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ARAŞTIRMA MAKALESİ RESEARCH PAPER

Spatiotemporal Assessment of Bacteriological Water Quality in Rivers: A Censoring-Aware Integrated Approach (Harşit Stream, Türkiye) [*]

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Abstract: This paper presents an integrated, reproducible framework for assessing bacteriological quality in rivers. The aim is to quantify spatial variation and temporal trends with non-parametric statistics using censored Kaplan-Meier (KM) summaries and a threshold event approach. For this purpose, monthly surface water samples were collected under sterile conditions at seven stations on the Harşit Stream (Giresun, Türkiye), and transported to the laboratory under a cold chain protocol. Total coliform (TC), Fecal coliform (FC), *Escherichia coli* (EC), and fecal Streptococci (FS) counts (MPN/100mL) were used as indicators of bacteriological quality. Findings were examined using descriptive statistics and Kaplan–Meier summaries, considering right censoring. Furthermore, station differences and relationships were tested. Moreover, multivariate structure and quality trends were evaluated using statistical analyses. Furthermore, bacteriological quality assessment was performed according to national and international guidance. This study verified the effect of KM summaries on censoring due to clustering at the upper limit. Wide-ranging positive and strong relationships were detected between parameters ($p<0.001$). A common gradient was detected in all bacterial indicators. The trend over time showed a decrease only at Station 2. Furthermore, the stations are clearly classified into high load (stations 6–7), low load (stations 1–3), and intermediate load (stations 4–5; with 2 higher distinctions) clusters. In conclusion, KM-based censoring of sensitive summaries and threshold event analysis comprehensively manage censoring in bacteriological stream data. In this way, decision makers will realize the risk indicators that show how long it will take to exceed the threshold free from substitution-based bias. This will facilitate rapid and equitable interventions in sustainable basin management. This application is one of the first systematic KM applications for river bacteriology in Türkiye and has the potential to be applied to different watersheds.

Keywords: Harşit stream, water quality, spatiotemporal analysis, censored data, survival analysis, multivariate analysis.

Akarsulardaki Bakteriyolojik Su Kalitesinin Uzamsal-Zamansal Değerlendirmesi: Sansür Duyarlı Entegre Bir Yaklaşım (Harşit Çayı, Türkiye)

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Öz: Bu çalışma akarsulardaki bakteriyolojik kaliteyi değerlendirmek için tekrar üretilebilir, entegre bir çerçeve sunmaktadır. Sansür duyarlı Kaplan–Meier (KM) özetleri ile eşik olay yaklaşımını entegre ederek parametrik olmayan istatistiksel yöntemlerle uzamsal farklılıkları ve zamansal eğilimleri nicelleştirir. Bu amaç için Harşit Çayı'nın (Giresun, Türkiye) yedi farklı bölgesinden aylık yüzey suyu örnekleri steril koşullar altında toplanmış ve soğuk zincir protokolü kapsamında laboratuvara taşınmıştır. Su örneklerinin toplam koliform (TC), fekal koliform (FC), *Escherichia coli* (EC) ve fekal streptokok (FS) sayımları (MPN/100mL) bakteriyolojik kalitenin göstergeleri olarak kullanılmıştır. Bulgular, sağ sansürleme dikkate alınarak tanımlayıcı istatistikler ve KM özetleri kullanılarak incelenmiştir. Ayrıca, istasyon farklılıkları ve ilişkileri test edilmiştir. Dahası, çok değişkenli yapı ve kalite eğilimleri istatistiksel analizler kullanılarak değerlendirilmiştir. Bakteriyolojik kalite değerlendirmesi ulusal ve uluslararası kılavuzlara göre de yapılmıştır. Çalışmada KM özetleri, üst sınırda kümelenme nedeniyle sansürlemeye etkisini doğrulamıştır. Parametreler arasında geniş kapsamlı pozitif ve güçlü ilişkiler tespit edilmiştir ($p<0,001$). Tüm bakteriyel göstergelerde ortak bir gradyan tespit edilmiştir. Zaman içindeki eğilim, sadece İstasyon 2'de bir azalma göstermiştir. Ayrıca, istasyonlar açıkça yüksek yük (istasyonlar 6-7), düşük yük (istasyonlar 1-3) ve orta yük (istasyonlar 4-5; 2 daha yüksek ayrımla) kümelerine sınıflandırılmıştır. Sonuç olarak, KM tabanlı sansür duyarlı özetler ve eşik olay analizi bakteriyolojik akarsu verilerindeki sansürü bütüncül biçimde yönetmektedir. Bu sayede, karar vericiler ikameye dayalı yanlılıktan arındırılmış, eşik aşımı ne kadar sürede olacağını gösteren net risk göstergeleri görerek sürdürülebilir havza yönetiminde hızlı ve adil müdahaleleri kolayca gerçekleştirebilecektir. Bu uygulama, Türkiye'de akarsu bakteriyolojisine yönelik ilk sistematik KM uygulamalarından biridir ve farklı havzalara uygulanabilme potansiyeli taşımaktadır.

Anahtar kelimeler: Harşit çayı, su kalitesi, uzamsal-zamansal analiz, sansürlü veri, sağkalım analizi, çok değişkenli analiz.

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INTRODUCTION

Water has been among the most valuable natural resources for civilizations throughout history. Water, which has been accepted as the symbol of life since the beginning of human history, is unconsciously used, causing great damage to the ecosystem. Especially in parallel with the rapid increase in industrial development since the Industrial Revolution, the problem of pollution in water resources is a remarkable situation throughout the world. Although it is known that water covers three quarters of the world, in fact, it is obvious that we have a global water problem.

