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# AN INTEGRATED PHYSICOCHEMICAL AND MICROBIOLOGICAL ASSESSMENT IN THE VJOSA RIVER

## SUMMARY

Once regarded as a pristine freshwater system, the Vjosa River is increasingly subject to anthropogenic pressures that compromise both ecological integrity and public health. This study presents an integrated twelve-month assessment (October 2024-October 2025) combining microbiological indicators *Escherichia coli* and intestinal enterococci with physicochemical parameters measured *in situ* using a multi-parameter probe (AP-2000 Aquaread). Thirteen monitoring stations were established along the main channel and principal tributaries, with sampling conducted on a monthly basis. Pronounced spatial and seasonal variability was observed throughout the study period. Water temperature ranged from winter minima below 10°C to summer maxima exceeding 24°C, while dissolved oxygen exhibited an inversely correlated seasonal trend. Electrical conductivity and total dissolved solids (TDS) were elevated at stations influenced by urban inputs and tributary inflows. Microbiological analysis revealed widespread faecal contamination, with mean *E. coli* concentrations predominantly classified within Class II; however, episodic peaks reaching Class III were recorded at several stations. Following internationally accepted microbiological water quality classifications, Class II denotes moderate faecal contamination, while Class III reflects critical pollution levels associated with elevated sanitary risk for both recreational and agricultural water use, consistent with Apha *et al*. (2017) and Who (2017) guidelines. Elevated water temperatures, reduced discharge, and moderate declines in dissolved oxygen during summer months coincided with marked increases in faecal indicator bacteria (FIB). Conversely, cooler, high-flow periods were associated with significantly lower microbial loads. Stations characterised by elevated conductivity and TDS consistently demonstrated higher levels of faecal contamination, suggesting a strong link between physicochemical conditions and microbiological water quality. These findings demonstrate that physicochemical and hydrological conditions substantially modulate microbiological pollution dynamics in the Vjosa River. The integration of microbial and physicochemical monitoring provides a more robust and comprehensive framework for assessing river health, and enables the identification of critical temporal windows and spatial hotspots of heightened sanitary risk.

**Keywords**- Faecal contamination; *Escherichia coli*; Physico-chemical parameters; River water quality; Seasonal variability; Vjosa River.

## INTRODUCTION

Rivers are inherently dynamic systems, continuously shaped by natural processes and anthropogenic activities. Water quality in riverine environments reflects the cumulative influence of upstream land use, adjacent catchment conditions, and prevailing waste management practices. Over recent decades, accelerating urbanisation, agricultural intensification, and inadequate wastewater treatment infrastructure have contributed to a measurable deterioration of surface water quality across Mediterranean and Balkan river systems (Bartram, 2000; Çullaj *et al.*, 2005; Çullaj *et al.*, 2007). Microbiological pollution represents one of the most pressing water quality challenges, posing risks not only to public health but also to ecosystem functioning and integrated water resource management. Faecal indicator bacteria (FIB) principally *Escherichia coli* and intestinal enterococci, are widely employed as reliable proxies for faecal contamination of human or animal origin (Edge and Boehm, 2010; Boehm and Sassoubre, 2014). Elevated FIB concentrations are indicative of potential co-occurrence with pathogenic microorganisms, thereby increasing the risk of waterborne disease transmission, particularly in contexts involving recreational exposure, agricultural water use, or direct human consumption (Kay *et al.*, 2005; Who, 2017). International guidelines and regulatory frameworks accordingly mandate routine monitoring of these indicators for sanitary risk assessment and surface water quality classification (Apha *et al.*, 2017; Who, 2017). The principal sources of microbiological contamination in river systems include untreated sewage discharges, livestock effluents, and agricultural runoff (Jamieson *et al.*, 2002; Servais *et al.*, 2007). However, the fate, transport, and persistence of FIB within riverine environments are substantially governed by prevailing physicochemical conditions (Davies-Colley and Smith, 2001; Herrig *et al.*, 2019). Parameters including water temperature, dissolved oxygen, pH, electrical conductivity, and total dissolved solids exert considerable influence over bacterial metabolism, growth dynamics, and spatial distribution (Leclerc *et al.*, 2001; Edge and Boehm, 2010). Elevated temperatures accelerate microbial metabolic activity and reproduction, while reduced river discharge diminishes the dilution capacity for pollutant loads (Kay *et al.*, 2005). Fluctuations in dissolved oxygen and ionic concentrations further affect microbial stress responses and broader ecosystem processes. Despite the general recognition of these relationships, field-based studies that rigorously quantify the physicochemical drivers of microbiological pollution remain limited, particularly in lesser-studied catchments of Southeast Europe (Çullaj *et al.*, 2005; Miho *et al.*, 2006).

