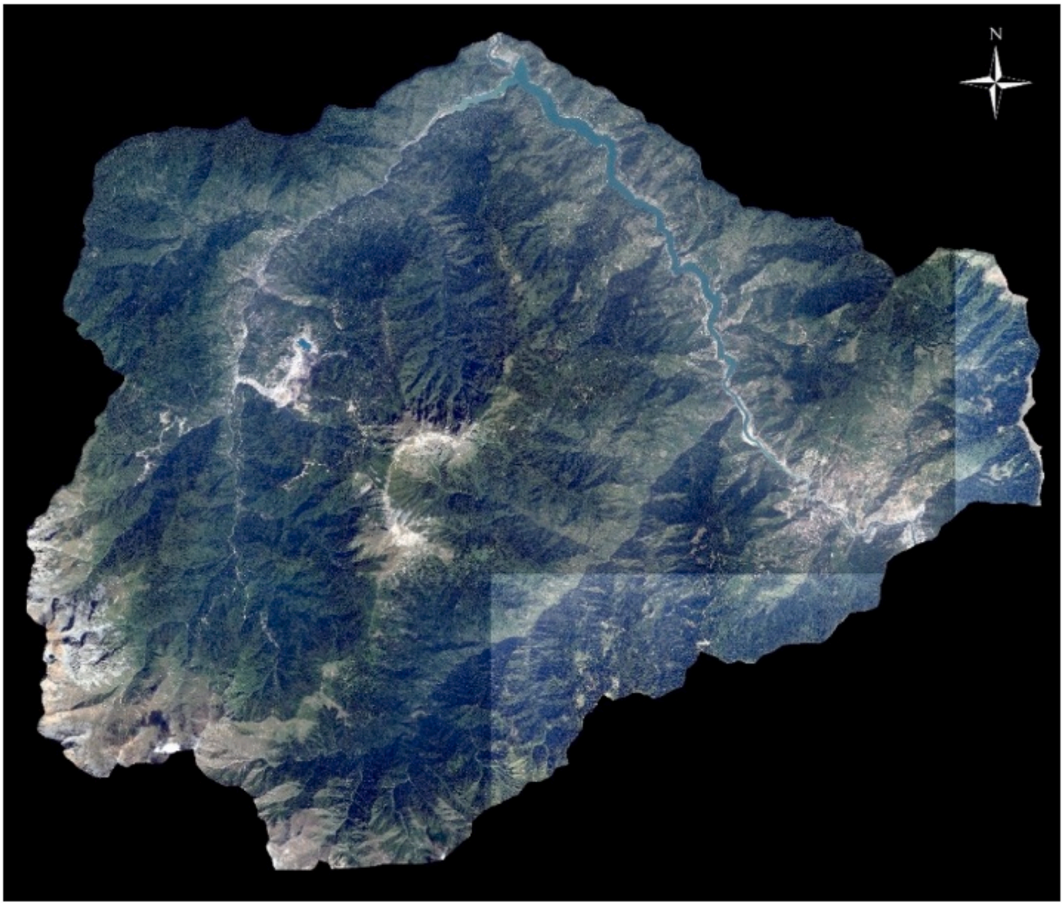

Fig. 6. A SPOT 7 satellite image of the study area.

Table 2
The results of ANOVA analyses showing the grouping of annual average water quality parameters for all the catchments and the dam reservoir.

Water Quality Parameters	Catchments of the Study Area				
	MSC	HSC	FSC	GSC	Dam Reservoir
Water Temperature (°C)	11.10 B	11.70 B	11.3 B	12.7 B	15.5 A
pH	8.11C	8.11C	8.25 AC	8.25 AB	8.44 A
EC (mS/cm)	309.43 A	156.79 B	268.35 AB	253.35AB	310.59A
Salinity (ppt)	0.21 A	0.10C	0.17 AC	0.15 BC	0.18 AB
TDS (mg/L)	274.96 A	132.98 B	227.31 AB	205.18 AB	247.43 A
DO (mg/L)	10.90 A	10.76 A	10.24 AB	10.69 A	9.57 B
TSS (mg/L)	71.25 A	37.19 AB	15.32 B	9.85 B	4.39 B
NO_3–N (mg/L)	2.89	3.32	2.29	2.01	2.99
NH_4–N (mg/L)	0.27 ab	0.08 b	0.66 a	0.10 b	0.15 b

Please note that the means with letters are indicating the statistical significance among the water quality parameters between sub-sections of the project area while the means with no letters do not. Also, the small letters show significant levels are lower than 0.05 ($p < 0.05$) whereas the capital letters imply significant levels are lower than 0.001 ($p < 0.001$). MSC (Murgul Stream Catchment); HSC (Hatila Stream Catchment); FSC (Fabrika Stream Catchment); GSC (Godrahav Stream Catchment).

addition, the drainage network map of the study area was manually derived from 1/25,000 topographic country map sheets. The long-term meteorological data of the study area were obtained from the meteorological stations scattered within the responsibility area of the Directorate of Artvin Meteorology Services. The data consisted of a 32-year dataset and covered the years 1988–2019.