The sustainable management of water resources on a global scale is at a more critical juncture than ever before due to climate change, urbanization, agricultural activities, and other pressures on urban infrastructure (IPCC, 2022; UNESCO, 2024). In many countries, monitoring reports prepared by the UN and at the national level reveal that freshwater ecosystems, including rivers, are deteriorating in terms of flow regimes, area loss, and pollution loads, posing a direct risk to both water security and ecological vulnerability (Dudgeon, 2025). Such trends, combined with sharp declines in freshwater biodiversity, require science-based, site-specific management approaches to protect and improve resources (Tickner et al., 2020).

Countries require usable water to take forward-looking strategic steps. Potential is of great importance in the distribution of the amount of water that needs to be known. Türkiye's annual average rainfall is 670 mm. Maximum average precipitation (1400 mm/year) is in the Eastern Black Sea region, the lowest average rainfall (400 mm/year) in Kızılırmak, and it falls into Konya closed basins. According to these precipitations, our country's gross annual water potential is 501 billion m³. Of this total potential, approximately 166 billion m³/yearly part goes directly to flow, with the remaining 335 billion m³/annual part infiltrating. It does not pass into surface flow due to reasons such as evaporation and vegetative transpiration. The total water amount of our rivers is on average with the contribution of water leaking underground. 186.1 billion m³/year level. Rivers, which play an important role in the water cycle, are known to account for 0.5% of total flow. They are under constant pressure from human activities such as domestic, industrial, and agricultural sources (Akyel, 2007).

Rivers are indispensable for biodiversity and life in the terrestrial ecosystem. It is the most important source of usable water, which is an element. Growing is becoming increasingly limited as a result of the pressure of industrialization and human factors. The importance of protecting usable fresh water resources is increasing day by day and gaining vital value. Disturbances in the water quality of such sources threaten the aquatic ecosystem and also result in the death of aquatic organisms and so cause environmental problems. Water quality is a fundamental determinant for the functionality and biodiversity of river ecosystems. Food networks, habitat quality, species distributions, and ecosystem services are rapidly affected by deteriorations in water quality (Dudgeon, 2024; Sayer et al., 2025). Recent studies indicate that freshwater biodiversity loss has accelerated due to the simultaneous impact of multiple threats, highlighting the necessity of comprehensive, watershed-based restoration and pollution reduction approaches to reverse this trend (Orr et al., 2024; Ahmed et al., 2022). In addition, advanced statistical methods and artificial intelligence-based applications are providing new perspectives for the sustainable use of water resources (Alver et al., 2025; Palabıyık & Akkan, 2025; Isık & Akkan, 2025; Ahıskalı et al., 2025; Işık et al., 2024).

For this reason, the primary aim of this paper is to quantitatively characterize the spatiotemporal patterns of bacteriological water quality in the Harşit Stream (Türkiye) through a multi-station monitoring design and to assess these patterns through a risk-based lens informed by national and international guideline thresholds. Focusing on (i) classical microbial indicators-including Total Coliforms (TC), Fecal Coliforms (FC), *Escherichia coli* (EC), and Fecal Streptococci (FS)- (ii) the study integrates a comprehensive suite of statistical approaches: descriptive analyses, inter-station comparisons, correlation assessments, temporal trend evaluations, time-to-threshold (survival) analyses, multivariate summaries, and clustering techniques. Furthermore, (iii) bacteriological variations are visualized across both spatial and temporal dimensions, followed by a compliance evaluation based on threshold values drawn from WHO, EU, EPA, Canadian, and specifically Turkish SWQR standards. By offering not only an in-depth snapshot of current water quality conditions but also a reproducible, data-driven evaluation framework, this research contributes directly to identifying contamination hotspots, delineating manageable risk zones, and supporting evidence-based environmental management and policy decisions.

MATERIAL AND METHOD

Study area: In this study, Harşit Stream flows into the Black Sea within the borders of Giresun province. It was aimed to reveal the current physicochemical and bacteriological water quality of the stream. Harşit Stream originates from Vavuk Plateau within the borders of Gümüşhane province, enters the provincial territory near Günyüzü and flows into the sea in the east of Tirebolu. Its length within the provincial borders is 50 km, and it is the longest river in the province with a total of 160 km. There are Doğankent I and II hydroelectric power plants on the Harşit Stream. The flow rate of the stream is 232 m³/sec.

Harşit Stream has an annual fresh water potential of 178 hm^3. It is one of the most important fresh water resources for the province. In this study, water samples were taken from 7 different points, from Günyüzü location, where Harşit Stream enters the provincial border, to the point where it discharges into the Black Sea collection was carried out (Akkan, 2017).

The definition of station points is as follows: Station No. 1: Where Harşit Stream enters the borders of Giresun province. It covers the vicinity of the Günyüzü locality. Station no. 2: It covers the outlet of the Doğankent district and represents the area under intense pressure from both the district wastewater and the dam lake. Station number 3: It represents the area where agricultural activities are carried out after trout farms. Station No. 4: It represents the area where water is transferred to tanks before Aslancık HEPP and where the water level is mostly low. Station No. 5: The area, which was a former sand and gravel quarry operation, is located after the Aslancık HEPP operation and corresponds to the location under the influence of the power plant. Station No. 6: It represents the area where domestic garbage is left by the local people and where sand-gravel enterprises operate intensively. Station No. 7: It covers the discharge point of Harşit Stream into the Black Sea and covers the location where domestic, small-scale industrial ,and agricultural activity wastes have an intense impact.