The Vjosa River basin constitutes a particularly pertinent study system in this regard. Its longitudinal gradient spanning mountainous headwaters to densely populated lowland areas incorporates tributaries draining agricultural zones, rural settlements, and urban centres, creating a complex mosaic of pollution pressures. Previous investigations have documented faecal contamination in portions of the river; however, these studies were largely confined to microbiological indicators and did not systematically examine the physicochemical drivers underlying observed contamination patterns (Miho *et al.*, 2006; Çullaj *et al.*, 2007).

The present study addresses this gap by providing the first comprehensive, year-long water quality assessment of the Vjosa River (Çullaj *et al.*, 2005; Miho *et al.*, 2006; Çullaj *et al.*, 2007). Through monthly measurement of key physicochemical parameters alongside microbiological sampling at thirteen monitoring stations, this investigation examines: (i) spatiotemporal variability in water quality; (ii) relationships between environmental conditions and microbial contamination; and (iii) the identification of critical periods and locations of elevated sanitary risk (Edge and Boehm, 2010; Herrig *et al.*, 2019). These findings advance mechanistic understanding of microbial pollution dynamics in comparable riverine systems and provide an evidence base for improved monitoring strategies and basin-scale water resource management.

## MATERIALS AND METHODS

### Study Area and Sampling Design

The present study was conducted within the Vjosa River basin in Albania, a system of recognised ecological significance in Southeast Europe (Çullay *et al.*, 2005; Miho *et al.*, 2006; Çullaj *et al.*, 2007). Originating in the mountainous headwaters, the river traverses a longitudinal gradient through agricultural lowlands and urban settlements, receiving inflow from several tributaries that drain a diverse mosaic of land uses, including rural communities, livestock farming areas, and cultivated fields (Çullaj *et al.*, 2005;

Miho *et al.*, 2006). This spatial heterogeneity renders the basin particularly suitable for investigating the interplay between environmental gradients and multiple pollution sources (Jamieson *et al.*, 2002; Servais *et al.*, 2007). Thirteen monitoring stations were established along the main channel and principal tributaries (Tab. 1). Stations were stratified according to their position along the river continuum and the prevailing degree of anthropogenic influence. Upper catchment sites were located in headwater reaches with minimal human disturbance, mid-channel stations were situated in zones characterised by intensive agricultural activity, and downstream stations were positioned in areas subject to elevated urban pressures and the cumulative effects of tributary inflows (Çullaj *et al.*, 2005; Miho *et al.*, 2006).