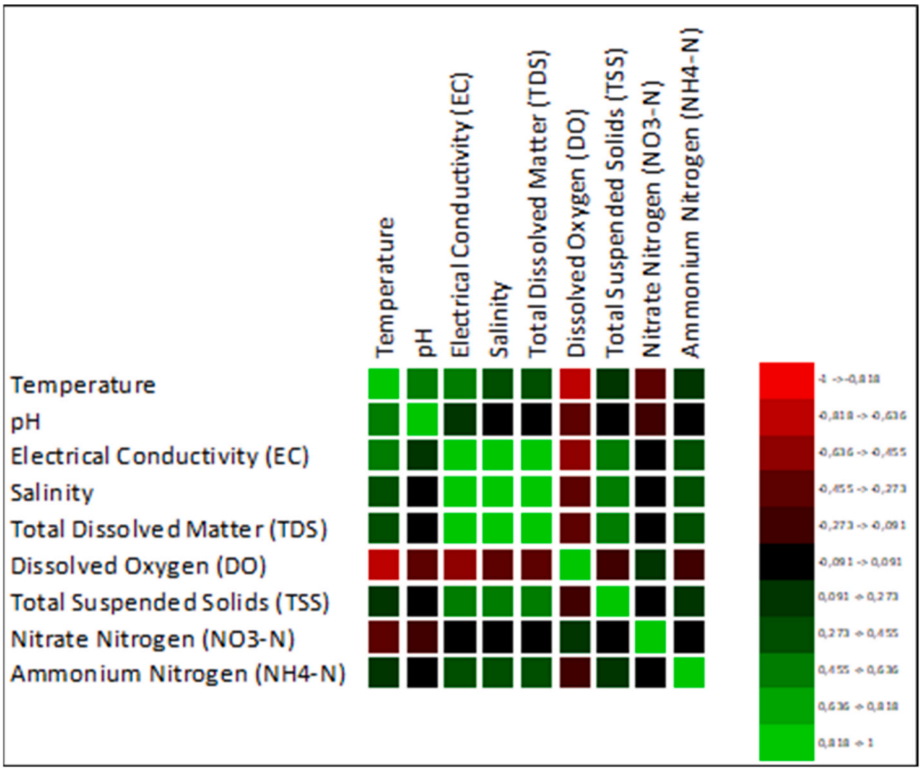

Fig. 7. The Pearson's correlation matrix showing relationships among the measured parameters in this study.

3. Results and discussion

3.1. *The outcomes of ANOVA and Pearson's correlation analyses*

As mentioned above, in the present study, the amounts of TSS and discharge and measurements of some water quality parameters were determined in the field and the mean levels of all the measurements were evaluated according to the Surface Water Quality Regulation of Turkey (SWQR) [31,32], the most important legislative document on classifying some water quality parameters of both surface and coastal waters and identifying the procedures and principles for their monitoring and protection. The field measurement data that were obtained to uncover the current status of some water quality parameters, which was one of the important outcomes of our study and the results of the statistical analysis (ANOVA) made on these data using JMP statistical software [33] are given below. Firstly, the results of the ANOVA analyses applied to the measured data are given in Table 2 and the findings of each water quality parameter and related statistical analysis results are discussed under the subheadings below.

In addition, Pearson's correlation matrix was produced to confirm if there is a linear or opposite relationship between the measured parameters in this study (Fig. 7). According to the correlation matrix, the parameters of salinity (ppt), EC (mS/cm), and TDS (mg/L) show very strong positive relations (represented by light-green color) with each other, as expected, with r-value ranging from 0.965 to 0.996. Moreover, the correlation analysis also indicated several moderate positive relationships including the TSS with the salinity (r = 0.555), EC (r = 0.544), and TDS (r = 0.552), and the water temperature with both the pH (r = 0.515) and TSS (r = 0.521). On the other hand, the parameters with a strong negative correlation were the water temperature and DO (represented by red color) with r-value of −0.810.

3.2. *Assessment of water quality parameters*

3.2.1. *Water temperature*

The temperature of the water in streams is affected by variables such as altitude, climate, streamflow, and groundwater temperature in case it is fed by groundwater [34,35]. In addition, as pointed out by Hanafiah et al. [34], various human disturbances that particularly damage or decrease the natural vegetation cover along the streams might also impair the water temperature, especially in the middle and lower portions of the catchments where human-induced impacts are intense. Moreover, as in this study, the temperature of the water can also be affected by the deceleration of the water flow from the source to the river mouth and the increase in air temperature because of the effect of altitude and the expansion of the river bed [35]. The annual average water temperature values of Murgul, Hatila, Fabrika, and Godrahav Streams were found to be 11.1, 11.7, 11.3, and 12.7 °C, respectively (Table 2). Although the

