IMPACTS OF CONSECUTIVELY BUILT RUN-OF-RIVER HYDROPOWER PLANTS ON WATER QUALITY OF KABACA STREAM IN TÜRKİYE

ÖZALP, M.* – ÖZAY, G.

Department of Forest Engineering, Faculty of Forestry, Artvin Coruh University, Seyitler Campus, 0800, Artvin, Türkiye

**Corresponding author
e-mail: mozalp@artvin.edu.tr; phone: +90-533-363-4417*

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Abstract. This study examined the effects of multiple run-of-river hydroelectric power plants (RoR-HEPPs) on water quality, discharge, and total suspended solids (TSS) in Kabaca Stream, Türkiye. At ten sampling points, portable devices were used to measure pH, water temperature, dissolved oxygen (DO), electrical conductivity (EC), salinity, total dissolved substances (TDS), and nitrate-nitrogen (NO_3-N) values. Monthly discharge and TSS quantities were estimated on-site and in the lab. To study the effects of RoR-HEPPs on selected water quality indicators, sample locations were split into three categories: *before* regulators, in *between* HEPPs, and *after* HEPPs. The sequentially constructed RoR-HEPPs negatively affected the mean values for most water quality parameters in Kabaca Stream, as the mean amounts of EC, salinity, TDS, and TSS measured as 65.9 µS/cm, 0.047 ppt, 0.064 mg/l, and 4.60 mg/l at the *before* sections increased to 98.7 µS/cm, 0.072 ppt, 0.099 mg/l, and 17.34 mg/l at the *after* sections. The installation of water transmission lines and roads for the RoR-HEPPs destroyed steep mountainous forest slopes, releasing massive amounts of sediments and other contaminants into the stream bed. Since the RoR-HEPPs taken in up to 90% of the stream water, the mean discharge rate dropped from 3.27 m^3/s at the after sections to 0.90 m^3/s at the between sections.

Keywords: *stream ecology, RoR-HEPP, quality of running waters, water regime, suspended sediments*

Introduction

Regardless of their size, all types of running water systems (rivers, streams, creeks) provide clean/fresh water for both human consumption (e.g., drinking, irrigation, industrial use) and other living things in nature, as well as suitable areas for settlements, agricultural land for food production, and flood protection. Consequently, running water resources (such as streams) and their adjacent watersheds play a crucial role in the ecological systems of the entire planet.

However, freshwater resources, which mostly depend on precipitation, are unfortunately not in a balanced state or sufficient amount in every region of our world. In addition, freshwater resources, already considered very limited in the world on a global scale, have started to be classified as even more scarce-resource in recent years due to the problem of pollution as a result of numerous human-induced interventions (Martins et al., 2022; Lintern et al., 2018) including mismanagement, misuse and inappropriate practices on these resources (Yuceer and Coskun, 2016; Ozalp et al., 2017; UNWWAP, 2018; Dutal and Reis, 2020). Such anthropogenic disturbances generally started with the invention of irrigation and accelerated dramatically worldwide with economic and/or technological developments, especially since 1950 (Schmutz and Sendzimir, 2018).

Human activities that are particularly practiced in and around stream ecosystems include transforming riparian areas and/or riverscapes into arable and residential lands,

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constructing large/small dams, canals and culverts, extracting and/or transferring excessive amounts of water from streams and lowering water quality through pollution (Best, 2019; Brusseau et al., 2019). In other words, freshwaters -mainly clean in the upper parts of the catchments- are seriously deteriorated due to both diffuse and point source pollution elements as a result of anthropogenic disturbances particularly in and around the downstream sections of stream ecosystems (Vörösmarty et al., 2010; Enea et al., 2017). This, in turn, reduces the quality of all surface waters, especially streams and lakes, and accordingly restricts their use for drinking, industrial, agricultural, recreational or other purposes (Ramírez et al., 2014; Kim and An, 2015; Hamid et al., 2020).

Out of all these disturbances causing dramatic changes in running water ecosystems, building large dams on rivers/streams have been one of the most applied human-induced activities. Particularly starting from the 1950s, in order to find an alternative way for energy sources other than fossil fuels, especially the developing countries such as Türkiye headed towards constructing numerous large dams and hydroelectric plants to produce energy (Özdemir et al., 2020). However, in recent years, both the global energy demand showing an increasing trend and the approaching threats of climate change has forced many countries to search for clean and renewable energy sources, causing particular interest to invest and/or support for the widespread development of small-scale hydropower plants, also called the Run-of-River type hydroelectric power plants (from now on will be referred as RoR-HEPPs) (Couto and Olden, 2018; Kuriqi et al., 2019).

Moreover, one other reason for the increasing trend in building RoR-HEPPs in recent years is the fact that the hydropower potential of many large rivers and streams around the world has already been used because of the building of large hydropower plants on them (Poff and Zimmerman, 2010; Lange et al., 2018). This, in turn, makes way for some countries to promote the construction and development of small hydropower plants (SHPs) (particularly those of RoR-HEPPs) on smaller streams and/or creeks in watersheds (Kibler and Tullos, 2013). According to Anderson et al. (2015), the RoR plants produce energy without storing water, as they use a certain amount of the flow running in a creek/river channel. Typically, weirs are built within the channel in order to divert and/or regulate water to a turbine for generating electricity and then the diverted water can be returned to the main channel from the tailrace of the facility.

For many years, the RoR-HEPPs were mostly considered as having low damaging impacts on the surrounding ecosystems when compared to large dams (Kibler and Tullos, 2013) and thus the energy produced by RoR-HEPPs was also considered cheap, sustainable (Kaunda et al., 2012; Zapata-Sierra and Manzano-Agugliaro, 2019), and clean in respect to low carbon emissions (Serpoush et al., 2017; Alvarez et al., 2020).

However, there are also studies indicating that RoR-HEPP facilities can actually cause serious damage (Pang et al., 2015; Alvarez et al., 2020; Hayes et al., 2018; Kibler and Alipour, 2017) to the parts of the stream that they are built on. For example, one of the most detrimental effects happens on the flow regime of streams, particularly the water volumes that should be released to the riverine ecosystem following water abstraction by HEPPs, known as the ecological and/or environmental flows (e-flows) (Kuriqi et al., 2019). For instance, the amount of environmental flow release is set to be 10% as RoR-HEPPs may use up to %90 of the natural flow in streams (Özalp et al., 2010; Kurdoglu, 2016; Ozay, 2019), which, in turn, creates changes in natural flow regime, lower the water quality and disrupt the sediment dynamics of streams (Kurdoglu, 2012; Anderson et al., 2015; Lange et al., 2018). In addition, such facilities negatively impact the stream ecosystem and its close environment because they usually cause land degradation, biodiversity and habitat loss and weakening of riparian vegetation due to both road building, placements of weirs, constructing of water delivery tunnels/channels and the reduction of the flow in the stream bed (Ziv et al., 2012; Benchimol et al., 2015; Hayes et al., 2018).

Similar to some other developing countries, Türkiye has also become one of the countries trying to close the energy gap (between the use of their own energy sources and importing mostly oil-based external sources) by reducing foreign dependency. For this purpose, the country has passed new regulations since the early 2000s in order to promote hundreds of run-of-river hydroelectric power plants (RoR-HEPPs) already running and planning several hundred more in recent years (Kurdoglu, 2012; Ozay, 2019). In this context, increasing the share of hydraulic energy by increasing the number of both large dams and RoR-HEPPs has been among the most used methods in order to generate more electrical energy to close the gap (Muluk et al., 2009).

However, the sudden and unplanned constructions of numerous RoR-HEPPs in Türkiye -especially since the early 2000s- caused severe perturbations on many stream ecosystems around the country as well as the social dispute between the government and the people living along these streams (Kurdoğlu, 2012).

The Turkish Electricity Transmission Corporation reports that, as of December 2022, a total of 751 hydroelectric power plants (141 large dams and 610 RoR-HEPP facilities) have been built in Türkiye since 1924 (TETC, 2022). The Coruh River Watershed, one of the country’s 25 major watersheds, is considered to have one of the highest potentials for hydraulic energy. This is the primary reason why, as of 2021, there are a total of five large dams and twenty-six RoR-HEPP facilities operating in the middle and lower portions of the Coruh River in Artvin province. Additionally, hundreds of these facilities are either under construction or in the planning stages. Consequently, Artvin is ranked fourth for the total number of major dams and RoR-HEPPs combined and sixth for the average hydraulic energy production compared to other cities in the nation (GDSHW, 2021).

With a total of 26 (and increasing) HEPPs in Artvin, it is obvious that almost all the streams within the Coruh River Basin have at least one HEPP on them while some of them have multiple power plants. Selected as the research area of this study, Kabaca Stream has three RoR-HEPPs, constructed one after another and in operation since 2008. However, there is a lack of knowledge on how these multiple RoR-HEPPs impact the stream ecosystem and its close environment, particularly with respect to some water quality parameters, water regime and discharge, and sediment being generated and/or distributed along the stream channel.

Therefore, the main purpose of this research was to find out whether the three sequentially constructed RoR-HEPPs have been causing any negative impacts on some physicochemical water quality parameters, discharge, water regime and transported sediments for the Kabaca Stream. In addition, the study also aimed to investigate the temporal and spatial changes of several water quality parameters along the stream in order to identify its pollution levels based on the quality classes listed in the Water Pollution Control Regulation (WPCR) of the country.