**Tab. 1** - Geographic coordinates of monitoring sites along the Vjosa River.

| Station Number | Station Name | Latitude | Longitude |
|---|---|---|---|
| **Site_01_MIF** | Mifol | 40° 38′ 3.40″ N | 19° 27′ 42.97″ E |
| **Site_02_VSC** | Hambare | 40° 33′ 50.02″ N | 19° 34′ 22.19″ E |
| **Site_03_POC** | Pocem | 40° 29′ 33.55″ N | 19° 43′ 40.84″ E |
| **Site_05_MEM** | Memaliaj | 40° 21′ 32.77″ N | 19° 54′ 54.44″ E |
| **Site_13_GJO** | Gjorm | 40° 18′ 45.07″ N | 19° 39′ 8.93″ E |
| **Site_06_DRA** | Dragot | 40° 16′ 46.29″ N | 20° 2′ 57.70″ E |
| **Site_15_DRI** | Drinos | 40° 15′ 39.81″ N | 20° 3′ 14.39″ E |
| **Site_14_BEN** | Benc | 40° 15′ 48.77″ N | 20° 0′ 21.35″ E |
| **Site_17_GJK** | Gjirokaster | 40° 9′ 49.64″ N | 20° 6′ 12.68″ E |
| **Site_16_KDQ** | Kardhiq | 40° 9′ 20.36″ N | 20° 5′ 55.07″ E |
| **Site_07_ARO** | Kelcyre | 40° 14′ 51.23″ N | 20° 19′ 58.61″ E |
| **Site_09_VJO** | Vjose | 40° 5′ 32.12″ N | 20° 34′ 8.95″ E |
| **Site_11_SAR** | Sarandopor | 40° 5′ 27.39″ N | 20° 37′ 39.06″ E |

By structuring the monitoring network in this manner, longitudinal changes in water quality could be tracked along the river continuum, and the influence of specific locations on overall water quality could be assessed. Sampling was conducted monthly from October 2024 to October 2025 (Fig.1). At each station, surface water samples were collected at a depth of 30-50 cm using sterile glass bottles in accordance with ISO 19458 for microbiological sampling (ISO, 2006). Samples were immediately stored in insulated containers at 4°C and transported to the laboratory within 6-7 hours of collection. Upon arrival, microbiological analyses were initiated without delay to preserve sample integrity, following standardised laboratory protocols (Apha *et al.*, 2017).


**Fig. 1** - Sampling stations along the Vjosa River (GIS-generated).

## Physico-Chemical Measurements

At each sampling event, physicochemical parameters were measured *in situ* using a multi-parameter probe (AP-2000 Aquaread) (Fig.2). This portable instrument is designed for field deployment in riverine, lacustrine, and transitional water environments. It records data digitally, thereby eliminating manual transcription and the associated risk of data entry error (Goblirsch *et al.*, 2023).

The following parameters were recorded at each station: water temperature (°C), pH, electrical conductivity (EC, μS/cm), total dissolved solids (TDS, ppt), and dissolved oxygen (DO, expressed as both percentage saturation and concentration in mg/L) (Leclerc *et al.*, 2001; Edge and Boehm, 2010).


**Fig. 2** - Field measurements of physico-chemical parameters in the Vjosa River.

Prior to each sampling event, the probe was calibrated in accordance with the manufacturer's specifications. Where conditions permitted, measurements were taken at mid-channel positions to ensure adequate water mixing and to obtain readings representative of the full cross-sectional water body at each station (Davies-Colley and Smith, 2001). The selected parameters were chosen on the basis of their well-documented influence on microbial survival, transport, and proliferation in freshwater environments (Leclerc *et al.*, 2001; Edge and Boehm, 2010).

**Microbiological Analysis**

The microbiological quality of water samples was assessed through the enumeration of faecal indicator bacteria, specifically *Escherichia coli* and intestinal enterococci (Edge and Boehm, 2010; Boehm and Sassoubre, 2014). Analyses were performed using the Most Probable Number (MPN) method, in accordance with ISO 9308-1 and applicable standard protocols (Iso, 2014; Apha *et al.*, 2017). Serial dilutions were prepared for each sample and inoculated into selective growth media. Standardised laboratory procedures were followed throughout incubation and result confirmation to ensure accurate detection and enumeration of faecal indicator organisms (Apha *et al.*, 2017). Following incubation, MPN values were calculated using probability tables and expressed as CFU or MPN per 100 mL. Samples were subsequently classified into microbiological water quality categories based on internationally established thresholds for surface and recreational waters (Who, 2017), providing a basis for inter-station comparison and the identification of periods of elevated sanitary risk.