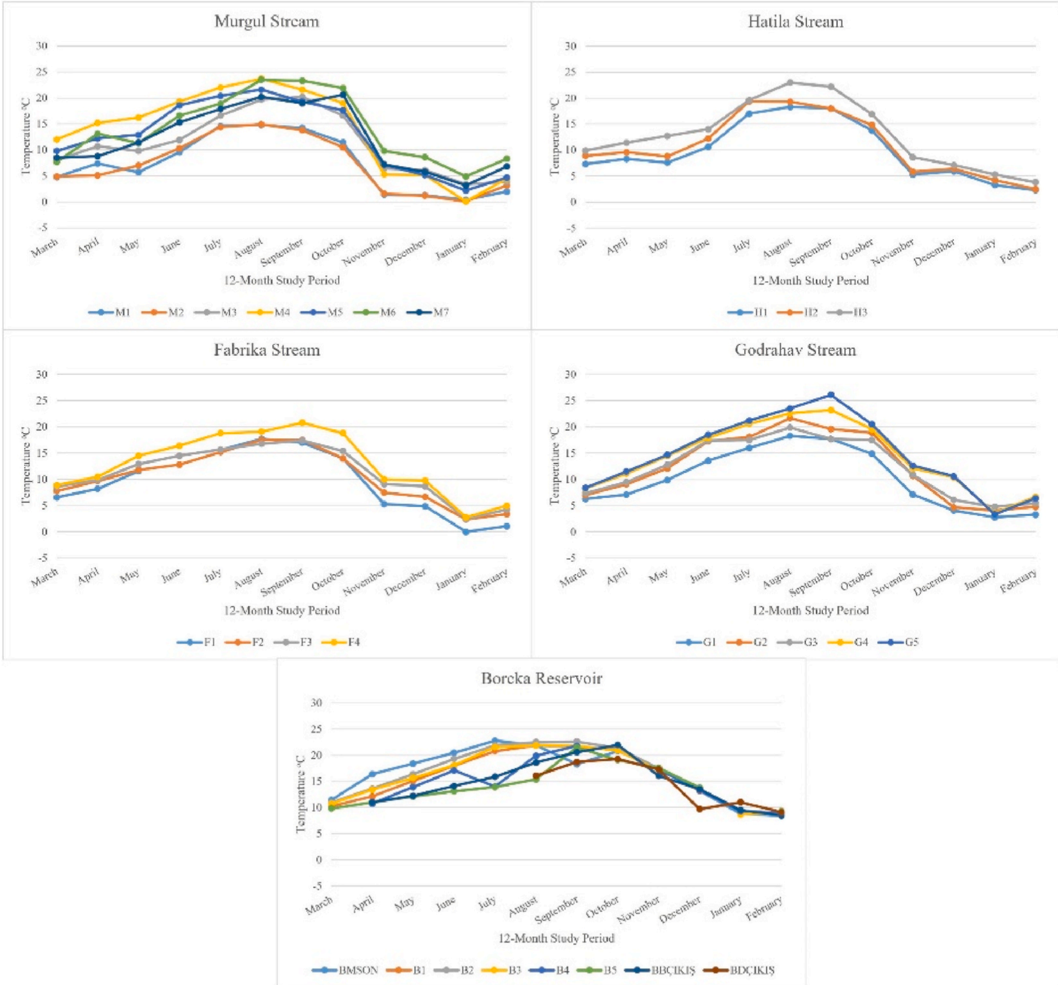

Fig. 8. Annual water temperature changes for the streams of Murgul, Hatila, Fabrika, and Godrahav and for the reservoir of Borcka Reservoir.

average stream water temperatures were close to each other with no significant differences among the four streams, significantly higher water temperature values -as expected-were detected for water in the reservoir (15.5 °C), (2). Here, the fact that the reservoir area absorbed more heat because of its large surface area and a stagnant water regime might be the main reason for this outcome. In addition, as is seen in Fig. 8, it was clear that the water temperature at the first sampling points (in higher elevations) was lower than at the sampling points close to the river mouth of each catchment, as stated by Hamid et al. [15].

This was expected because while the elevations of the first measurement points were 1495 m, 800 m, 1100 m, and 880 m for MSC, HSC, FSC, and GSC, respectively, the average elevation of the last measurement points (close to the reservoir) in the streams was ranging between 167 m and 195 m (Fig. 8). Similarly, In the bordering watershed (the Eastern Black Sea), measurements made only at the output points (close to sea level) of 11 streams yielded higher water temperatures ranging from 13.95 °C in Fırtına Stream to 16.83 °C in Pazarsuyu Stream [36]. When evaluated in the scope of Surface Water Quality Regulation of Turkey, the temperature values of the stream waters in our project area were classified as "High-Quality Waters (1st Class) since their values are generally below 25 °C [31].

3.2.2. pH

The monthly changes in pH values of both the stream and the reservoir waters in the study area are given in Fig. 9, while the ANOVA results are shown in Table 2. According to the Surface Water Quality Regulation and the World Health Organization, in general, pH values ranging between 6.5 and 8.5 are ideal for both natural and drinking waters [31,37]. As for the current study, when all the mean pH values of waters in all the streams and the reservoir were evaluated, it was noticed that the waters had a mild-alkaline characteristic with pH ranging from 8.11 to 8.44 (Table 2). In other words, Fig. 9 shows that there was no significant change in pH values because they all show a parallel trend from the source to the river mouth. However, statistical tests revealed that the reservoir waters had a substantially higher mean pH value (8.44) than the other four stream waters (Table 2). The M4 of Murgul Stream has the lowest (6.3) and highest (10.3) pH readings of all the sampling stations.

Fig. 9. Monthly changes of pH values for the streams of Murgul, Hatila, Fabrika, and Godrahav and the reservoir of Borcka Dam.

The main reason for both of these extreme pH values at M4 can be directly associated with the copper mine that has been operated within the higher parts of the Murgul Catchment since the 1950s, releasing wastewater to surface and groundwater resources from the mining activities (Fig. 2). In another study conducted in Murgul Catchment, similar findings were reported with the lowest (2.7) and the highest (10.8) pH values along the stream branches near the mining area [38]. Overall, when the data in Table 2 is evaluated, it is seen that the quality of stream water in all catchments of this study was generally in good condition (within the 1st class) with respect to pH, except for some measurements for M4 sampling point related with the mining area. In a study that was conducted to determine the water quality in the Kargı Stream of Antalya, pH values were measured between 7.03 and 9.4, and average values were reported to be between 7.87 and 8.26 [39]. For example, in this study, the annual average pH values were found to be between 7.5 and 8.5 as the pH values of the productive waters reported in the literature.

3.2.3. Electrical conductivity (EC)

The ability of water systems to transfer electric current, known as EC, depends on the amount of dissolved ions and inorganic dissolved solids, which is why salinity is significantly connected with EC [34]. It was reported in previous studies that electrical conductivity could be an indicator to provide data about the amount of dissolved substances and pollution levels in surface water systems [40]. In addition, the amount of EC in water resources varies especially depending on the water temperature and the total ion concentration in water. It is known as a good measure of the concentration of charged ions in running waters and is closely affected by natural processes (e.g., rock weathering) and/or anthropogenic drivers (e.g., accelerated erosion, pollution) [15]. Particularly, the ion density in water depends on the salinity rate, factors created by the geological structure, and external factors depending on the general land usage in the area [41]. For this study, the EC values for waters of streams and the reservoir are given in Fig. 10 while the mean amounts are given in Table 2. It is obvious and predicted that the EC increases for all the streams from the source to the river mouth (from lower-numbered sampling locations to higher sample points) when the values of EC distribution are evaluated in Fig. 10. Such trends in EC values, in our opinion, are primarily the result of the addition of substances from a variety of human-induced disturbances,