The collecting samples of surface water: In order to evaluate physicochemical variables, the sample containers used in the research were washed in an acid bath (1-2% HCl) and pure water, respectively, one day before going out to the field. Then, the sample containers were rinsed with pure water and dried in the oven, making them ready for use. Water sample collection was collected through a Nansen bottle in accordance with the procedures of Turkish Water Quality Control Regulation "Sampling and Analysis Methods Communiqué" (2009) and was brought to the laboratory with a cold chain without wasting time. For bacteriological analyses, after appropriate sterilization conditions were met in dark glass water sample bottles, water samples were collected sterilely (100 mL) from 20 cm below the stream surface and brought to the laboratory within 4 hours, again maintaining the cold chain, and then analyses were carried out according to standard methods (APHA, 1992).

The bacteriological analyses of the water samples: During the examination of water samples in terms of bacteriological parameters, total coliform (TC), fecal coliform (FC), fecal streptococci (FS) bacteria and *E. coli* (EC) counts were determined. Most Probable Number (MPN) method procedures were used using lactose broth for total coliform bacteria count. 3x10 mL, 3x1 mL, 3x0.1 mL water samples were inoculated into 10 mL lactose broth cultures sterilized under appropriate conditions. Single strength lactose broth was used for 0.1 and 1 mL samples, and double strength lactose broth was used for 10 mL samples. After the inoculated samples were incubated at 37 °C for 24-48 hours, the total coliform counts in 100 mL of the tubes with acid and gas formation were determined according to the MPN tables (Madden and Gilmour, 1995). The tubes with positive results in the MPN method, which was performed to determine the total coliform bacteria count, were inoculated into EC Broth medium and incubated at 45.5 °C for 24 hours, and then the tubes that formed gas in Durham tubes were evaluated as fecal coliform positive, and the total fecal coliform counts in 100 mL were determined according to the MPN tables. The acid and gas formation positive tubes in the MPN method were inoculated into EMB agar with the reduction technique and incubated at 37 °C for 18-24 hours. At the end of the incubation period, the colonies that formed a metallic green zone were subjected to the IMVIC test, and the suspicious colonies were re-inoculated into lactose broth and incubated at 44.5 °C for 24-48 hours and then confirmed, and the number of *E. coli* was determined. Sodium aside medium was used to detect fecal streptococci. Under appropriate conditions, 5 mL of sodium aside medium was placed in sterile tubes and 1 mL of water sample was added and left for incubation for 24-48 hours. Tubes with turbidity as a result of incubation were evaluated as positive, and the number of fecal streptococci was calculated (Balcı, 2007). All procedures were carried out in 3 replicates according to Anonymous (1995).

Statistical Analyses

Descriptive Statistics: The sample size (N), minimum, quartiles (Q1, median, Q3), mean, standard deviation, and geometric mean were reported for the parameters. The count results reported with ”>” were stored in the database as values equal to the numerical upper limit. Descriptors of the Kaplan–Meier type were provided when there was right censoring; this approach is commonly recommended for dealing with censoring in environmental data (Oelsner et al., 2017).

Intergroup Comparisons: Differences in distribution between stations were tested using the Kruskal–Wallis Test. When significant, pairwise comparisons were performed using the Dunn post-hoc method, and Holm-Bonferroni and (for the independence assumption) Sidak corrections were applied for multiple comparison errors (Streiner, 2015).

Correlation Analysis: Monotonic relationships between parameter pairs were assessed using Spearman's rank correlation; this method is a non-assumption-sensitive approach commonly used in environmental data (Zar, 2010).

Time Trend Analysis: Mann–Kendall (MK) was used to test for monotonic trends, and Theil–Sen median slope estimation was used for trend significance. The

Seasonal Mann–Kendall test was applied for series where seasonality might be dominant. These procedures are consistent with current institutional guidelines and widespread applications in water quality time series (Shoda et al., 2022; Diwyanjalee et al., 2024).

Multivariate Analysis: Principal Component Analysis (PCA) was used to summarize the common pattern among parameters; component selection considered eigenvalues >1, percentage of variance explained, and cumulative variance (Aydin Uncumusaoğlu and Akkan, 2017). All analyses were performed in MATLAB.

Traditional evaluations: At the same time, the data were evaluated based on national and international organization guidelines. Turkish SWQR data, EU 2006/7/EC (inland waters) classes, WHO (2021) 95th percentile bands for EN, US EPA (2012) single-sample statistics, and Canadian (2024) single-sample BAV thresholds were used as a basis. Right-censored measurements were quantified assuming a minimum exceedance, and single-sample exceedance ratios were calculated at the station level using P95/P90.

RESULTS

In this study, water samples were collected from seven stations along the Harşit Stream for a period of twelve months and comprehensively evaluated in terms of bacteriological quality monitoring variables. A total of n = 84 samples were analyzed, and the descriptive statistics for TC, FC, E. EC, and FS counts are shown in Table 1.