**Data Analysis**

Descriptive statistics were calculated on both a monthly and an annual basis for all physicochemical and microbiological parameters (Apha *et al.*, 2017). Spatial variability was assessed through systematic comparison of parameter values across monitoring stations, while temporal variability was evaluated by examining seasonal and month-to-month fluctuations throughout the study period. To characterise the relationships between physicochemical conditions and microbiological contamination, covariations among water temperature, dissolved oxygen, electrical conductivity (EC), total dissolved solids (TDS), and the concentrations of *E. coli* and intestinal enterococci were examined (Edge and Boehm, 2010; Herrig *et al.*, 2019). Particular emphasis was placed on contrasting seasonal hydrological regimes, specifically, the warm, low-flow conditions characteristic of summer months and the cooler, high-flow periods associated with winter and spring (Kay *et al.*, 2005). This comparative framework enabled a systematic assessment of the combined influence of hydrological and environmental factors on microbial pollution dynamics within the study basin.

## RESULTS AND DISCUSSION

### Spatial and Seasonal Variability of Physico-Chemical Parameters

The physicochemical conditions of the Vjosa River exhibited marked spatial and temporal variability throughout the study period (October 2024-October 2025). As presented in Tab. 2, parameter values varied considerably across monitoring stations, reflecting systematic longitudinal gradients along the river channel as well as pronounced seasonal fluctuations.

The table condenses the complete annual dataset into minimum, mean, and maximum values, facilitating direct inter-site comparison and delineating the overall range of variability within the basin. It illustrates the inherent heterogeneity of the river system, capturing both upstream-downstream gradients and the influence of tributary inputs and anthropogenic activities (Çullaj *et al.*, 2005; Miho *et al.*, 2006). By synthesising the annual behaviour of water temperature, dissolved oxygen, electrical conductivity, total dissolved solids, and pH, the table provides a reference framework for interpreting the spatial and seasonal patterns presented in the subsequent Figs, and for evaluating the extent to which physicochemical conditions govern the microbiological status of the river (Leclerc *et al.*, 2001; Edge and Boehm, 2010).

Water temperature ranged from winter minima below 10°C to summer maxima exceeding 24°C at several monitoring stations. The monthly temperature evolution (Fig. 3) reveals a well-defined seasonal cycle, characterised by minimum values recorded during December-February, a progressive

**Tab. 2** - Summary statistics of physico-chemical parameters (temperature, dissolved oxygen, electrical conductivity, total dissolved solids, and pH) across monitoring stations (October 2024–October 2025).

| Site | Temp Min (°C) | Temp Mean (°C) | Temp Max (°C) | DO Min (%) | DO Mean (%) | DO Max (% | EC Min (µS/cm) | EC Mean (µS/cm) | EC Max (µS/cm) | TDS Min (ppt) | TDS Mean (ppt) | TDS Max (ppt) | pH Min | pH Mean | pH Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site_01_MIF** | 10.30 | 16.74 | 23.46 | 88.54 | 91.80 | 93.80 | 201.34 | 207.01 | 215.40 | 323.78 | 332.64 | 355.60 | 7.81 | 7.96 | 8.08 |
| **Site_02_VSC** | 9.60 | 17.41 | 23.93 | 89.05 | 91.36 | 94.10 | 196.30 | 205.88 | 214.25 | 224.01 | 243.78 | 305.67 | 8.55 | 8.68 | 8.78 |
| **Site_03_POC** | 9.40 | 17.49 | 23.97 | 90.64 | 94.33 | 97.20 | 270.18 | 282.64 | 296.30 | 252.67 | 262.12 | 276.46 | 8.14 | 8.24 | 8.35 |
| **Site_05_MEM** | 10.40 | 18.42 | 24.87 | 96.72 | 98.38 | 100.50 | 115.08 | 123.94 | 138.21 | 292.61 | 308.49 | 345.32 | 7.43 | 7.58 | 7.67 |
| **Site_06_DRA** | 8.40 | 15.53 | 22.47 | 99.70 | 101.43 | 104.20 | 367.48 | 379.26 | 392.18 | 260.51 | 270.11 | 287.51 | 8.13 | 8.29 | 8.50 |
| **Site_07_ARO** | 8.20 | 14.91 | 21.47 | 99.46 | 102.30 | 105.80 | 367.42 | 381.56 | 401.30 | 141.99 | 153.55 | 213.32 | 7.55 | 7.67 | 7.76 |
| **Site_09_VJO** | 8.01 | 15.75 | 22.51 | 94.68 | 99.06 | 103.40 | 442.91 | 458.12 | 472.88 | 116.12 | 126.26 | 166.23 | 7.41 | 7.57 | 7.70 |
| **Site_11_SAR** | 7.80 | 14.58 | 21.49 | 103.30 | 105.61 | 109.40 | 488.33 | 501.79 | 518.65 | 99.79 | 105.60 | 132.41 | 8.04 | 8.20 | 8.44 |
| **Site_13_GJO** | 8.70 | 15.69 | 22.65 | 106.17 | 108.71 | 112.50 | 302.40 | 316.88 | 329.47 | 165.10 | 174.38 | 206.44 | 8.61 | 8.73 | 8.84 |
| **Site_14_BEN** | 7.90 | 14.28 | 21.00 | 105.30 | 108.59 | 112.30 | 467.43 | 481.92 | 495.66 | 97.02 | 102.57 | 121.34 | 8.27 | 8.43 | 8.70 |
| **Site_15_DRI** | 7.70 | 16.46 | 23.34 | 97.60 | 102.20 | 106.80 | 338.87 | 352.74 | 368.52 | 241.63 | 252.21 | 277.22 | 8.27 | 8.40 | 8.61 |
| **Site_16_KDQ** | 8.20 | 17.76 | 24.92 | 95.92 | 97.94 | 100.40 | 364.64 | 378.25 | 392.77 | 296.85 | 307.45 | 345.44 | 8.20 | 8.32 | 8.42 |
| **Site_17_GJK** | 9.90 | 17.57 | 23.87 | 96.11 | 98.07 | 101.30 | 288.79 | 298.63 | 312.09 | 293.96 | 311.16 | 355.77 | 8.22 | 8.35 | 8.49 |