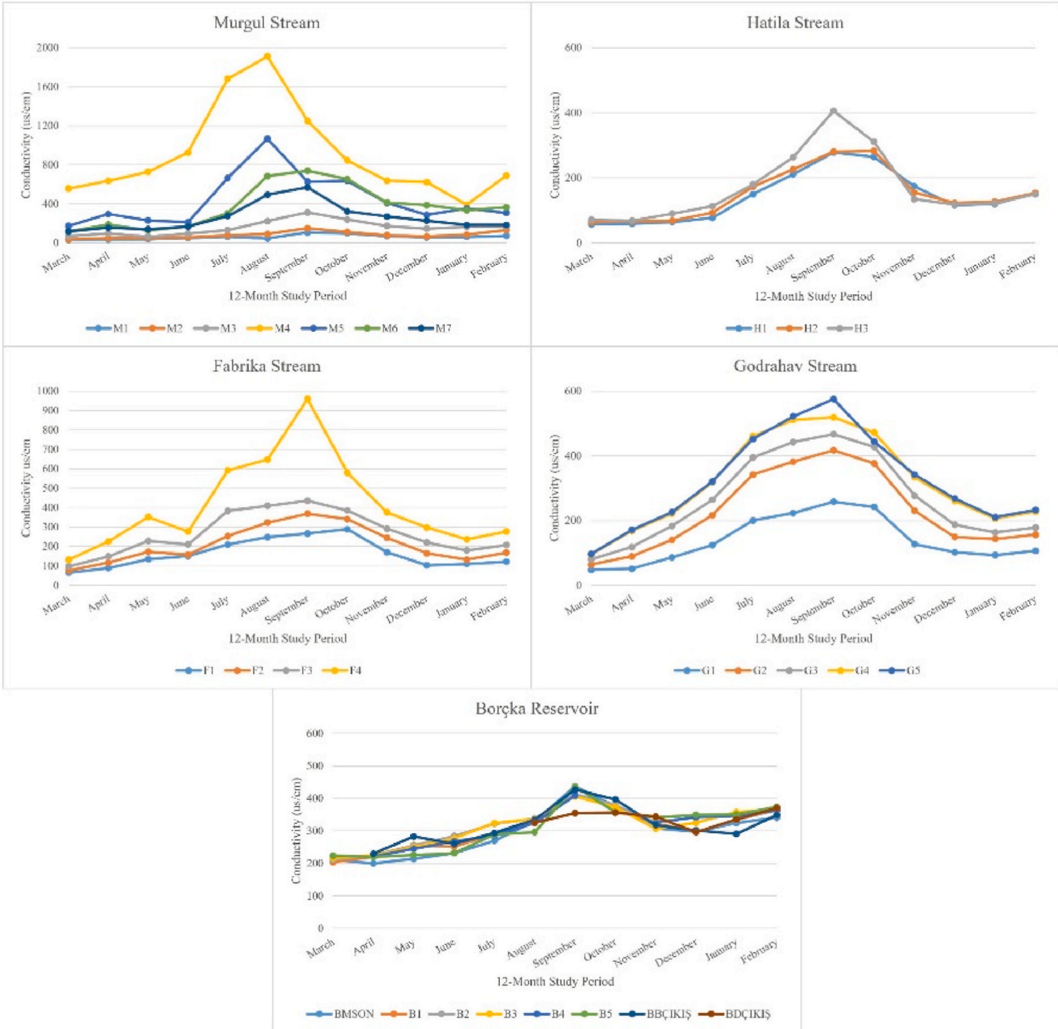

Fig. 10. Monthly changes of EC values for the streams of Murgul, Hatila, Fabrika, and Godrahav and the reservoir of Borcka Dam.

such as soil erosion from agricultural activities, wastewater from urban areas, both solid and dissolved ions from mining areas, and cut/fill materials from road constructions that have been ongoing since the construction of significant dam projects began in the mid-1990s. When comparing catchments with respect to EC, we can conclude that it is also directly related to various land use (e.g., forest, agriculture, settlement, etc.) types of each catchment in the study area as the amount and variety of dissolved substances reaching streams with surface flow changes according to land use [42]. For example, it was obvious to see the higher EC values at the last sampling point (F4) within the FSC, most probably because majority of the urban area of Artvin city center is situated in this catchment (Fig. 4), causing a large amount of materials to reach Fabrika Stream through wastewater and runoff. Also, it is presumed that the seasonal fluctuation in the graph of GDH occurred because of the high agricultural activities in this catchment. Here, it can be argued that there is a possible increase in the amount of dissolved substance reaching water resources because of excessive and improper fertilization in agricultural activities increasing electrical conductivity [41]. In the list of Surface Water Quality Regulations, it is recommended that the amount of electrical conductivity should be lower than 400 μs/cm in waters of "1st CLASS" quality. Based on this viewpoint, in our study area, it is possible to argue that the conductivity values of all other points -except for the M4 point measured in the mining area of the Murgul Stream Catchment - M5 and M6 points were affected by the Murgul district settlement, and the seasonal increases detected at F4 point at the exit of the Fabrika Stream Catchment, are in "1st CLASS" water quality. However, there are also studies in the literature in which the electrical conductivity exceeded these limit values. For example, in a study that was conducted to determine the water quality in Kargı Stream (Antalya), it was reported that the average electrical conductivity values varied between 346 and 599 μs/cm [39]. Also, in the study that was conducted in Tersakan Stream Watershed, where agricultural and residential usage was intense, it was reported that there was agricultural fertilization and spraying, and domestic and industrial wastes were intense. In this respect, it was reported that the lowest electrical conductivity value was 525 μs/cm in spring, and the highest value was 610 μs/cm [43]. In this study, at M4 and M5 points, which were the measurement points where the wastes caused by mining