Materials and methods

Study area

The Kabaca Stream, selected as the study area, is located in the Murgul Stream Catchment within the borders of Murgul County of the Artvin Province (Türkiye). The determined points are at an altitude of 900–1800 m and most of the land consists of forestland (*Fig. 1*).

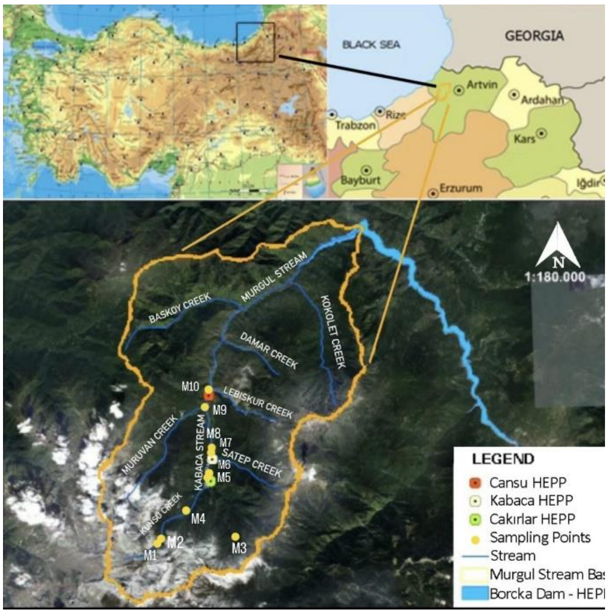

Figure 1. *General view of the study area and the locations of sampling points and the three RoR-HEPP facilities built along the Kabaca Stream*

The typical climate of the study area is that the summers are hot and the precipitation is frequent at the same time, while the winters are mild. With the humid air coming from the Cankurtaran Pass and the Coruh River, it is both under the influence of the climatic characteristics of the Black Sea region, and due to the mountainous terrain with sudden changes in altitudes, precipitation is seen at early intervals and fog formation is observed (Yüksek and Ölmez, 2002). In addition, due to the variations of aspect, altitude and orographic factors in Artvin province, which is deeply divided by the Coruh River and its tributaries, the temperature distribution also changes over short distances (Ceylan, 1995). According to the long-term observation data of Artvin Meteorology Station between 1949 and 2018, the average annual temperature and precipitation are 12.4°C and 690 mm, respectively (TSMS, 2019).

Being under the influence of three different climate zones (terrestrial, Mediterranean, oceanic) and having altitude changes up to 4000 m, rich water resources and geological and/or geomorphological differences, the lands within Artvin provide various habitats for many different kinds of plants to grow. That is why, as stated by Eminağaoğlu et al. (2015), Artvin is one of the most diverse provinces in the country with respect to plant species as there are a total of 2727 vascular plant taxa, 761 genera and 137 families. In the parts of Artvin facing the Black Sea, the pseudomaquis belt lies on the slopes of Hopa–Cankurtaran and Arhavi–Karadağ (at 0 m to 50/100 m). Moreover, while pure alder forests are grown between 50/100 m and 700/800 m altitudes, there are beech forest stands are found within the altitudes ranging from 700/800 m to 1800 m. In addition, close to the Borçka-Çifteköprü districts, forest areas dominated by chestnut trees, especially at an altitude of 300-800 m (Güner, 2000).

As for the geological structure, Artvin province is located within the North Anatolian orogenic belt. This metamorphic series, starting from the lower parts of the Coruh River and continuing towards the northeast over Zeytinlik Village (Sirya), forms the oldest topography of the region (Gattinger, 1962). Rhyodacite, basalt, andesite and granite bedrocks in the study area are in the igneous rocks group, while claystone and limestone are in the sedimentary rocks group.

Sampling locations and data collection

In order to investigate the effects of the multiple RoR-HEPPs on Kabaca Stream with respect to the water quality, discharge and TSS values, a total of 10 sampling points (*Fig. 1*) were placed along the stretch of the stream with the coordinates listed in *Table 1*.

Table 1. *GPS coordinates of the water quality sampling locations along Kabaca Stream*

Water sampling points	Coordinates	
M1	N 41° 09’ 13”	E 41° 31’ 09”
M2	N 41° 09’ 23”	E 41° 31’ 39”
M3	N 41° 08’ 33”	E 41° 33’ 58”
M4	N 41° 10’ 18”	E 41° 32’ 24”
M5	N 41° 10’ 40”	E 41° 32’ 48”
M6	N 41° 10’ 54”	E 41° 32’ 38”
M7	N 41° 11’ 31”	E 41° 32’ 55”
M8	N 41° 11’ 41”	E 41° 32’ 55”
M9	N 41° 13’ 49”	E 41° 32’ 45”
M10	N 41° 14’ 08”	E 41° 32’ 51”

All the RoR-HEPPs constructed within the study area can be classified as “diversion without storage” type (*Fig. 2*) according to the schematic depiction by Couto and Olden (2018), based on the operation modes of hydropower plants having either storage and/or diversion structures.

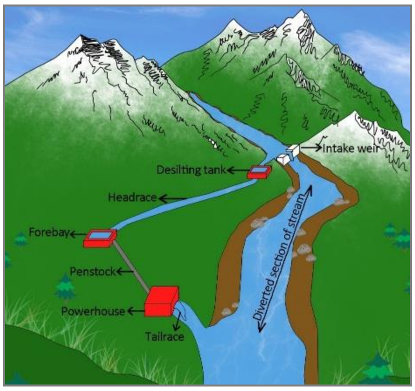

Figure 2. *The key components of a RoR-HEPP and its main effect in lowering the water level/amount in the diverted section of stream*

When determining where to locate sampling points, attention was given to ensure choosing the places that would best represent the entire study area. To better reveal the effects of the HEPPs, the sampling locations (*Fig. 1*) were distributed along the stream to form three groups as; (I) M1 and M3 points (before the stream water is taken (undisturbed) by the weirs), (II) M2, M4, M6, M8 points (between the weir and tailwater of the stream or the bypass reach along the diverted section) and (III) M5, M7, M9, M10 points (the water released by the HEPP after production of the energy - tailrace outlet).

At all sampling points, pH and the water temperature were measured using the Hach-Lange HQ40D (HACH Company in Loveland, Colorado-USA), while the values for electrical conductivity, salinity, TDS, DO and NO_3-N were determined by the YSI/Professional-Plus (Xylem Inc. in Washington, DC-USA) device directly in the field for a year. In addition, water samples were taken from each measurement point in 1-liter colored polyethylene containers to estimate the amount of total suspended sediments (TSS) in the water of the stream. For this, the water samples taken were first filtered with the help of Whatman filters with a pore diameter of 0.8 µm and a size of 47 mm in a device known as a vacuum filtration set. Then, these filters were dried in an oven at 105°C for 24 h, kept in a desiccator, brought to room temperature, and the suspended matter remaining in the filter was weighed on a scale (Radwag brand 0.0001 g precision). Calculation of the amount of TSS was calculated as mg/L using the formula (*Eq. 1*) given below:

$$TSS\left(\frac{mg}{l}\right) = (A - B)x\,\frac{1000}{V} \qquad \text{(Eq.1)}$$

In this formula, A = weight of filter paper + dry residue (mg), B = weight of filter paper (mg), V = sample volume (ml).

Finally, at all sampling points, the amount of water flowing in the stream (discharge-m^3/s) was calculated based on the relationship between the water flow rate (m/sn) measured by the portable “FLOWATCH 2 JDC” brand device and the cross-sectional area (m^2) of the stream bed. All measurements were conducted on a monthly basis beginning in April 2018 and continuing through March 2019 within the scope of the TUBITAK project, which began in January 2018 and was finished in February 2020.

Using the XL Stat and SPSS programs, the annual means of all observed parameters were statistically examined using various tests (e.g., ANOVA, correlation, regression, etc.). The goal of these statistical analyses was to determine whether the sequentially built three RoR-HEPP facilities influenced the water quality parameters, discharge, and TSS quantities in Kabaca Creek. Furthermore, the statistical test findings were used to reveal the overall pollution level as well as monthly variations in the average value of parameters with respect to both temporal (sampling points) and spatial (sampling periods) comparisons. Lastly, correlation and/or regression analysis were run on the water quality parameters to see if there were any significant correlations between the measured values.

Results and discussion

Overall water quality status of Kabaca Stream

The mean, minimum and maximum values of all the water quality parameters measured for this study were listed in *Table 2*. In addition, the results of the ANOVA analyses showing the significance levels (P and F values) after evaluating the monthly measurements of each parameter for the one-year time period were also shown with respect to both spatial and temporal comparison. Moreover, Pearson’s correlation between the measured water quality parameters in Kabaca Stream was also given in *Table 3*.