increase through spring and early summer, a peak in July-August, and a subsequent decline into early autumn (Kay *et al.*, 2005). Downstream stations and tributary-influenced sites consistently exhibited higher summer temperatures relative to upstream mountainous reaches, a pattern attributable to both broad climatic gradients and reduced riparian shading in lowland areas (Davies-Colley and Smith, 2001).

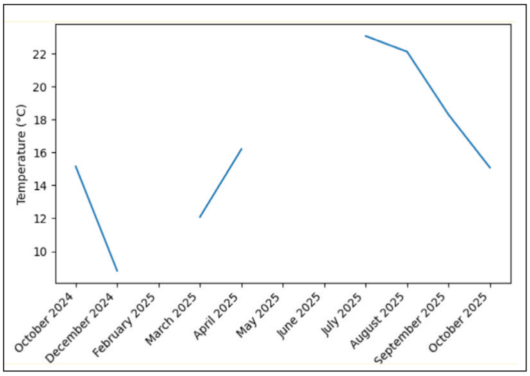


**Fig. 3** - Monthly variation of water temperature across the Vjosa River stations.

Dissolved oxygen levels peaked in autumn and winter, often going above 100% saturation. But in summer, especially July and August, those numbers dropped sharply (see Fig. 4). The lowest oxygen readings lined up with the hottest months and low river flow, which points to less mixing with air and higher metabolic demand in the water (Davies-Colley and Smith, 2001; Herrig *et al.*, 2019). If you look at different locations, spots influenced by tributaries and areas down in the lowlands had lower DO in summer than places upstream (Çullaj *et al.*, 2005; Miho *et al.*, 2006).