Bacterial count: TC bacterial count (MPN/100 mL) was determined as follows: Median=150, Q3=460, Max= >1100, Mean=245.46, IQR = 436.5, and GeomMean = 84.53. Since 25% of the measurements were equal to the upper measurement limit of ≥460 maximum value, it is thought that the actual peak values may be higher. FC bacteria count (MPN/100 mL) was determined as follows: Median=95, Q3=240, Max= >240, Mean=111.42, IQR=217 and GeomMean=42.05. When the Q3 is equal to the upper limit, at least 25% of the observations are saturated. EC bacteria count (MPN/100 mL) was determined as follows: Median=9, Q3=120, Max= >240, Mean=54.27, IQR=120, and GeomMean=9.26. A lower quartile value of 0 indicates frequent low/ND values; a Q3 value of 120 indicates occasional medium–high episodes. FS bacteria count (MPN/100 mL) was determined as follows: Median=23, Q3=23, Max= >240, Mean=46.56, IQR=4 and GeomMean=18.70. Median=Q3=23 MPN/100mL, indicating a distinct concentration at the method step, with upper limit events being more limited (Max= >240 MPN/100mL). When examining the distribution of data for bacteriological quality monitoring variables, the distribution is significantly skewed to the right, with a clear concentration dominance at the upper limit (mean > median; geometric means are low). Considering the stepwise counting limit of the MPN Method, a clustering towards the upper limits is observed in the findings (particularly >240 and >1100).

Table 1. Descriptive statistics findings (MPN/100mL)

	N	Mean	Min	Max	Std	Median	GeomMean	Q1	Q3	IQR
TC	84	245.46	0	>1100	277.2	150	84.532	23.5	460	436.5
FC		111.42	0	>240	97.674	95	42.046	23	240	217
EC		54.274	0	>240	64.904	9	9.2603	0	120	120
FS		46.56	0	>240	68.071	23	18.704	19	23	4

Findings for stations

The bacteriological quality monitoring parameters for the stations are shown in Figures 1 to 4. Station 1: All indicators (MPN/100mL) are at low levels (TC Median=20.5; FC Median=23; EC Median=0; FS Median=16). The limitation of the IQRs (≈52–55) for TC/FC indicates relatively low variability, the widespread presence of ND (0) in EC, and a concentration around/below 23 in FS. Upper limit values are rarely detected. Station 2: Medium-high load and wide dispersion were detected. TC Median=121.5 (Q3=240; Max=1100; IQR ≈191), FC Median=23 (Q3=95), EC Median=9 (Q3=71.5), FS Median=23 (Q3=95) were found. A pronounced upper limit in TC and rises during event periods and a high IQR (≈72–86) in EC/FS were observed. Station 3: Low–medium levels and increasing variability were reported. TC Median=59 MPN/100mL (IQR ≈168), FC Median=23 MPN/100mL (IQR ≈84), EC Median=0 (Q3=24), FS Median=23 MPN/100mL (Q3=58) were found. While ND-dominant structure persisted in EC, moderate-high episodes were occasionally observed in TC. Station 4: High central tendency and wide distribution were noted. TC Median=150 MPN/100mL (Q3=350; IQR ≈332), FC Median=95 MPN/100mL (Q3=240; IQR ≈236), EC Median=0 (Q3=120), FS Median=23 MPN/100mL (narrow IQR ≈9) were found. A clear clustering at the upper limit is evident in FC, and the upper limit is strong in TC. Station 5: A medium-high center and wide upper limit were detected in TC/FC. TC Median=150 (Q3=350; IQR=292), FC Median=59 (Q3=240; IQR=217), EC Median=0 (Q3=120), and FS Median=23 (Q3=23; IQR=13.5) were found. Frequent access to saturation (240) was observed in FC. Station 6: Persistently high contamination has been observed. TC Median=460 (Q3=460; Max=1100), FC Median=240 (Q3=240), EC Median=120 (Q3=120), and FS Median=23 were reported.

All quartiles in FC were at the upper limit, while in TC there was a wide spread (IQR=235) in the range of 225–460 and repeated high values were observed. Station 7: Dramatic highest levels have been detected. TC Median=460 (Mean≈498; Max=1100), FC Median=167.5 (Q3≈203.8), EC Median=120 (Q3=120), and FS Median=23 (IQR=0) were found. High central tendencies and relatively narrow IQRs for TC/FC/EC suggest that the high contaminations are permanent.

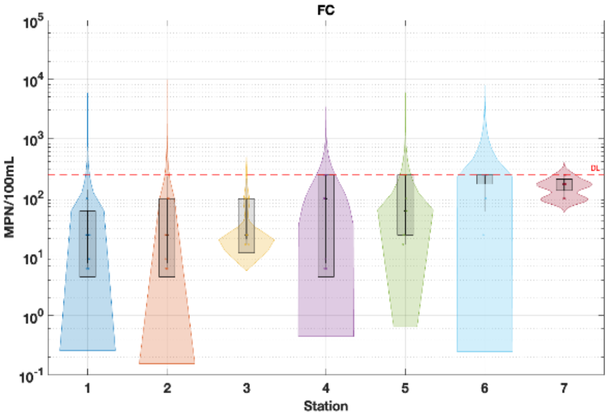

Figure 1. Station-wise distribution of Fecal Coliforms (FC) in the Harşit Stream (violin plots; log-scale; dashed line = detection limit)