Table 2. *The means and some descriptive statistics of all the water quality parameters and the significance levels based on both the sampling times and points*

Parameters	**Means**	**Minimum**	**Maximum**	**Temporal (sampling times)**		**Spatial (sampling locations)**	
				F-Values	**P-Values**	**F-Values**	**P-Values**
Water Temp (°C)	7.31	-0.1	21	80.317	<0.0001*	0.425	0.919
pH	7.20	6.1	8.4	15.733	<0.0001*	0.972	0.467
DO (mg/L)	11.5	8.4	14.26	41.475	<0.0001*	0.509	0.865
EC (us/cm)	86.6	30	246	14.187	<0.0001*	5.418	<0.0001*
Salinity (ppt)	0.062	0.020	0.210	20.396	<0.0001*	3.677	0.000*
TDS (mg/L)	0.087	0.031	0.289	20.614	<0.0001*	3.928	0.000*
NO_3^-N (mg/L)	1.847	0.160	8.400	14.532	<0.0001*	0.575	0.815
TSS (mg/L)	11.2	0.100	140.8	1.131	0.346	9.223	<0.0001*
Discharge (m^3/s)	1.78	0.040	9.410	2.608	0.006*	6.014	<0.0001*

*Values are statistically significant either at $p < 0.05$ or at $p < 0.01$

As can be seen from *Table 2*, it is understood that many parameters show significant differences as a result of statistical analyses depending on both time and sampling points. Here, it is also seen that the number of parameters that differ statistically in the temporal context (all parameters except TSS) is higher than the parameters that differ depending on the location (EC, Salinity, TDS, TSS, and discharge). It can be said that this result is an expected result since most of the parameters used in the study (water temperature, dissolved oxygen, flow rate, etc.) depend on seasonal temperature changes and precipitation patterns.

Table 3. *Pearson’s correlation between the measured water quality parameters in Kabaca Stream*

Water quality parameters		**Sign. level***	**(-) 0 (+)**
pH	Water temp.	0.0000	
DO	Water temp.	0.0000	
DO	pH	0.0000	
NO_3-N	Water temp.	0.0131	
NO_3-N	EC	0.0019	
NO_3-N	DO	0.0026	
Salinity	Water temp.	0.0016	
Salinity	EC	0.0000	
Salinity	DO	0.0021	
Salinity	NO_3-N	0.0012	
TDS	Water temp.	0.0011	
TDS	EC	0.0000	
TDS	DO	0.0012	
TDS	NO_3-N	0.0032	
TDS	Salinity	0.0000	
Discharge	TSS	0.0000	

*Only the correlations statistically significant both at $p < 0.05$ and $p < 0.01$ were listed

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The mean values of the measured water quality parameters were compared to the standards (if available for the investigated parameters) set forth by the country's Water Pollution Control Regulation (WPCR) to evaluate the overall pollution level of the measured water quality parameters and to analyze their temporal and geographical fluctuations along the Kabaca Stream. This was accomplished by discussing the general status of the selected water quality parameters below under the subtitle of physicochemical properties.

Physicochemical properties

Water temperature

When the temporal evaluation is made, it was clear and expected (due to the seasonal changes in climate) that the mean water temperature in the stream was significantly higher for summer months (particularly in August and September), whereas it dropped to nearly 0°C from December through February (*Fig. 3*).

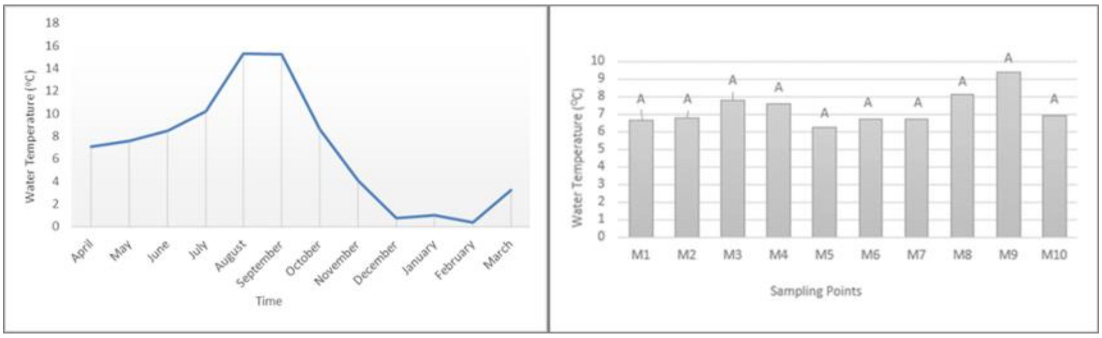

Figure 3. *Variations of average water temperatures based on both the sampling times (temporal) and the sampling points (spatial) along the Kabaca Stream*

The ANOVA analysis revealed that the differences in average water temperatures were statistically significant among the sampling times (temporal) as the highest and the lowest mean water temperatures were recorded for August at 15.27°C and for February at 0.35°C, respectively. This outcome was expected as seasonal changes in weather and precipitation patterns play a direct role in the temperature of the stream. On the other hand, no statistical difference was detected between the sampling points (spatial) (*Table 2; Fig. 3*), potentially caused by the sequential RoR-HEPPs constructed in the stream, interfering with the natural flow regime along the stream. Also, the fact that several small tributaries reach the main branch of Kabaca Stream as seen in *Figure 1*, particularly along the middle and lower sections, keeps the average water temperature of water in a similar range.

In the study conducted on Solaklı Stream, flowing within one of the sub-watersheds of the Black Sea Region, parallel results were reported in terms of seasonal distribution, but the average water temperature (12.76°C) was relatively higher -as expected- due to the fact that the sub-watershed was on the slopes of the region facing the sea (Verep and Calis, 2021). In addition, in research carried out in the upper part of the Coruh River, with the effect of the continental climate, the water temperature showed the usual seasonal distribution and the water temperature was closer to the averages found in this study (min. 0°C in February and the max. 20.2°C in July) (Birici et al., 2017).

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Table 3 shows Pearson’s correlations between the parameters measured for this study and it is seen that the water temperature had negative relation with pH, DO, salinity, and TDS while it resulted in positive relation with NO_3-N. It is already known that dissolved oxygen content varies inversely with water temperature. Similarly, in this research, the regression analysis revealed that the DO decreased as the water temperature increased in the stream with R^2 value of 0.80 (*Fig. 4*).

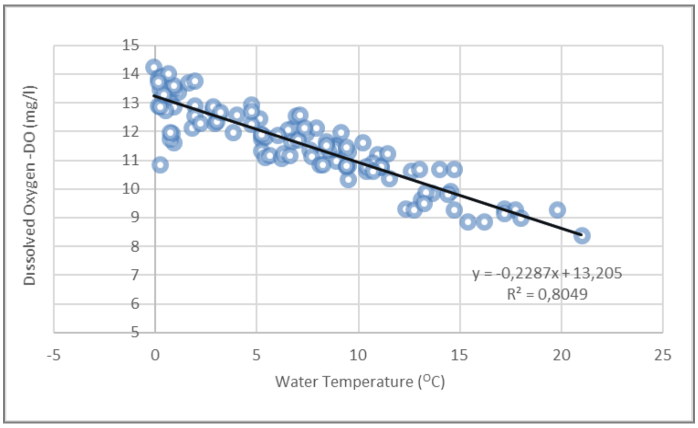

Figure 4. *The linear regression between dissolved oxygen (DO) and water temperature in the Kabaca Stream*

pH

According to the Water Pollution Control Regulation (WPCR), the optimal value for the pH in surface waters must be between 6 and 9. As for this study, the results revealed that the average highest pH value was 8.24 in March, and the lowest was 6.91 in October (*Fig. 6*). When the monthly average values of the pH values at all the sampling points were examined, it can be concluded that the waters of Kabaca Stream waters were within “the 1st class” (“High-Quality Waters”) (*Fig. 5*).

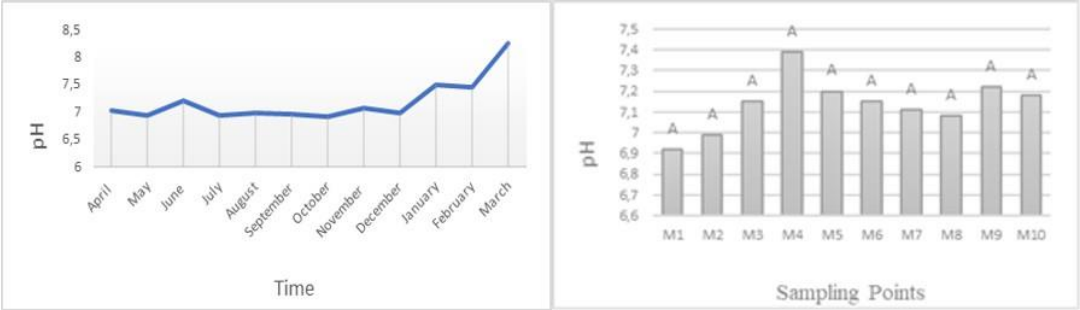

Figure 5. *Variations of average pH values based on both the sampling times (temporal) and the sampling points (spatial) along the Kabaca Stream*

According to the results of the ANOVA analysis, it was found that the mean measurement values of the pH were significantly different with respect to temporal comparison (between the sampling times) while there were no statistical differences detected spatially (between the sampling points) (*Table 2*). In the evaluation made to determine the water quality and pollution level of Fatsa Çalışlar Stream, they reported very similar but also higher pH than the current research. The average pH values in that study were estimated as 8.77, 8.84, and 8.80, respectively, at the 1st, 2nd, and 3rd stations, while the annual average pH value was determined as 8.80 (Santaflıoglu, 2018). According to the correlation analysis, it was found that the pH parameter had statistically negative and positive relationships with the water temperature and dissolved oxygen, respectively (*Table 3*).