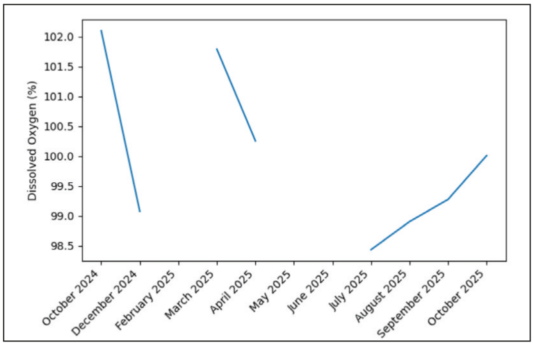


**Fig. 4** - Seasonal trend of dissolved oxygen (DO%) in the Vjosa River.

Electrical conductivity (EC) and total dissolved solids (TDS) exhibited considerable spatial variability across the study area (Tab. 2). Upstream stations recorded comparatively low EC and TDS values, consistent with minimal anthropogenic influence in headwater reaches. Elevated EC and TDS concentrations were recorded at stations subject to urban proximity and major tributary confluences, notably Poçem, Sarandoporo, Drino, and Kardhiq, indicative of wastewater discharges, agricultural runoff, and enhanced geochemical inputs to the river (Çullaj *et al.*, 2005; Miho *et al.*, 2006; Servais *et al.*, 2007). A seasonal increase in both parameters was observed during summer and early autumn, corresponding to reduced river discharge and diminished dilution capacity (Davies-Colley and Smith, 2001; Herrig *et al.*, 2019). pH values remained largely stable throughout the study period, ranging between 7.4 and 8.8 and indicating near-neutral to mildly alkaline conditions. Minor seasonal variation was recorded, with a slight elevation in pH during summer months, attributable to enhanced photosynthetic activity and reduced buffering capacity associated with lower flow conditions (Leclerc *et al.*, 2001). Collectively, these results demonstrate that the physicochemical environment of the Vjosa River is subject to continuous seasonal dynamics and is responsive to anthropogenic inputs, particularly at identified pollution hotspots. The convergence of elevated water temperatures, reduced dissolved oxygen, and increased ionic concentrations during summer months creates conditions known to modulate microbial survival, transport, and proliferation within the riverine system (Edge and Boehm, 2010; Herrig *et al.*, 2019).

**Relationship Between Physico-Chemical Conditions and Microbiological Indicators**

Concentrations of faecal indicator bacteria exhibited marked seasonal variability, fluctuating in accordance with prevailing physicochemical conditions, particularly water temperature and ionic composition (Edge and Boehm, 2010; Herrig *et al.*, 2019). *Escherichia coli* concentrations increased substantially during summer months, reaching peak values in August, before declining through winter and early spring (Kay *et al.*, 2005; Servais *et al.*, 2007). A consistent positive association was observed between rising water temperatures and elevated bacterial concentrations, reflecting the well-established influence of thermal conditions on microbial growth and reproduction (Leclerc *et al.*, 2001).

**Tab. 3** - Mean and maximum Escherichia coli (FC) and intestinal enterococci (EF) concentrations and water quality classification across Vjosa River monitoring stations (October 2024–October 2025).

| Station | Mean FC (CFU/100 mL) | Max FC (CFU/100 mL) | Mean EF (CFU/100 mL) | Max EF (CFU/100 mL) | Water Quality Class |
|---|---|---|---|---|---|
| **S-01-MIF** | 228 | 460 | 288.2 | 1100 | **Class II** |
| **S-02-VSC** | 270.4 | 460 | 127.9 | 460 | **Class II** |
| **S-03-POC** | 172.9 | 240 | 215.4 | 460 | **Class II** |
| **S-05-MEM** | 314.9 | 460 | 123.1 | 150 | **Class II** |
| **S-06-DRA** | 230.2 | 460 | 244 | 460 | **Class II** |
| **S-07-ARO** | 259.1 | 460 | 160.2 | 460 | **Class II** |
| **S-09-VJO** | 196.8 | 460 | 226.6 | 460 | **Class II** |
| **S-11-SAR** | 316.1 | 1100 | 152.6 | 240 | **Class III** |
| **S-13-GJO** | 335.2 | 460 | 208.6 | 460 | **Class II** |
| **S-14-BEN** | 189.9 | 460 | 276.4 | 1100 | **Class II** |
| **S-15-DRI** | 426.8 | 1100 | 93.6 | 150 | **Class III** |
| **S-16-KDQ** | 414.4 | 1100 | 291.4 | 1100 | **Class III** |
| **S-17-GJK** | 323.8 | 460 | 314.9 | 460 | **Class II** |