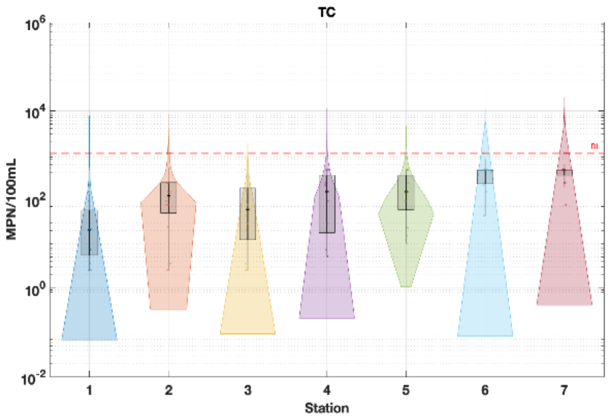

Figure 2. Station-wise distribution of Total Coliforms (TC) in the Harşit Stream (violin plots; log-scale; dashed line = detection limit)

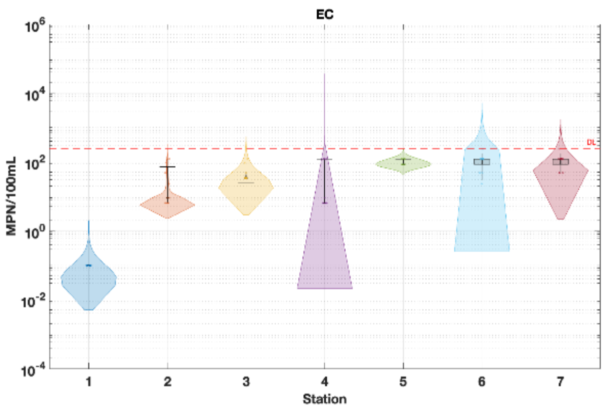

Figure 3. Station-wise distribution of *E. coli* (EC) in the Harşit Stream (violin plots; log-scale; dashed line = detection limit)

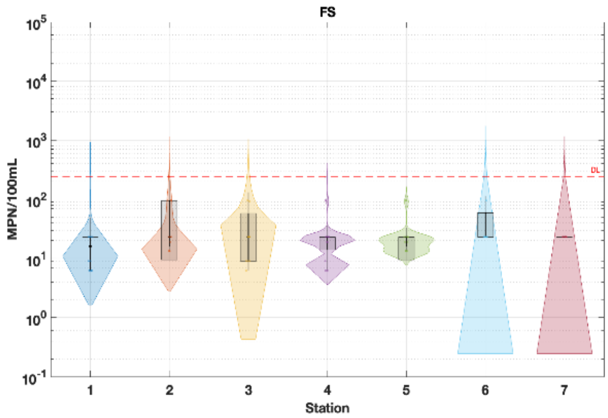

Figure 4. Station-wise distribution of Fecal Streptococci (FS) in the Harşit Stream (violin plots; log-scale; dashed line = detection limit)

Statistical evaluations: The behavior of bacteriological monitoring parameters at sampling points was tested using the Kruskal-Wallis Test. The findings indicate that there are significant differences between stations for TC, FC, and EC, while the difference for FS is not statistically significant. Furthermore, multiple comparisons (Dunn–Šidák) showed that stations 6–7 consistently differed from stations 1–3 in the upper/middle section (and partially from station 2 for FC). TC: A significant relationship was observed between 1 and 6, 1 and 7, 3 and 6, and 3 and 7. Furthermore, a consistently higher significant relationship was observed between 6 and 7. FC: A significant relationship was observed between 1 and 6, 1 and 7, 2 and 6, and 3 and 6. EC: Significant relationships were observed between 1 and 6, 1 and 7, 3 and 6, and 3 and 7.

The relationship between the bacteriological quality variables monitored in surface water samples from the Harşit Stream was tested by Spearman's correlation test. Significant positive correlation values were found between TC, FC, EC, and FS on a large scale (Figure 5). A very strong relationship was found between the TC–FC–EC. FS was found to have a significant but relatively less strong relationship with all indicators.

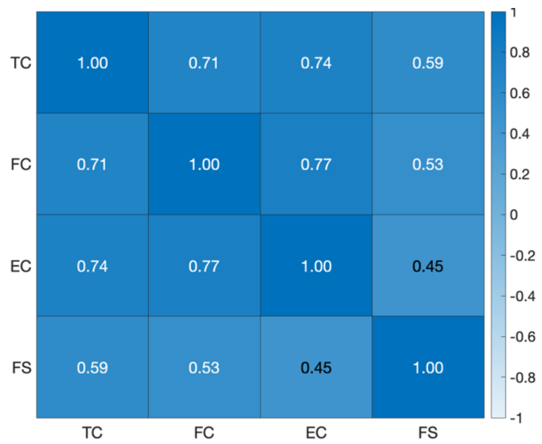

Figure 5. Nonparametric (Spearman) correlation structure of bacteriological metrics