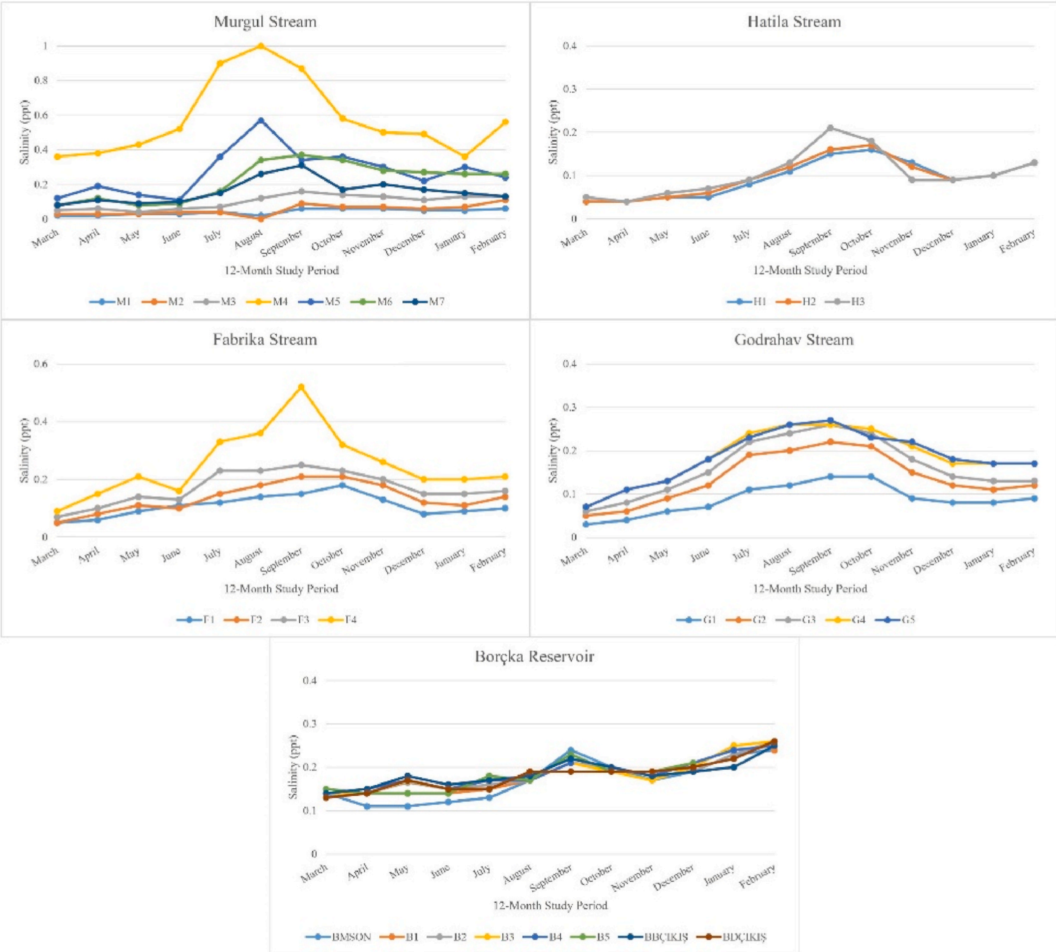

Fig. 11. Monthly changes of salinity values for the streams of Murgul, Hatila, Fabrika, and Godrahav and the reservoir of Borcka Dam.

activities and urbanization were mixed in MDH, the annual average electrical conductivity values were measured to be 877 and 477 µs/cm, respectively. Also, an annual average of 412 µs/cm was measured at F4 point in FDH, where domestic wastes, especially because of intense urbanization, were mixed.

3.2.4. Salinity

It is a well-known fact that the salinity amount can vary in surface waters depending on the soluble salts in the watersheds where they are present, the rocks, and therefore, the geological structure and the land usage status (i.e. agriculture, settlement, forest, etc.). In this respect, temperature also has indirect impacts on salinity rates, since it has effects on increasing solubility of water [41]. For this reason, increased salinity values were detected in water in the graphs that show the distribution of salinity, which was similar to the trend in conductivity values depending on the temperature change from the source to the river mouth. In addition, Hanafiah et al. [34] reported that the EC naturally coincides with the level of dissolved salts and minerals in water and; thus, shows a strong correlation with the salinity, as happened in this study.

In our study, as expected, the highest (1 ppt) and average highest (0.21 ppt) salinity values were detected in sampling locations along the Murgul Stream with the highest average value of 0.58 ppt found at the M4 point (Fig. 11). The main factor in obtaining this result was that this catchment is much more severely exposed to human-induced interventions such as (a) mining operated as open pits, (b) several RoR-HEPP projects (7 in total), and (c) the intensity of road and infrastructure works because of urbanization, compared to other catchments. In a similar study, seasonal averages of the values that were measured in the scope of determining the water and sediment quality in the Seydisuyu (Eskişehir) Watershed were measured as 0.28 g/L in autumn, 0.24 ppt in winter, 0.27 ppt in spring, and 0.3 ppt in summer [44]. When the graphs that show the salinity values of the catchments (Fig. 11) are examined, it is seen that the changes according to the months were in the horizontal direction in general, and there were fluctuations in Hatila and Godrahav Catchments. In this respect, it can be argued that the fluctuations in HSC are caused by the drinking water pipeline works in this catchment running parallel to the stream bed at some points. In these works, it is estimated that there might be an increase in salinity values as a result of the washing of the rocks in the excavation wastes poured into the stream bed during the expansion of the

Fig. 12. Monthly changes of TDS values for the streams of Murgul, Hatila, Fabrika, and Godrahav and the reservoir of Borcka Dam.

existing roads and the laying of the pipes. As for GSC, it is assumed that both the natural and artificial fertilizers used in agricultural activities and domestic (e.g. detergents) and sewage wastes coming from the residential areas might have increased the salinity in the stream waters of GSC.

3.2.5. Total dissolved substances (TDS)

In general, the dissolved organic matter, inorganic salt contents, and other dissolved minerals in water resources are expressed as TDS and their amount in natural water resources may differ mostly depending on the additions of domestic wastes, drainage waters, and industrial wastewaters [34]. Moreover, heavy metals and water-soluble parts of organic substances, all kinds of industrial wastes, pesticides/herbicides that are used in agriculture, and some forms of household wastes can also increase the total dissolved substance contents in water [45].

It is presumed that while the excavation works regarding the new drinking water pipeline were the primary reason for the fluctuation of TDS in HSC, the fluctuation in GDH was mainly caused by agricultural and domestic activities, which is similar to the trend observed for EC. When the values in BBR were examined, it was determined that there were increased values in the months when the precipitation increased, which was an expected result because the water amount reaching the dam from streams, and therefore, the dissolved substance amount carried will also increase, especially in spring, with the increased melting snow and precipitation.