The mean and maximum concentrations of *Escherichia coli* (FC) and intestinal enterococci (EF) recorded at each monitoring station throughout the study period, are summarized in Tab. 3. The disparity between mean and maximum values reflects the occurrence of episodic contamination events, particularly during warmer months, and corroborates the observed association between seasonal temperature elevation and increased bacterial concentrations (Kay *et al.*, 2005; Servais *et al.*, 2007). Based on internationally accepted microbiological water quality classifications, stations exhibiting moderate *E. coli* loads were designated as Class II, corresponding to moder-

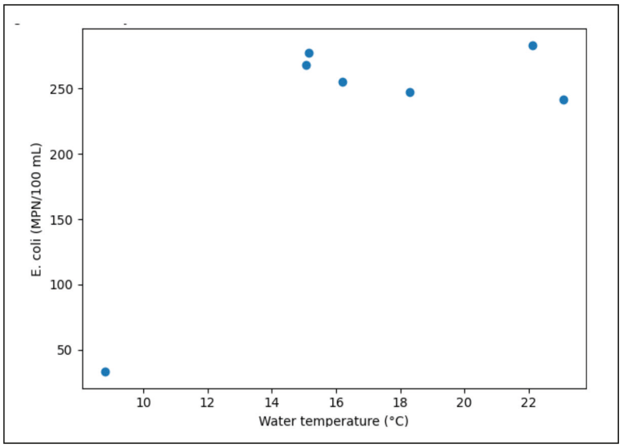


**Fig. 5** - Monthly mean Escherichia coli concentrations in relation to water temperature.

ate faecal contamination, while stations recording elevated maximum concentrations and heightened sanitary risk were classified as Class III, indicative of critical pollution levels (Apha *et al*., 2017; Who, 2017). This classification framework, grounded in established microbiological water quality criteria, was applied consistently across all monitoring stations and is further elaborated in the Results and Discussion section (Apha *et al*., 2017; Who, 2017).

When water temperatures exceeded 20°C, *E. coli* concentrations increased markedly (Fig. 5), whereas values falling below 12°C were associated with a substantial decline in bacterial counts. This thermal response is consistent with established evidence that elevated temperatures promote *E. coli* persistence and proliferation, while cold conditions impose physiological stress and suppress bacterial survival (Leclerc *et al*., 2001; Kay *et al*., 2005). A significant inverse relationship was also observed between dissolved oxygen concentrations and faecal indicator bacteria. Reductions in dissolved oxygen corresponded with elevated *E. coli* counts, a pattern particularly pronounced during summer low-flow periods. The concurrent occurrence of high water temperatures and depleted dissolved oxygen appears to create conditions conducive to enhanced bacterial survival, while simultaneously attenuating natural microbial die-off processes (Davies-Colley and Smith, 2001; Herrig *et al*., 2019).