A PCA test was conducted to determine the source of the bacteriological load on the water quality of the Harşit Stream. Component structure. PCA loads summarize the common and distinctive patterns between variables on three main axes (Figure 6): PC1 shows positive and similar loads across all indicators (TC = 0.53, FC = 0.53, EC = 0.47, FS = 0.46). This represents the overall fecal contamination intensity in the samples; an increase in the PC1 score is associated with a joint increase in the four parameters. The high and similar loading of TC and FC indicates that these two indicators contain excess load and reflect the same dimension with similar potency. This situation can be interpreted as meaning that the combined use of the TC–FC pair may provide marginal load with limitation when selecting variables in modelling and monitoring designs. PC2 represents a distinct compositional load axis among the indicators: EC load is negative (−0.69), while FS load is positive (+0.72). The loads of TC and FC on this scale are negligible. This structure captures the variation in fecal indicator composition between samples by positioning EC dominance and FS dominance at opposing poles. Therefore, high negative scores on PC2 indicate EC-dominant conditions, while high positive scores indicate FS-dominant conditions. This distinction may reflect differentiation in terms of source type (e.g., human/domestic animal origin) and environmental processes. This provides additional diagnostic information for indicator selection in monitoring strategy design. PC3 captures a two-block composition distinction among the indicators: TC and FC with negative loads, EC and FS with positive loads. This relationship represents the contrast between the total/fecal coliform load and the EC–FS load. Negative PC3 scores indicate a coliform-dominant composition, while positive scores indicate an EC–FS-dominant composition. This offers additional diagnostic value in monitoring design in terms of source separation and targeted intervention by reflecting the compositional nuances in the sample matrix (e.g., different contaminant mixtures, source type variations, differences in the environmental persistence/degradation of indicators).

The temporal pattern of bacteriological water quality in the Harşit Stream was examined using the non-parametric Mann–Kendall trend test and robust slope estimation with the Theil–Sen method. No statistically significant monotonic trend was detected in most station–parameter pairs throughout the twelve-month series. The only significant trend found was a decreasing trend for TC–Station 2 (Theil–Sen slope < 0; $p < 0.05$). In other station–parameter combinations, the trend was either insignificant or borderline, with insufficient statistical evidence.

The relationship between stations was examined using cluster analysis. The dendrogram obtained using the Ward–Euclidean method after log transformation and standardization of the data suggests a three-band clustering between stations (Figure 7). Stations 6 and 7 are clustered together at the shortest merging distance. These stations represent a persistently high level in terms of TC/FC/EC (consistent with KW and PCA-PC1). Similarly, Stations 4–5 are relatively close to each other. The accumulation at the upper limit in FC and the wide IQR in TC due to the similarity of episodic high sampling times support this cluster. Stations 1 and Station 3 are nearby; although Station 2 is higher than Stations 1– Stations 3 in most parameters (especially TC), it generally associates with Stations 1– Stations 3 in the dendrogram, acting as a connecting bridge between the upper clusters.

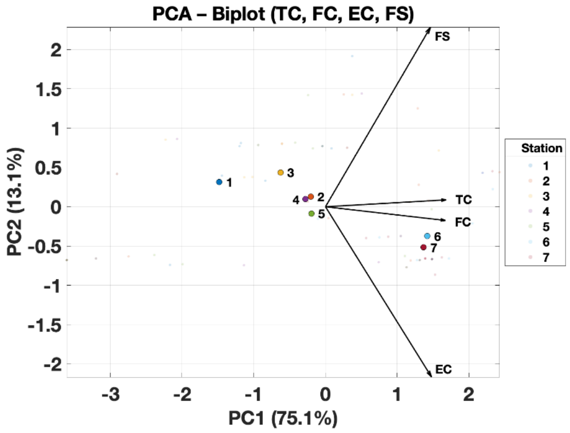

Figure 6. Multivariate structure of bacteriological quality: stations and indicators by PCA

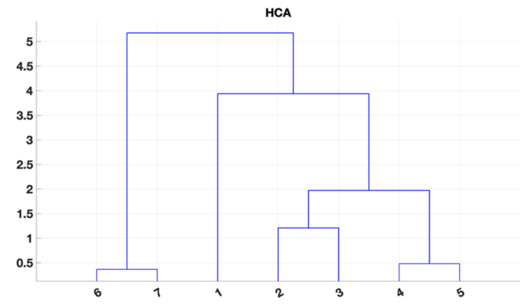

Figure 7. Hierarchical clustering (HCA) of sampling stations (dendrogram)

DISCUSSION

Bacteriological contamination in rivers is primarily a combination of point and diffuse sources such as domestic discharges and agricultural-surface runoff. It poses a significant public health risk in terms of drinking water, recreation, and irrigation. Microbial levels exhibit high temporal and spatial variability due to seasonality, hydrodynamic conditions, and short-term episodes. TC, FC, EC, and FS indicators provide significant insights into source type and environmental impacts. This paper presents the monitoring of bacteriological quality evolution in the Harşit Stream, which is the most significant freshwater source in Giresun. Moreover, the origin, distribution, and spatial trends of the current situation were also reported.

In a study from Giresun, the bacteriological pollution level of the Gelevera Creek (Giresun) was reported. Researchers found that the percentages of TC, FC, and FS in surface water samples were 100%, 100%, and 93.75%, respectively. Furthermore, EC was detected in the samples collected in almost every season. Moreover, the findings showed that the surface water samples from the Gelevera Creek were bacteriologically contaminated (Akkan & Çolaker, 2020). Similarly, another study in Gelevera Creek has indicated that bacteria isolated from surface water and sediment samples showed a high level of antibiotic and heavy metal resistance (Işık & Akkan, 2021). Furthermore, another study in Yağlıdere Stream in Giresun found that FK, FS and EC counts were higher than reference values at multiple stations in almost every month of the year. According to the study, the level of bacteriological contamination in the water and sediment of Yağlıdere Stream threatens the stability of the ecosystem (Akkan et al., 2019). High levels of detergent pollution were detected in the Harşit Stream during another study (Akkan, 2017). Also worldwide, in the Inaouene and Larbaa Rivers (Taza, Morocco), contamination from TC, FC, EC and FS has been observed (Sghiouer et al., 2024); in the Southwest Region of Cameroon, coliform group bacteria have contaminated drinking water (Banseka and Tume, 2024), and in the Panama Canal Watershed (PWC), fecal indicator bacteria were detected in 21 rivers (Chavarria et al., 2024). In the Brunei River, coliform bacteria levels were predicted to change over a five-year period using bidirectional long short-term memory Mann-Kendall trend analysis, revealing significant upward trends in coliform levels (Onifade et al., 2025).