The water at the M4 point was determined to be “2nd CLASS” according to the Water Pollution Control Regulation -only with respect to the TDS- among all the measurement points in the study area [31]. It was reported in the literature that the average TDS concentration in water resources was 200 mg/L in mountainous areas [46]. In a study that was conducted on the rivers within the borders of the city of Trabzon, it was reported that TDS values ranged between 21 and 319 mg/L [47]. Literature shows that water resources containing TDS concentrations lower than 1000 mg/L are usually acceptable [34]. As stated in the previous studies, the TDS results showed a parallel trend with the outcomes of both salinity and EC values in this study as seen in Fig. 12, and Table 2. In addition, Pearson’s correlation indicated that there are significant relations between these three parameters.

Fig. 13. Monthly changes of DO values for the streams of Murgul, Hatila, Fabrika, and Godrahav and the reservoir of Borcka Dam.

3.2.6. Dissolved oxygen (DO)

Dissolved oxygen and other gases like carbon dioxide in stream water change depending on partial pressure, temperature, salinity, respiration, and photosynthesis [45]. It's well known that water's dissolved oxygen level regulates chemical and biological processes [1,48,49]. Dissolved oxygen, one of the most significant characteristics in water quality, should be between 8 and 14 mg/L in natural freshwaters and dropping below 5 mg/L becomes harmful to living things [41]. When Fig. 13 is examined, except few monthly DO values being below the critical value of 5 mg/L at very few measurement points and times (e.g., DO of 4.44 mg/L in June at F4 point -the output of Fabrika Stream) and the average DO amounts very rarely dropped lower than the critical value.

The major reason for the lower DO values in Fabrika Stream can be closely related to the anthropogenic wastes possibly causing DO levels to be impaired since the FSC consists of most of the settlement areas of Artvin city center and some agricultural lands; thus, the waters within this catchment receives significant amounts of both sewage (raw and treated, human and nonhuman) and agricultural runoff [1]. However, it can be concluded that according to the "Regulation on Surface Water Quality", the stream waters in the study area should be considered as "1st Class" (High-Quality Waters) with respect to the mean DO values since they were generally over >8 mg/L [31]. Also, it is known that the dissolved oxygen saturation varies inversely with salinity and temperature; similarly, it was seen that there was a tendency to decrease in dissolved oxygen amounts with increased temperature, particularly in the summer months of the study period (Fig. 13).

In a study that investigated the effects of RoR-HEPPs in Solaklı Stream Catchment (Trabzon) on water quality, the DO amounts were measured to be between 6.2 and 13.6 mg/L [50], the results that were parallel to the current study. Similarly, in determining the seasonal changes in physicochemical water quality of the rivers in the Eastern Black Sea Watershed, the authors reported the mean DO values ranging between 7.8 and 11.44 mg/L from the measurements of 11 different streams [36]. Moreover, in research monitoring the water quality of Karmuç Stream, which exits Lake Van, the mean DO values varied from 7.02 to 9.77 mg/L [51].

3.2.7. Total suspended solids (TSS)

Solid materials suspending and/or transported in running waters generally increase from the source to the river mouth along a watershed depending on the altitude, slope degree, rainfall, and land usage [48,52]. As a result of human activities and natural

Fig. 14. The common application of constructing concrete walls along the streambed to stabilize the banks to protect both the roads and RoR-HEPP facilities (on the left), and houses/buildings (on the right) in the lower part of the Murgul Stream.

Fig. 15. Monthly changes of TSS for the streams of Murgul, Hatila, Fabrika, and Godrahav and the reservoir of Borcka Dam.

Fig. 16. Monthly changes of NO_3^-N concentrations for the streams of Murgul, Hatila, Fabrika, and Godrahav and the reservoir of Borcka Dam.

environmental factors such as erosion, floods, and landslides, there might be increased amounts of TSS in surface waters [53]. When TSS levels are above the normal level, it tends to hinder the passage of energy from the sun into the water and upsets the carbon dioxide and oxygen balance, negatively affecting water quality. As a result, knowing the present TSS load carried by streams is critical for watershed management research and planning [54,55].

Similarly, when the sampling points in this study area were examined, it was also clear that the annual average TSS values generally tended to increase from the source to the river mouth for all the streams and catchments. However, various human-induced interventions can disrupt this balance by changing the natural structure of the channels, especially along the streams of Murgul, Fabrika, and Godrahav. For example, the construction of concrete walls along the streambed to stabilize the banks to protect both the roads, houses, and other structures as well as the establishment of several RoR-HEPP facilities for generating electricity are widespread within the catchment area of Murgul Stream [16,56] (Fig. 14).

Such structures and facilities operate as an impermeable barrier, allowing the natural movement of runoff water, sediments, organic materials, and other nutrients from the hillsides to the stream system, negatively impacting both the water quality and quantity of streams. Furthermore, it was projected that the TSS quantities would have several maxima in various months, many of which would be strongly associated to greater precipitation occurrences, notably in the spring months. (Fig. 15). For the current study, the mean TSS amounts varied significantly from 4.39 mg/L detected in the reservoir (due to the settlement of the materials with decreasing slope) to 71.25 mg/L detected in Murgul Stream (due to the intense disturbances) when all measurements were analyzed together (Table 2). However, among the sampling locations, the highest annual average TSS (with 236 mg/L) was calculated at the M4 sampling location within MSC. Since land use types of settlement, agriculture, and related activities in HSC (which covers most of the Hatila National Park) are quite limited, it followed a relatively more balanced course with respect to TSS values (Fig. 15).