Dissolved oxygen (DO)

The results showed that the maximum value of DO was measured in December (*Fig. 6*) at 13.34 mg/l while the minimum was detected as 9.33 mg/l in September (*Table 3*). According to the WPCR standards, the DO values should comply with the mean value of above 8 for surface waters to be considered clean. Therefore, when the values of the average DO amounts in this study were examined, it is clear that the water quality group of Kabaca Creek fell within the 1st Class and should be classified as "High-Quality Waters" (*Fig. 6*).

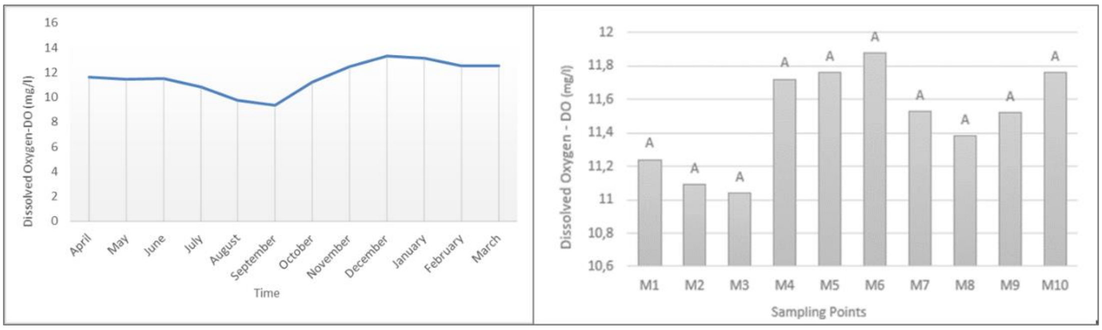

Figure 6. *Variations of average DO values based on both the sampling times (temporal) and the sampling points (spatial) along the Kabaca Stream*

As a result of the ANOVA tests, the mean DO amounts were found significantly different among the sampling times (temporal) whereas no statistical differences were detected among the sampling points (*Table 2*). The reason why only the temporal differences were statistically significant for this study can be associated with the seasonal fluctuations in water temperature (*Fig. 5*), one of the main features affecting DO levels in surface water resources. In the study conducted in the Solaklı Stream Catchment to investigate the effects of RoR-HEPPs on the water quality, the range in the average DO levels was wider than our study since the lowest value of the minimum DO value was measured in April with 5.5 mg/l and the highest amount was found to be 14.1 mg/l in January (Koralay, 2015).

Electrical conductivity (EC)

According to the WPCR standards of the country, the EC threshold value must be lower than 400 us/cm for the surface waters. When the average values of the electrical conductivity values measured at the sampling points were examined, it can be concluded that the EC values stayed in the 1st class range and thus considered "High-Quality Waters" (*Fig. 7*).

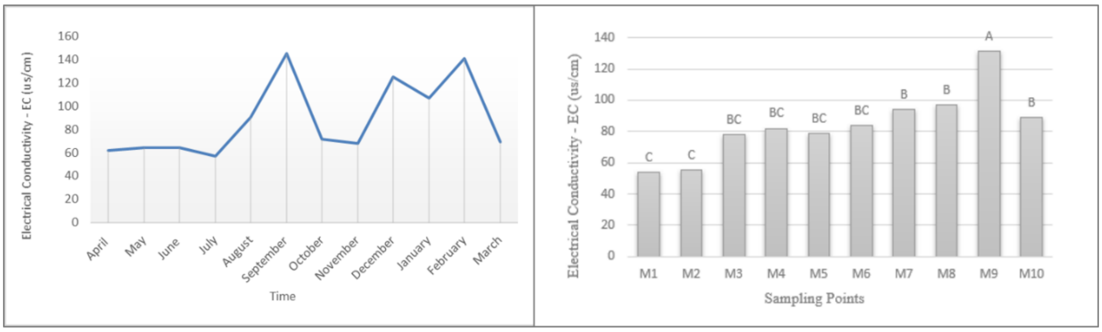

Figure 7. *Variations of average EC values based on both the sampling times (temporal) and the sampling points (spatial) along the Kabaca Stream*

The ANOVA analysis revealed that the differences in the mean electrical conductivity amounts in Kabaca Stream water were statistically significant among both sampling times and sampling points (*Table 2*). According to the time-dependent ANOVA result of the electrical conductivity, the highest value was measured as 145 µS/cm in September and the lowest value was found as 57 µS/cm in July. Among the sampling points, the highest and the lowest values were 131 µS/cm at M9 and 54 µS/cm at M1, respectively (*Fig. 7*). In the literature, depending on the land use types and the degree of human disturbances, various studies reported different amounts of EC in streams. For example, in research aiming to evaluate the monthly changes in the water quality parameters of Horohon Stream, the minimum value of the electrical conductivity was determined as 160 µS/cm in February 2012 and the maximum value was 244 µS/cm in September 2012 whereas the average EC was determined as 200 µS/cm (Mutlu et al., 2013). Moreover, a previous study examined the water quality parameters of Çarşıbaşı Stream reported that the EC values ranged between 65 and 332 µS/cm with the average value of 171.07 µS/cm (Könez, 2019). As it is already known, electrical conductivity in water is a parameter highly dependent on both the water temperature and the salinity. The result of the regression analysis proved a similar interaction between the electrical conductivity and the salinity parameters with the R^2 value estimated to be 0.83 (*Fig. 8*).

Salinity

When the temporal evaluation was made with salinity measurements seen in *Figure 12*, it was clear that -except April-June period- rather dramatic monthly changes became apparent. This outcome can be mostly associated with the seasonal changes both in the precipitation and the temperature as well as various inorganic and/or organic materials entering the stream due to human-induced disturbances including RoR-HEPP facilities, construction of new roads and mining activities. As for the spatial evaluation, it seemed that the salinity increased from upstream sampling points to downstream ones (*Fig. 9*) due to the addition of natural and/or man-made materials from the tributaries into the main channel, causing a rise in the amount of salt in the stream (Kaushal et al., 2005).

The results of the ANOVA analyses listed in *Table 2* revealed that the differences in mean salinity amounts were statistically significant between both sampling times and sampling points. With temporal comparison, the maximum salinity value was detected as 0.12 ppt in February while the minimum amount was determined as 0.03 ppt in July. On the other hand, among the sampling points, it was found that the highest value was

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0.09 ppt at M9 and the lowest value was 0.04 ppt at M1 (*Fig. 9*). In looking at the results of the correlation analysis, the parameter of salinity showed a negative relation with temperature while there were positive interactions with the parameters of EC, DO and NO_3-N parameters (*Table 3*).

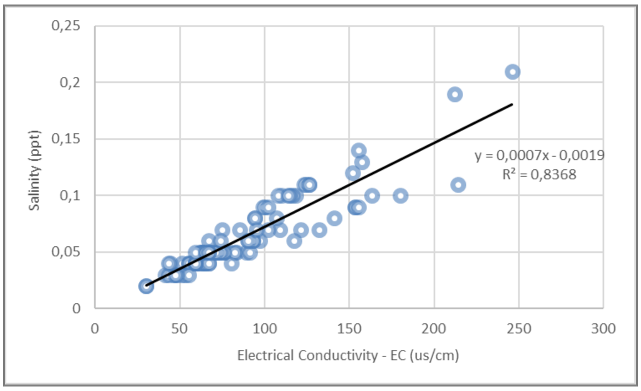

Figure 8. *Regression analysis showing high interaction between the electrical conductivity and salinity amounts*

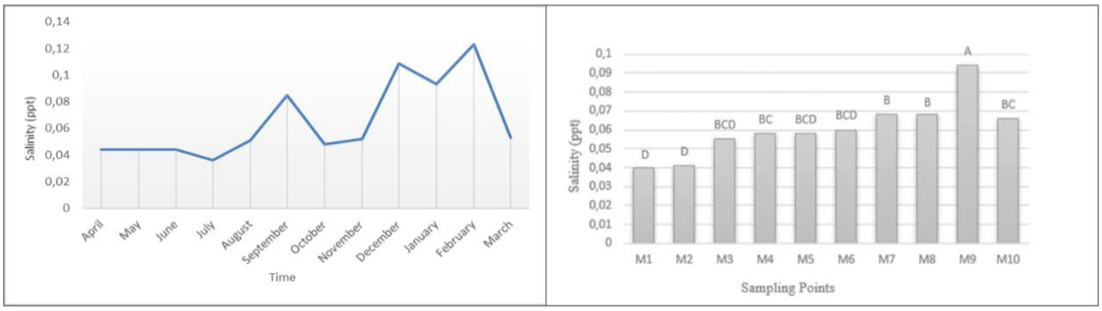

Figure 9. *Variations of average salinity values based on both the sampling times (temporal) and the sampling points (spatial) along the Kabaca Stream*

Total dissolved substances (TDS)

The literature has suggested that the amounts of total dissolved substance (TDS) in natural waters are generally proportional to the amounts of electrical conductivity (EC) and salinity parameters. Similarly, the results of this research also revealed that both temporal and spatial changes in TDS amounts showed parallel trends with the mean EC and salinity values. The average variation of the total dissolved substance at the sampling points was given in *Figure 10*, indicating monthly up and downs mostly depending on the seasonal precipitation and temperature changes.

In addition, it was clear that the amounts of TDS increased from the sampling points located at higher elevations to lower ones along the catchment (from M1 to M10), causing the addition of materials from the upstream to downstream (*Fig. 10*).