This paper shows that the bacteriological water quality in the Harşit Stream is distributed in a right-skewed distribution sensitive to the upper measurement limits (Figure 8). Inter-station comparisons consistently revealed a three-band spatial separation: persistent high load centers (Stations 6–7), an episodically rising medium–high band (Stations 4–5), and a low–medium background level (Stations 1–3). Correlation and PCA findings confirmed the dominance of overall fecal load fraction (PC1), EC↔FS composition contrast (PC2), and coliform–EC/FS block separation (PC3). Furthermore, no widespread temporal trend was observed, with only a significant decrease detected at TC–Station 2. This comprehensive view necessitates the priority control of high-load hotspots in basin management, event-based (episode-sensitive) monitoring design, and the institutionalization of robust/non-parametric statistics that accurately represent risk with censoring and upper bounds.

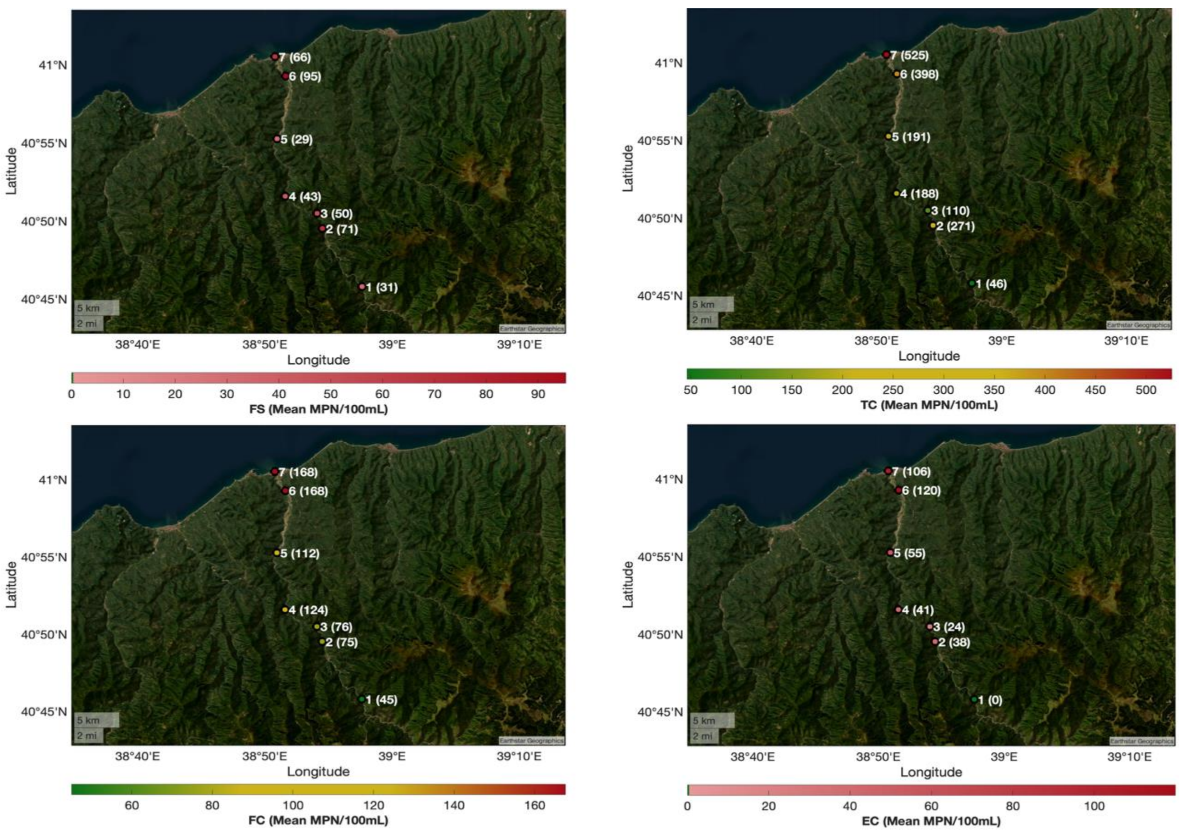

Figure 8. Station wise mean bacteriological quality variations in the Harşit Stream (MPN/100 mL; satellite base map)

The evaluation performed by national and international guidance organizations revealed remarkable findings (Figure 9). EC is at the SWQR guideline level (P95 ≤250) at all stations and is not an indicator limiting compliance; FS is the main parameter determining poor quality. Stations 2–4 and 6–7 near the discharge point exceed SWQR thresholds and fall into the poor-quality class. This spatial pattern is consistently confirmed in the EU 2006/7/EC classification (EC mostly "excellent," FS 2–4 and 6–7 pushing "sufficient") and WHO (2021) bands (1–5 A/B, 6–7 C/D). The single-sample thresholds of US EPA (2012) and Canada (2024), in particular, highlight episodic risks with frequent exceedances at 6–7. Methodologically, short time series and right-censored upper percentiles with ">" may predict conservative (low peak) estimates; conversely, single-instance thresholds provide event-focused alerts but do not represent long-term classification alone. Therefore, the findings indicate that EC and FS should be monitored as primary indicators in risk management and that stations at the mouth of the river should be prioritized for intervention.