Higher TSS levels, on the other hand, were detected, particularly at the FSC and GSC exit points, due to high amounts of organic and inorganic materials (as well as soil erosion) reaching the streams from the relatively larger residential and agricultural areas found in these two catchments. Finally, when the monthly fluctuations in TSS amounts reaching the reservoirs are analyzed, it is discovered that the majority of the TSS was delivered to the reservoir (affecting the economic life of Borcka Dam) via the Murgul Stream, especially during the spring season when considerable precipitation occurs. Literature data prove that the TSS amounts in streams may easily show changes mostly depending on land use types and anthropogenic factors. For example, in a study completed in close vicinity to our research area, Kenanoğlu et al. [57] reported some dramatic variations in the amount of TSS ranging from 90 to 609 mg/L and 59 and 1383 mg/L, in Murgul Stream and Coruh River, respectively. In another study, the average TSS amount was found to be between 30 and 190 mg/L for Solaklı Stream in Trabzon, and the changes in the TSS levels were likewise related to the effects of numerous RoR-HEPPs [50], as outlined in the present study. On the other hand, Hanafiah et al. [34] found much lower TSS values ranging from 1.67 mg/L to 8.17 mg/L (with an average value of 4.15 mg/L) in Tekala River, Malaysia and they related these low TSS amounts to the dense vegetation along the study area.

3.2.8. Nitrate nitrogen (NO_3–N)

The amount of nitrogen and its components, along with phosphorus, varies greatly depending on the geology, soil, climate, and vegetation. However, recently, their concentrations have been driven up by anthropogenic sources such as agricultural fertilizers, atmospheric deposition, nitrogen-fixing plants, and human and animal waste [15,58]. They can reach stream ecosystems through either point sources (e.g. municipal and industrial wastewaters) or as nonpoint sources (e.g. fertilizers and manure from farm fields) [59], mostly by surface and subsurface runoff [12,60]. In natural waters, nitrate is formed by the oxidation of ammonia, resulting from the decomposition of animal and vegetable wastes, the dissolution of fertilizers, and the conversion of nitrogen into nitrogen oxides as a result of electrical discharges in the atmosphere [61].

When the results of the present study were investigated, it was found that nitrate levels generally increased from the source to the river mouth. Additionally, the statistical analysis showed that there were not significant variations in the mean NO_3–N concentrations between any of the catchments and the reservoir (Table 2). Furthermore, it is clear from the graphs that, despite nitrate concentrations remaining consistent and low during the summer, there were variations in monthly readings, particularly during the spring and autumn/winter months, which were most likely brought on by precipitation events (Fig. 16). On the other hand, it was somewhat unexpected to find the highest mean and monthly NO_3–N concentrations within the HSC; this finding is most likely related to the significant discharge of organic matter from the heavily forested national park (Fig. 2). It is thought that some of the nitrate found in the waters of Murgul Creek might be released as the nitro-glycerin used during the explosions in the mining area, releasing nitrogen gas, which, in turn, transforms into various nitrogen forms after being oxidized or mixed with water [62]. It was presumed that the fluctuation in the nitrate values in Borcka Dam Reservoir (BDR) was mostly caused by the sediments (i.e. organic/inorganic substances) carried via the streams flowing from all the catchments of the study area. A small nitrate amount can be detected naturally in water as a common form of nitrogen, but a nitrate content of more than 5 mg/L may be an indication of contamination in water. According to the Surface Water Quality Regulation of Turkey, the value in 1st Class waters must be less than 3 mg/L [31]. In this regard, it is possible to conclude that the mean nitrate levels detected in the waters of all the streams included in this study were within this limit. However, it should be highlighted that at several sampling locations and times, the nitrate levels climbed significantly above the SWQR threshold values [31], causing the risk of pollution problems in the stream waters. When similar studies were evaluated, it was seen that they reported similar mean nitrate values. For example, Saruhan & Kırankaya [63] reported that the nitrate amounts varied between 2.50 and 7.40 mg/L for Asarsuyu Stream, indicating that the quality of the stream water lay between class I and II in terms of nitrate concentrations according to the Water Pollution Control Regulation in Turkey. In a study that was conducted for several streams along the Eastern Black Sea Region, it was found that nitrate values were ranging from 0,094 mg/L to 2396 mg/L, and with the mean amount of 0,685 mg/L, it was concluded that they were below the threshold value set by SWQR [31,36,64]. In addition, the average of 24-month measurements of nitrate was detected as 2.28 mg/L in Değirmen Stream and 3.30 in Imamın Stream, respectively in the project conducted in Kayseri Palas Plain [65]. In another study that investigated the effects of land use on water quality in the upper areas of the Manyame River Watershed in Zimbabwe, it was reported that NO_3–N measurements ranged between 0.020 and 1.890 mg/L during the rainy period and between 0.006 and 2.870 mg/L in the dry period [66].

3.2.9. Ammonium nitrogen (NH_4–N)

It is known that ammonia exists in natural waters in two forms as ionized ammonia or the ammonium ion (NH_4^+) and non-ionized (NH_3). In other words, ammonium (NH_4^+) is the form of ammonia (NH_3) compound and it is also the residue that forms as a result of the breakdown of protein or other nitrogenous organic materials of living things by bacteria [41]. Total ammonium concentration can increase as a result of discharges from wastewater treatment plants, industrial effluents, and agricultural runoff. Although ammonium does not cause toxic effects except at high concentrations, ammonia can cause toxic effects even at low concentrations and can sometimes be an indicator of pollution [63]. According to the World Health Organization, the optimal and acceptable values of ammonium amounts in surface waters are usually set below 0.2 mg/L, meaning that the higher concentrations may indicate possible pollution mostly caused by human-based activities through the release of sewage, animal waste, industrial or landfill sources into the water resources [67].

As for the present study, the results from the ANOVA analyses (Table 2) showed that the mean ammonium amounts were significantly higher in Fabrika and Murgul Streams, as 0.66 and 0.27 mg/L, respectively, compared to the Godrahav (0.10 mg/L) and Hatila Streams (0.08 mg/L) -as well as the reservoir (0.15 mg/L), indicating some degree of pollution in water quality based on the threshold values set by both the international [67] and the national standards [31]. This outcome with respect to the ammonium concentrations was expected since the urbanization and anthropogenic activities are denser within the catchments of both Fabrika and Murgul Streams than in the other catchments (Fig. 2). In addition, when the monthly NH_4–N distribution for the study area is examined, it can be argued that the ammonium concentrations at Murgul and Hatila Streams -and at some points in the dam