The ANOVA analysis revealed that the differences between sampling times and sampling points were statistically significant in terms of total dissolved substance amounts (*Table 2*). According to the results, the highest TDS measurement was done in February with 169 mg/l whereas the lowest value was recorded in July with 51 mg/l. Among the sampling points, the highest value was 129 mg/l at M9 and the lowest value was 54 mg/l at M1 (*Fig. 10*). The correlation analysis revealed that while the TDS amount was positively correlated with parameters of EC, DO, nitrate-nitrogen and salinity, it was negatively correlated with temperature parameter only (*Table 3*).

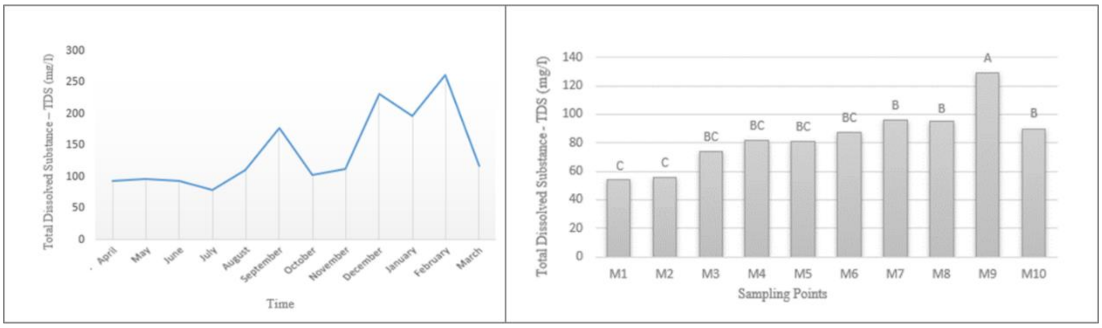

Figure 10. *Variations of average TDS values based on both the sampling times (temporal) and the sampling points (spatial) along the Kabaca Stream*

The regression analysis showed the TDS parameter had a very high linear interaction with both the salinity (R^2 = 0.99) and with the electrical conductivity parameter (R^2 = 0.83) (*Figs. 11* and *12*).

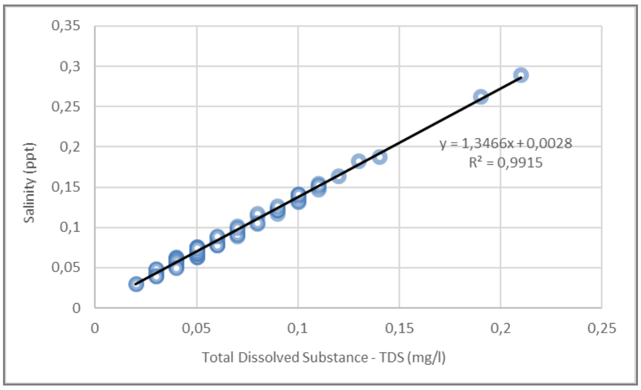

Figure 11. *Regression analysis showing high interaction between the salinity and TDS for the Kabaca Stream*

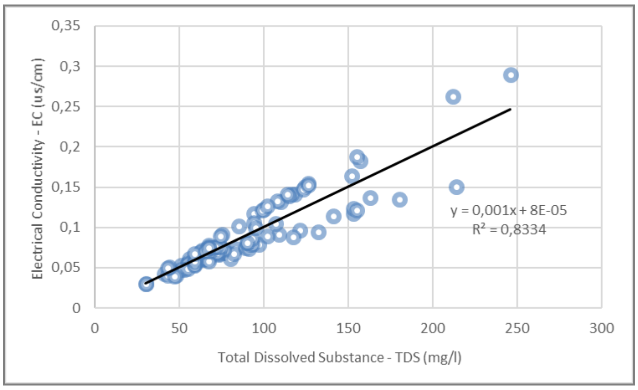

Figure 12. *Regression analysis showing high interaction between the EC and TDS for the Kabaca Stream*

All the mean amounts of TDS measured for this research were below the critical level of 500 mg/L that was set by the WPCR standards of Türkiye. Even though the study area has been impacted by several human-induced disturbances (RoR-HEPP facilities, mining activities and urbanization efforts such as building new roads, etc.), we assume that the high precipitation amounts and dense plant cover in the region plays a key role to keep some water quality parameters within the acceptable level. Similar outcomes were reported in a study evaluating the water quality and pollution level of Ordu Akçaova Stream as the average TDS level was found to be 145 mg/l (Alptekin, 2018). However, in watersheds that have been affected by intensive urbanization and/or industrialization, the surface waters can be severely polluted, as the study by Tokatlı (2020) revealed TDS amounts varied between 87 and 1310 mg/l, well over the standards set by the WPCR.

Nitrate nitrogen (NO_3-N)

According to the WPCR, the NO_3-N levels must be below 3.0 mg/l in natural surface waters in the country. As for this research, the mean NO_3-N amount was estimated to be 1.847 mg/l. Even though the level of NO_3-N exceeded this limit only for the October measurement (fell into the “2nd class” with “low polluted waters”), most of the time the waters of Kabaca Stream were within the “1st Class” (as “high-quality waters”) in respect to NO_3-N levels. (*Fig. 13*). However, the NO_3-N amounts found in this study were generally higher than the previous studies including the research carried out by Özen (2018), in which, the average NO_3-N values were reported between 0.22 mg/l and 0.34 mg/l.

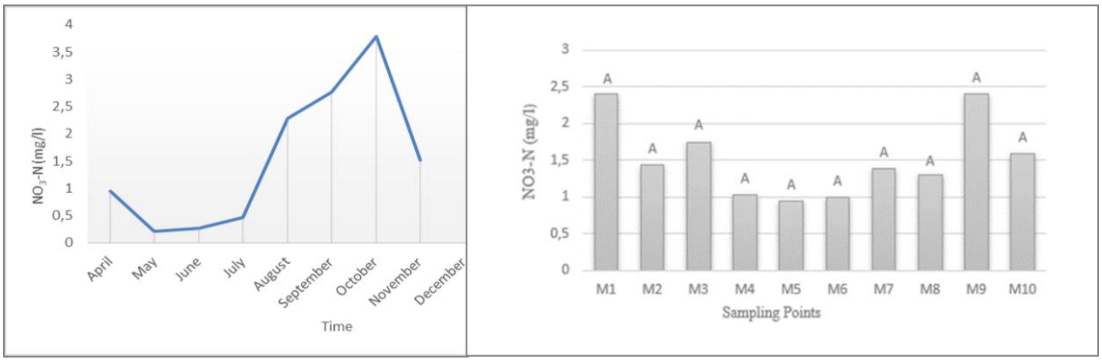

Figure 13. *Variations of average NO_3-N values based on both the sampling times (temporal) and the sampling points (spatial) along the Kabaca Stream (Please note that the NO_3-N amounts between December and March could not be measured due to the malfunction of the nitrate probe of the YSI-multiple water quality measuring device)*

According to the results of the ANOVA analysis, the temporal differences (among the sampling times) of the NO_3-N parameter were statistically significant whereas there were no statistical differences with respect to the spatial aspect (between the sampling points) (*Table 2*). The maximum value of the NO_3-N was recorded as 3.78 mg/l in October while the minimum was measured in May at 0.21 mg/l (*Fig. 13*). The correlation analysis showed that nitrate-nitrogen had a positive relationship with temperature and conductivity and a negative relationship with dissolved oxygen amount (*Table 3*).

Total suspended solids (TSS)

The results revealed that the annual averages of TSS amount with respect to both temporal (10.26 mg/l) and spatial (9.85 mg/l) distributions were similar to each other (*Table 2*). In general, except for the month of April and the sampling point of M9, there was parallelism in the TSS values (*Fig. 14*). The sharp increase visible that might be associated with new road construction (releasing excessive amounts of excavation to the Kabaca Stream) nearby the M9 point and close to the April sampling.

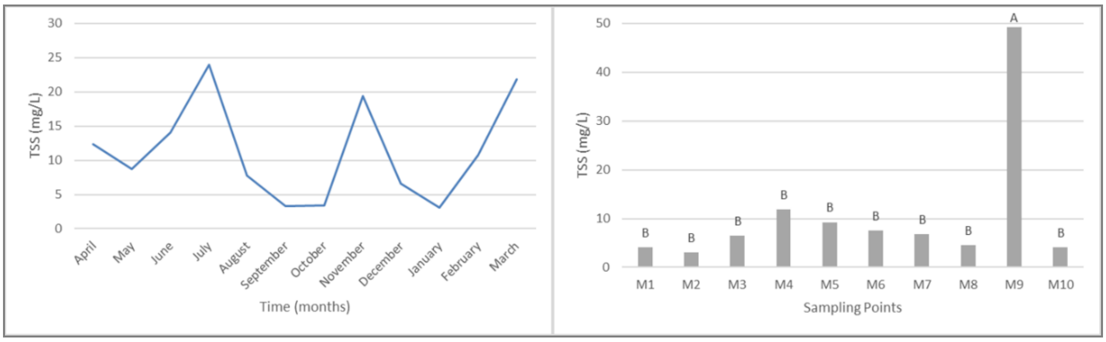

Figure 14. *Variations of average TSS values based on both the sampling times (temporal) and the sampling points (spatial) along the Kabaca Stream*

The ANOVA analysis revealed that there were statistically significant differences between the sampling points of the TSS values whereas there were no statistical differences between the sampling times (*Table 2*). TSS values were 114.7 mg/l at the highest M9 point and 3.66 mg/l at the lowest M2 point (*Fig. 14*). No limit value or standards have been determined for the amounts of total suspended sediments (TSS) for natural streams in Türkiye. Moreover, it should be noted that the number of water quality monitoring stations placed in the river systems in our country is quite insufficient, and therefore there is a shortage of collecting and/or producing long-term data on suspended solids and other water quality parameters (Isik, 2013). Similarly, while the European Environment Agency (EEA) does not set a threshold value for TSS, in only four states of the United States (Utah, Hawaii, North Dakota, and South Dakota) there are limit values set for the water quality standards in natural rivers (USEPA, 2003).