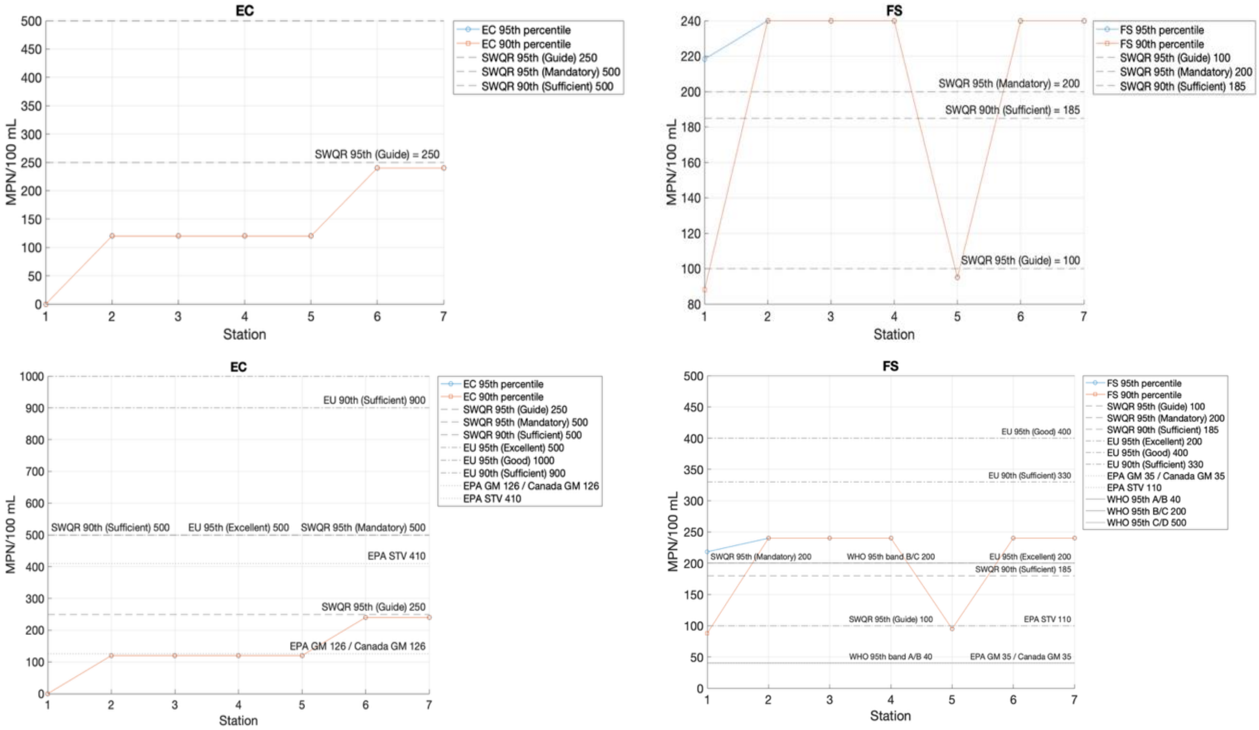

Figure 9. Percentile based guideline evaluation of bacteriological quality (90th–95th; multi reference lines shown)

CONCLUSION

It is thought that the sewage waste discharged into Harşit Stream, which has been determined to be bacteriologically dangerous throughout the year, should be restricted as soon as possible. The detection of existing pollution at the entrance to Giresun provincial borders at certain times shows that the stream is also exposed to intense sewage waste within the provincial borders of Gümüşhane. It has been determined that especially in station number 2 after the Doğankent district center, in station number 6 where garbage wastes in the Tirebolu district are randomly positioned on the edge of the river and in station number 7 covering the downstream point, intense sewage wastes are discharged into the stream environment. In addition, it has been observed that animals are slaughtered without complying with the necessary hygiene and sanitation rules at station number 7 and that waste directly contaminates the stream. It is foreseen that Harşit Stream water, which is also used for irrigation in agricultural activities, has the potential to cause widespread epidemics in the region. When considered as a whole, it has been observed that the Harşit Stream, which has very important recreational area potential for Giresun and our country, is being used in an unconscious manner, especially in stations 6 and 7, which are very close to wetland characteristics, and that agricultural activities are being carried out unconsciously. It is thought that the unplanned, unscheduled, and unconscious use of freshwater resources, which are extremely important for our country's natural resources, seriously harms the country's economy. It is also thought that inspection and permitting mechanisms should be established at the ministry level, especially for all kinds of activities to be carried out around our freshwater resources; otherwise the use of our natural resources, which are extremely important and have significant tourism potential, will be restricted due to gaps in local administrations.

Ethics Statement: This study did not involve human participants or animal testing. All sampling procedures complied with relevant institutional and national guidelines.

Author Contributions: Buse Eraslan Akkan: Methodology, Investigation, Data curation, Writing – original draft. Bülent Verep: Conceptualization, Supervision, Writing – review & editing. Cengiz Mutlu: Supervision, Validation, Visualization, Formal analysis, Review & editing.

Conflict of Interest: The authors declare no conflict of interest.

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Data Availability Statement: The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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