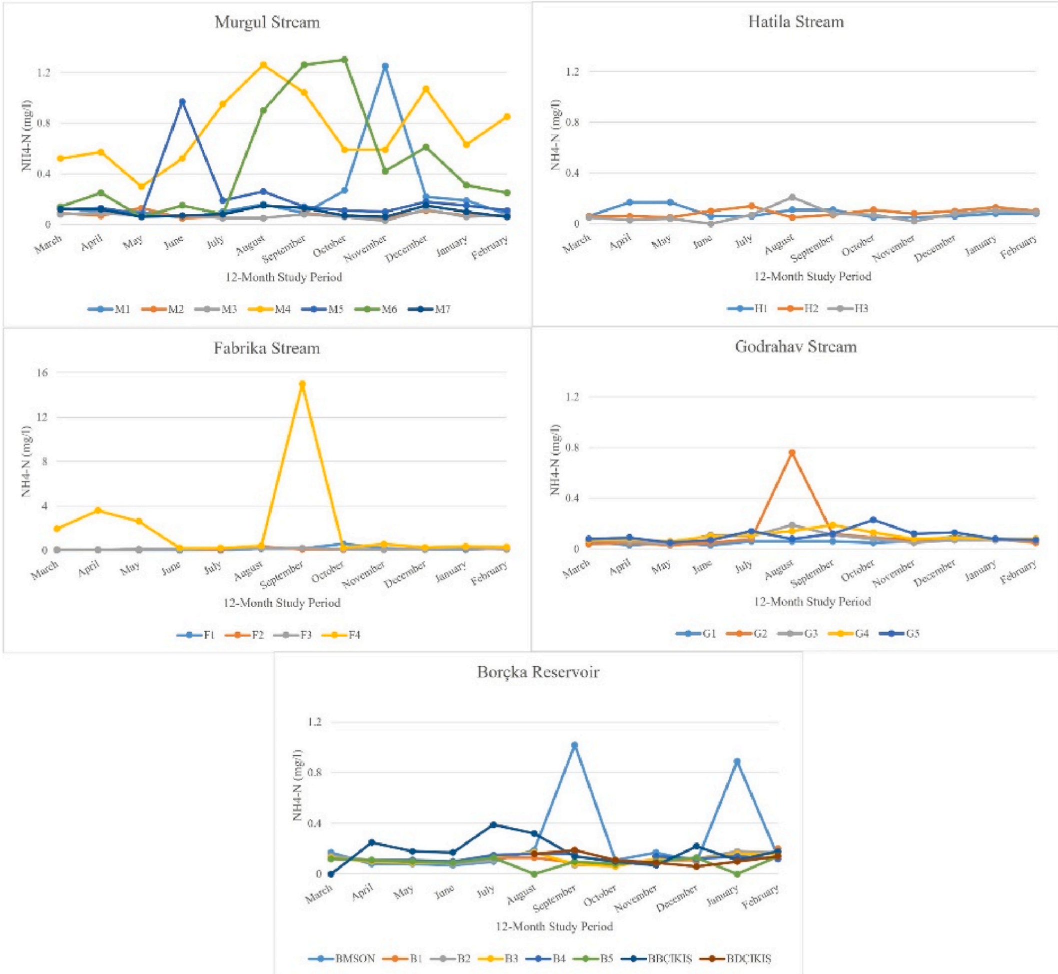

Fig. 17. Monthly changes of NH_4–N concentrations for the streams of Murgul, Hatila, Fabrika, and Godrahav and for the reservoir of Borcka Dam.

reservoir-showed a rather fluctuating course almost throughout the year when compared to the Fabrika and Godrahav Streams (Fig. 17).

While the fluctuations of NH_4–N concentrations in the Murgul Stream can be associated with human disturbances along the stream (e.g. building new roads and infrastructure works), the activities of living organisms near the stream (e.g. increased decomposition, litterfall, etc.) might be the main reason for the Hatila Stream. It was reported in previous studies that up to 12 mg/L of ammonium could be detected in surface waters [68]; however, according to Surface Water Quality Regulation, the ammonium concentration must be less than 0.2 mg/L in 1st Class waters [31]. However, in the present study, it was seen that this limit value was exceeded at specific points and times in some catchments, which suggests that there might be pollution in water resources in terms of ammonium contents. When similar studies were reviewed, it was found that NH_4–N measurements ranged between 0.020 and 0.131 mg/L throughout the year in a study that was conducted in rivers in Eastern Black Sea Region [36,64]. It was reported in a study that investigated water quality in Tersekan Stream Basin within the borders of Muğla that NH_4–N measurements ranged between 0.5 and 0.72 [43].

4. Conclusions

Many human-induced interventions have occurred within the Borcka Dam Watershed (BDW) including the construction of several large dams as well as new access roads, the conversion of forested lands to settlement and agriculture areas, the operation of open-pit mining activities, and the establishment of dozens of run-of-river hydroelectric power plants (RoR-HEPP), affecting the streams of the Hatila, Murgul, Godrahav, and Fabrika Catchments, as well as the reservoir of the dam. Thus, the primary goal of this project was to accurately record and evaluate monthly values of discharge, several water quality parameters, and suspended sediments in the streams and dam reservoir of BDW for a year in order to discover how these parameters vary annually with time and location.

According to Turkey's Surface Water Quality Regulations (SWQ), the yearly mean values of all water quality criteria for all four streams were mainly acceptable. Nonetheless, as previously stated, some of the measurements made at various times (temporal) and sample locations (spatial) surpassed the official water quality criteria for a number of water quality parameters.

Overall, it is obvious that in comparison to Hatila and Godrahav, the stream flows of the Murgul and Fabrika Catchments were influenced more, since the latter two catchments were more severely affected by significant and pervasive human-induced disruptions than the former. Similar research is required since human-induced disruptions continue to occur in the area, despite the current study offering extensive scientific data and findings on the water quality state of the main streams entering the reservoir of Borcka Dam. These activities and research will provide critical knowledge that will serve as the foundation for the proper use and management of the Borcka Dam Watershed's water resources.

Author contribution statement

Mehmet Özalp, Ph.D.; Saim YILDIRIMER: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Esin ERDOĞAN YÜKSEL: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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