Since the sediment amounts in surface waters can easily be impacted by seasonal precipitation events, land use cover/change, soil erosion, urbanization, and various human disturbances (Bezak et al., 2016), previous studies resulted in different averages for TSS depending on whether their study area is affected by any of the above factors. For example, in research that took place in Yanıklar Stream, the average amount of TSS was found close to the present study at 8.40 mg/L (Küçükler, 2020). However, lower averages were reported by Mutlu and Uncumusaoğlu (2016) in Kuruçay Creek, where the mean TSS amounts for the summer and winter seasons were estimated as 3.2 mg/L and 1.3 mg/L, respectively. It was clear that the latter study sites were affected by fewer human-induced disturbances than the current research. On the other hand, much higher average TSS concentrations with 156.4 mg/L in the summer and 31.5 mg/L in the autumn of 2019 were estimated for the study carried out in the Sera Stream Catchment and such high values were attributed to the dumping of spoil and excavations as well as remediation activities carried out in the stream bed (Mete et al., 2022).

Discharge and water regime

According to the results of the ANOVA tests, the mean discharge levels of Kabaca Stream were 1.47 m^3/s and 2.16 m^3/s for temporal and spatial comparisons, respectively (*Table 2*). During the study period, the highest discharge in Kabaca Stream was measured in June with 3.87 m^3/s, probably due to the snow melt increasing the water level. On the other hand, the lowest one was recorded in September with only 0.44 m^3/s, mostly can be associated with the summer and early fall months receiving less precipitation reducing water levels (*Fig. 15*). Among the sampling points, it was found that the highest discharge value, as expected, was found to be 7.51 m^3/s at the M10, the last and the lowest (in respect to elevation) measuring point of Kabaca Stream. The lowest flow was recorded as 0.59 m^3/s at the M6 point (*Fig. 15*), where there is the regulator of the second RoR-HEPP facility (*Fig. 1*) diverting most of the stream's water for electricity generation.

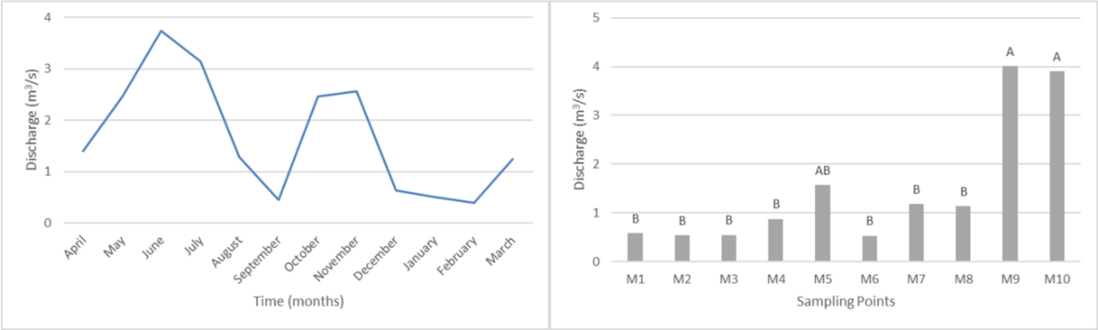

Figure 15. *Variations of average discharge values based on both the sampling times (temporal) and the sampling points (spatial) along the Kabaca Stream*

The ANOVA analysis revealed that while the differences between the sampling times (temporal) were statistically significant, there was no significantly important variation between the sampling points (spatial) (*Table 2*). It was determined in the results of the correlation analysis that there was an expected positive relationship between discharge and the amount of TSS (*Table 3*). As seen in *Figure 15*, there were some fluctuations in the annual distribution of discharge in the Kabaca Stream. It was assumed that besides the seasonal variation in precipitation and/or snow melt, the presence of sequential RoR-HEPPs also played a role in somehow radical up and downs recorded for the amount of water flow because the regulators of these facilities can lawfully take up to 90% of stream water, causing the reduction in the flow (Kurdoglu, 2016; Ozalp, 2010).

The effect of RoR-HEPP facilities on water quality parameters

One of the main goals of this study was to investigate whether the RoR-HEPP facilities that were sequentially built along the Kabaca Stream bed had any adverse effects on the water quality parameters that were being monitored. To compare the physicochemical parameters, the yields of suspended sediment, and the discharge, the sampling points in the study area were divided into three sections groups: (1) *before* the regulator, (2) *between* the regulator and each RoR-HEPP facility, and (3) *after* the tailwater outlet of each plant. Based on the classifications of these small hydropower plants described above, *Table 4* displays the findings of the ANOVA analysis on which water quality parameters were significantly impacted by these small hydropower plants.

Table 4. *The results of the ANOVA analysis showing which water quality parameters were impacted significantly by the RoR-HEPP facilities*

	Annual means				
Parameters	**Before (1)**	**Between (2)**	**After (3)**	**F values**	**P values**
Water temp.	7.19	7.33	7.34	0.005	0.995
pH	7.04	7.17	7.18	0.770	0.465
DO	11.15	11.55	11.65	0.915	0.404
EC	65.9 b	81.6 b	98.7 a	5.486	0.005**
Salinity	0.047 b	0.058 b	0.072 a	4.830	0.010**
TDS	0.064 b	0.082 b	0.099 a	5.056	0.008**
NO_3-N	2.081	1.193	1.584	1.687	0.192
TSS	4.60 b	7.13 b	17.34 a	4.007	0.021*
Discharge	0.99 b	0.90 b	3.27 a	13.888	0.0001**

*Significantly different at $p < 0.05$; ** Significantly different at $p < 0.01$. Please note that different letters indicate statistical significance among the means of the groups

Table 4 shows that statistical differences were found for the levels of EC, salinity, TDS, TSS, and discharge in this regard. In other words, it may be inferred that many of the water quality parameters were dramatically altered, particularly among the sections *before* and *after*, mostly due to the construction of several RoR-HEPPs along the Kabaca Stream. How these plants might have impacted the investigated parameters of Kabaca Stream was discussed in detail under the subtitles listed below.

Electrical conductivity (EC), salinity, total dissolved substances (TDS)

The statistical tests revealed that the average concentrations of EC, Salinity, and TDS in the *before* section (stream's natural portion) were much lower - indicating higher water quality standards - than in the *between* and *after* sections of the Kabaca Stream (*Table 4*).

It is clear that the water quality parameters of EC, salinity and TDS were statistically changed by RoR-HEPPs (*Figs. 16, 17* and *18*), both at the time of the construction and operation stages mostly due to the construction of new roads and mining activities. In other words, the results indicate that the stream waters were cleaner *before* the regulator due to the intrusion of both solids and dissolved substances at natural levels, but the amounts of such substances became excessive at the lower sections (*between* and *after*) of the stream causing pollution of the water.

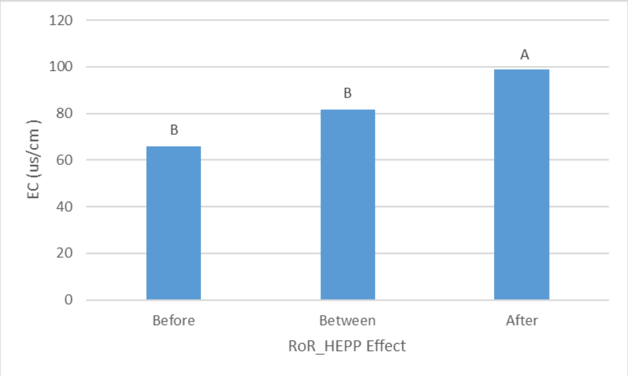

Figure 16. *Impact of the RoR-HEPPs on the EC amounts varying among the before, between and after sections of the Kabaca Stream*

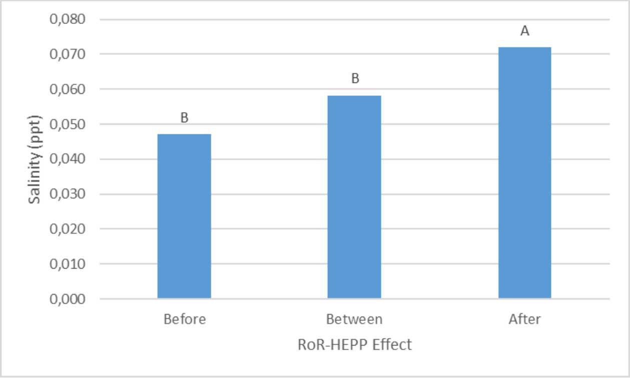

Figure 17. *Impact of the RoR-HEPPs on the salinity amounts varying among the before, between and after sections of the Kabaca Stream*

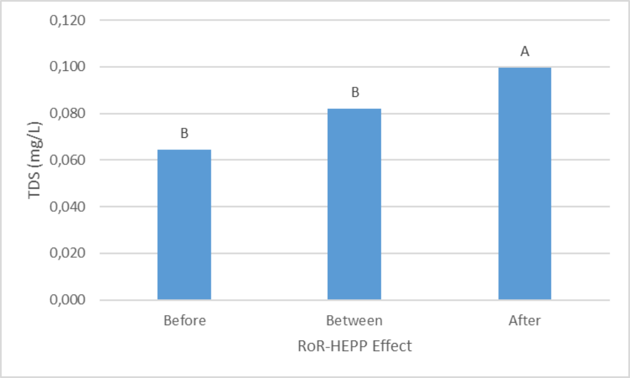

Figure 18. *Impact of the RoR-HEPPs on the TDS amounts varying among the before, between and after sections of the Kabaca Stream*

The results revealed that the levels of EC, salinity and TDS increased between upstream and downstream sampling points since excessive amounts of man-made materials from both the construction and running of RoR-HEPPs enter into the stream bed, causing a rise in the amount of both solid and dissolved substances (e.g. salt, etc.) for the stream water. Previous studies reported similar outcomes in watersheds where practices of the destruction of natural lands due to intensive urbanization, road building and mining activities, severely pollute surface waters (Kaushal et al., 2005; Hua, 2017; Alptekin, 2018; Tokatlı, 2020).

The intrusion of higher-than-usual levels of materials from disturbed lands within the Kabaca Stream catchment area may be the main cause of these increases in EC, salinity, and TDS concentrations. The Google Earth satellite images (*Fig. 19*) show the severe destruction of steep slopes brought on by the construction of the RoR-HEPP facilities as well as the construction of water transmission lines and new roads, which in turn causes soil erosion via surface runoff and allows a considerable amount of organic and inorganic materials into the river bed, especially in the sections after the regulators.

As a result of the survey conducted with the participation of 60 experts consisting of state and/or private enterprises and academicians, both leaving an inadequate amount of environmental flow (75%) and damaging mountain and riparian forests (51.6%) were rated as the most damaging issues associated with construction and/or running the

HEPP facilities in Türkiye (Kurdoglu, 2016). The results of the current study particularly supported the latter issue of that survey because it was concluded that the main change causing significant rises in the concentration of EC, salinity and TDS levels in the present study was more inorganic and/or organic materials reaching the stream due to the degradation of once-forested slopes along the research area (*Fig. 19*). In similar research investigating the effects of the Çambaşı RoR-HEPP on the physicochemical water quality, it was reported that the power plant changed most of the water quality parameters negatively and significantly between the pre-regulator (*before*) and the tailwater outlet (*after*) including TSS, EC and TDS for 107%, 102% and 39%, respectively (Verep and Çalış, 2021).

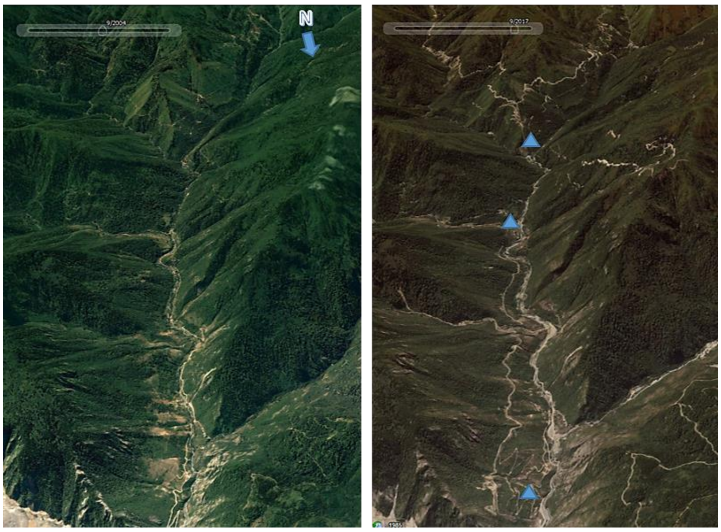

Figure 19. *The GoogleEarth images (September 2004 on the left and September 2017 on the right) illustrate how vegetated steep slopes were fragmented along the Kabaca Stream*

Alterations in total suspended sediments (TSS)

Changes in sediment quantity and/or distribution can negatively impact the habitat composition and morphology of stream systems because sediments -whether transported or deposited- play a significant role in the number and health of ecosystems as well as the biodiversity in and around the stream bed (Benejam et al., 2016; Hauer et al., 2018). When all types of HEPPs are constructed, the natural dynamic equilibrium, which is characterized by a continuous interplay between erosion, deposition, and remobilization of material, is disturbed (Hayes et al., 2018; Agrawal et al., 2011). This causes sediment to accumulate upstream of dams, reduces downstream fertilization (such as irrigation and aquatic organisms) due to a lack of sediment and nutrients, and poses a downstream pollution risk as well (Hauer et al., 2018).

The findings of the present study also revealed that the annual TSS averages differed statistically across the three sections (*Fig. 20*). The main reasons for this difference are that the RoR-HEPP facilities use up to 90% of the stream water for energy production via the regulators and that the sediment carried in the stream water was kept in the resting pools (also known as stilling pools or sand traps), resulting in a significant shift in the amount and distribution of sediment, particularly along the downstream of the stream bed (Arroita et al., 2015; Hayes et al., 2018).

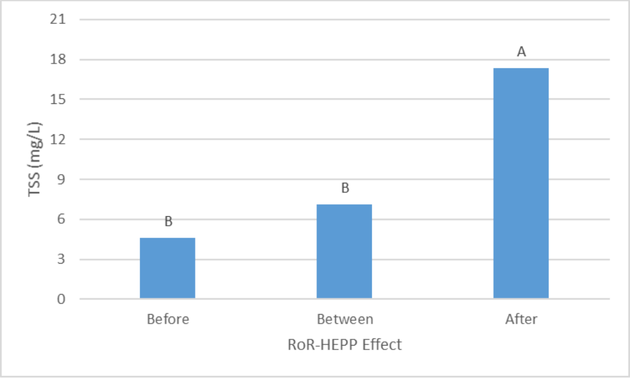

Figure 20. *Impact of the RoR-HEPPs on the TSS amounts varying among the before, between and after sections of the Kabaca Stream*

In the results, it was anticipated that the annual TSS average was estimated as 4.60 mg/l in the *before-section* -consisting of M1 and M3 sampling locations- located at altitudes between 1400 and 1450 m, where there was a pristine forest structure surrounding these locations. However, in the *between-section* (M2, M4, M6, and M8), the TSS concentration increased to 7.13 mg/l, but this increase was not due to the natural sediment carried by the stream because the regulators removed and stored the natural sediment in the resting pools. Instead, this increase in TSS was believed to have been caused by the kilometers of roads built for the construction of water transmission pipes. In addition, this increase was not statistically significant from the TSS average in the *before-section*. In contrast, *Table 4* revealed that the amount of TSS (17.34 mg/l) in the *after-section* of the Kabaca Stream was considerably higher than in the *before and between-sections*. This result was primarily attributable to the fact that the lands surrounding all the sampling locations (M5, M7, M9, and M10) in the after section have been severely disturbed by human-induced activities (*Fig. 19*). It should be noted that one of the reasons for the high TSS concentration at the sampling points in the after section may be related to soil erosion caused by the destruction of vegetation in the middle and lower portions of the watershed as a result of the construction of kilometers of roads and water transmission channels for the HEPPs. In addition, the other reason can be related to the fact that several tributaries within the watershed discharge water and sediments to the Kabaca Stream bed, thereby increasing TSS concentrations near the sampling points in the after section.

Therefore, the effect of HEPPs on the quantity of TSS transported in the Kabaca Stream is more evident when comparing the *before* and *after sections*. The fact that the average TSS concentration of 7.13 mg/l at the *between section* is less than the annual average TSS concentration of 11.2 mg/l for all sampling sites shown in *Table 2* can be attributed directly to the impacts of the RoR-HEPP facilities. The main reason why the TSS ratio in the *between section* remains at 7.13 mg/l is that when the water is taken from the stream by the regulators, it must rest in the stilling pools *before* being fed to the penstocks. During this time, the sediment, which is naturally present in the stream water, settles out, resulting in the removal of sediment from the stream ecosystem. This explains why it is statistically much lower than the calculated average concentration of TSS (17.34 mg/l) in the *after section* (*Table 4*).

Similarly, Mete et al. (2022) concluded that both the disruption caused by the operation of the Yıldızlı HEPP and the regulation works performed in the stream bed contributed to an increase in the average TSS concentrations in the downstream station of 129.5% and 212.3% during the summer and fall seasons, respectively. In addition, Koralay (2015) discovered that RoR-HEPPs had a negative impact on both the quality and quantity of water in the Solaklı Catchment’s mainstream, as significant changes occurred in water quality parameters including the TSS amounts.

Discharge and flow regime changes

Among the most frequently reported ecological effects of constructing and operating RoR-HEPP facilities is flow modification, which, in general, causes water depletion in certain sections of the stream (e.g. the bypass reach), destruction in longitudinal connectivity, and habitat fragmentation (Kuriqi et al., 2021). According to multiple studies, including the present one, RoR-HEPPs significantly alter the natural flow regime in the redirected river segments; therefore, it is essential to promote an ecologically appropriate flow, particularly in the diverted section of stream ecosystems (Anderson et al., 2015; Lange et al., 2018; Kibler and Alipour, 2017).

Our findings revealed that RoR-HEPPs in the study area utilized a sizable portion of the water (up to 90% is allowed by law) from Kabaca Stream. Statistical analyses demonstrated that the amount of water left for the stream as environmental and/or minimum flow was much less in the *between-section* with 0.89 m^3/s compared to the *after-section* with 3.26 m^3/s where all the water released back to the stream increasing the discharge amount to its normal levels (*Fig. 21*).

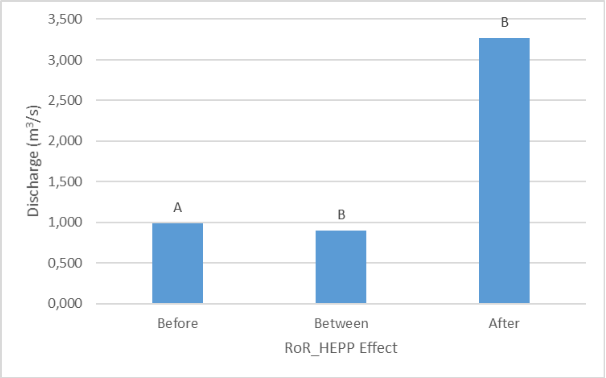

Figure 21. *Impact of the RoR-HEPPs on the discharge amounts varying among the before, between and after sections of the Kabaca Stream*

As for the RoR-HEPP facilities installed in the study area, the quantity of environmental flow and/or minimal discharge was set to be 10% of the average discharge of the previous ten years, in accordance with the Agreement on the Water Use Right of Türkiye. However, the study’s findings also demonstrated that when determining the actual amount of environmental and/or minimal discharge, consideration must be given to each area’s geographic location and ecological requirements, and preparations must be made in accordance with those requirements.

It is widely assumed that hydroelectric plants do not consume or pollute the water they use to produce energy; however, they disrupt the natural flow, altering both the temporal and spatial distribution of the flow. Because water flow is the primary driver of stream ecological processes, disruption of natural flows has a significant impact on river ecosystem functioning. Accordingly, Pang et al, (2015) discovered in their research that, while stream flows from the upper reach were guaranteed, lower parts of the stream experienced periodic drying-up during the daily operation of the power plant, resulting in downstream ecosystem degradation and service losses.

In their study, Ozalp et al. (2010) underlined that the vegetation and habitats of aquatic life would be adversely impacted and that this effect would be substantially more severe in dry seasons when precipitation and consequently stream discharge dropped.

Another study (Koralay, 2015) that looked at how multiple RoR-HEPP facilities affected stream ecosystems found that if the streamside vegetation declined as a result of those facilities' negative effects, the stream's water temperature would rise, causing a decrease in the amount of dissolved oxygen, which would lower the likelihood of aquatic organisms surviving. Moreover, according to a related study, discharge pattern alterations not only have an effect on the long-term economic viability of a hydropower facility, but may also pose significant challenges to the ecological and/or ecosystem functions (e.g. decomposition of leaf-litter) of the stream (Martínez et al., 2017).

Water temperature, pH, DO and NO_3-N

When *Table 4* is examined, it is seen that there were no statistically significant differences between the averages of water temperature, pH, DO and NO_3-N parameters, among the *before*, *between* and *after-sections* of the RoR-HEPPs. As can be seen from the graphs of these parameters (*Fig. 22*), it was observed that the average values increased particularly between the *before and after sections*, but it was determined that these differences were not statistically significant.

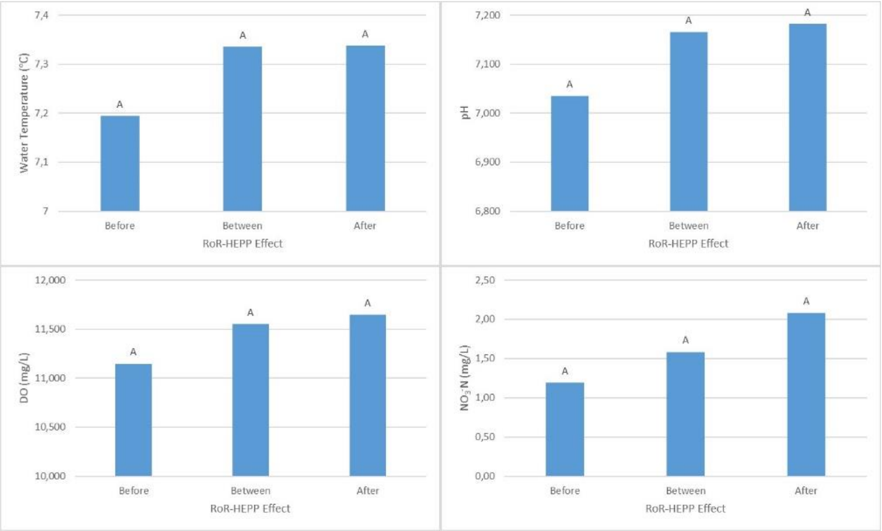

Figure 22. *Impact of the RoR-HEPPs on the water temperature, pH, DO and NO_3-N amounts among the before, between and after sections of the Kabaca Stream*

Similarly, there are few studies also available in the literature showing that HEPPs do not significantly change at least some of the water quality parameters in stream ecosystems. For example, Alvarez et al. (2020) discovered no significant differences in the physicochemical parameters of pH, temperature, dissolved oxygen, and conductivity between sampling points and years for any of the four plants they studied, with the exception of temperature for one of the plants. Furthermore, Koralay (2015) observed that based on the measurement points, both Arca and Camlıkaya HEPPs built and operated on Solaklı Stream showed no statistically significant differences in the tested parameters of water temperature, pH, EC, DO, TDS, salinity, and TSS.

Conclusion

Construction of run-of-river hydroelectric power plants (RoR-HEPPs) on streams around the world has increased rapidly in recent years, especially in developing countries like Türkiye in an effort to address the energy gap. This has had a negative impact on the quantity and quality of water resources, as well as the distribution of sediments along stream ecosystems. Türkiye has implemented new rules since the early 2000s in order to promote hundreds of run-of-river hydroelectric power plants (RoR-HEPPs), which were previously mostly thought to have less detrimental implications for stream ecosystems when compared to large dams. However, it has come to light that the RoR-HEPP facilities have the potential to seriously harm and disturb the ecosystems of many streams, as well as to spark social unrest between the state and the residents who live near these streams. One of those stream ecosystems is the Kabaca Stream in Artvin, Türkiye, where three RoR-HEPPs were built in succession, severely degrading the mountainous and steep slopes and changing the water quality and regime as well as the amount and distribution of sediment along the stream. However, just a few studies on the potential consequences of these structures on stream ecosystems have been done in this area of the country. Thus, the primary goal of this study was to investigate the effects/changes that these RoR-HEPPs could have on specific water quality parameters, discharge, and total suspended solids (TSS) in Kabaca Stream. The pH, water temperature, dissolved oxygen (DO), electrical conductivity (EC), salinity, total dissolved substances (TDS), and nitrate-nitrogen (NO_3-N) values were measured in the field at ten sampling points chosen along the stream using the YSI Professional Plus portable devices, while the monthly discharge and TSS quantities were estimated both on-site and in the lab. To investigate the impact of RoR-HEPPs on selected water quality indicators, sample sites were divided into three groups: *before* the regulators, *between* successive HEPPs, and *after* the HEPPs.

Overall, the construction of multiple RoR-HEPPs along the Kabaca Stream can be inferred to have significantly altered (increased or decreased) a number of water quality parameters, particularly between the *before* and *after sections*. For instance, the findings revealed that the average discharge rate of 3.27 m^3/s in the after sections decreased to 0.89 m^3/s in the *between sections*, indicating a considerable decrease in the volume of water in the stream because up to 90% of the stream water was used by the ROR-HEPPs. According to the “Water Usage Rights Agreement,” the quantity of environmental flow established by the country’s legislation is 10% of the ten-year average discharge. However, the study’s findings also demonstrated that when determining the actual quantity of environmental flow, each region’s geographical location and ecological needs must be taken into account.

With respect to the evaluation of water quality, it was determined that the majority of parameters displayed statistically significant temporal and spatial variations. The analyses also revealed that the number of parameters that statistically differ for the temporal comparison (all parameters except TSS) was greater than the number of parameters that differ based on location (EC, Salinity, TDS, TSS, and discharge). This result suggests that the majority of the parameters examined in this study (water temperature, dissolved oxygen, flow rate, etc.) were highly dependent on seasonal temperature fluctuations and precipitation patterns in the region. According to the country's water quality regulations, the majority of the mean water quality parameters in this study were classified as first or second class, indicating that the waters of the Kabaca Stream were typically in acceptable condition. Nonetheless, for a number of monthly measurements, the values of a few water quality parameters reached the third or even fourth-class level, indicating a pollution threat at specific sampling locations.

On the basis of these findings, it would be rational to argue that human interventions, particularly in the upper portions of forested watersheds, have direct effects on the water quality and the amount of sediment produced and transported in those watersheds, and thus have negative effects on the natural structure of stream ecosystems.

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