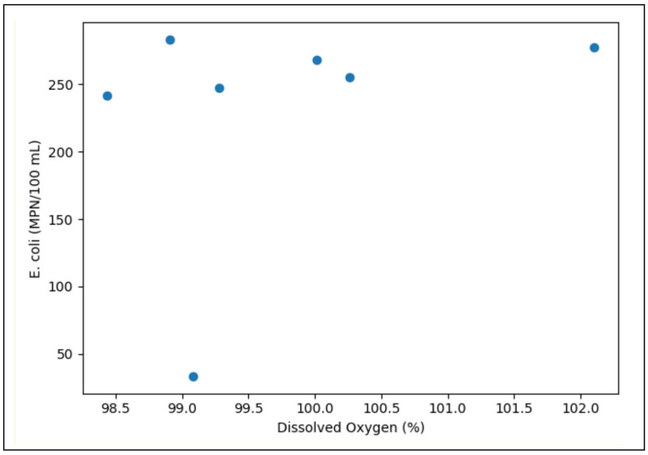


**Fig. 6** - Relationship between dissolved oxygen (DO%) and faecal indicator bacteria.

Integrated analysis of the physicochemical and microbiological datasets reveals that faecal contamination in the Vjosa River is not solely a function of pollutant loading, but is substantially modulated by prevailing environmental conditions (Edge and Boehm, 2010; Herrig *et al*., 2019). Elevated water temperatures, reduced river discharge, increased ionic concentrations, and depleted dissolved oxygen collectively create conditions that favour bacterial persistence and proliferation, amplifying episodic pollution events into sustained public health risks (Leclerc *et al.*, 2001; Servais *et al.*, 2007). Summer low-flow periods emerge as the critical window of concern, during which the river's natural capacity for contaminant dilution and buffering is most severely diminished, and environmental conditions are most conducive to bacterial survival and accumulation (Davies-Colley and Smith, 2001; Kay *et al.*, 2005). This is corroborated by the spatial distribution of contamination: stations consistently recording elevated EC and TDS values, notably Poçem, Sarandoporo, Drino, and Kardhiq, also exhibited the highest *E. coli* concentrations. These sites are predominantly located at tributary confluences or within zones subject to urban and agricultural influence, where the concurrent accumulation of pollutants and dissolved constituents intensifies contamination pressure (Çullaj *et al.*, 2005; Miho *et al.*, 2006; Servais *et al.*, 2007). As evidenced by Tabs 1-2 and Figs 5-6, the data collectively demonstrate that environmental conditions are a primary determinant of microbiological water quality, capable of transforming moderate contamination inputs into critical sanitary risks. This effect is most pronounced during summer months, when bacterial survival is enhanced, and the river's intrinsic self-purification capacity is at its seasonal minimum (Davies-Colley and Smith, 2001; Kay *et al.*, 2005; Herrig *et al.*, 2019).

## CONCLUSIONS

The present study demonstrated that faecal contamination is widespread along the Vjosa River and is strongly influenced by both anthropogenic activities and seasonal physicochemical conditions (Çullaj *et al.*, 2005; Çullaj *et al.*, 2007). During the monitoring period (October 2024-October 2025), the highest *Escherichia coli* concentrations were recorded during summer, with a peak monthly average of approximately 301-302 MPN/100 mL observed in August 2025. In contrast, the lowest average values were recorded in June 2025 (216 MPN/100 mL), coinciding with higher river discharge and dilution effects (Kay *et al.*, 2005; Servais *et al.*, 2007).

Spatial analysis revealed that contamination was not uniformly distributed along the river. Stations located near tributaries and areas affected by urban and agricultural activities, particularly Poçem (Site-03), Sarandoporo (Site-11), Drino (Site-15), and Kardhiq (Site-16), consistently showed the highest microbial loads, with maximum values reaching up to 1100 CFU/100 mL (Miho et al., 2006; Servais *et al.*, 2007). Although average contamination levels generally remained within Class II water quality, several stations episodically reached Class III levels, indicating periods of elevated sanitary risk (Apha *et al.*, 2017; Who, 2017).

The study also showed a strong relationship between microbiological contamination and physicochemical conditions. Increased water temperature, reduced dissolved oxygen, elevated electrical conductivity, and higher total dissolved solids were associated with increased bacterial concentrations, especially during low-flow summer conditions (Davies-Colley and Smith, 2001; Leclerc *et al*., 2001; Edge and Boehm, 2010; Herrig *et al*., 2019).

Overall, these findings indicate that the Vjosa River remains under significant pressure from faecal contamination, particularly during the summer months and in tributary-influenced areas (Çullaj *et al.,* 2005; Miho *et al*., 2006). Continuous microbiological and physicochemical monitoring, improved wastewater treatment, and better management of agricultural and livestock activities are necessary to reduce pollution and protect both ecosystem integrity and public health (Apha *et al*., 2017; Who, 2017).

## REFERENCES

Apha, Awwa, Wef, 2017 – Standard methods for the examination of water and wastewater. American Public Health Association, Washington: 1545 pp.

Bartram J., 2000 – Monitoring bathing waters: A practical guide to the design and implementation of assessments and monitoring programmes. World Health Organization, Geneva: 240 pp.

Boehm A.B., Sassoubre L.M., 2014 – Enterococci as indicators of environmental fecal contamination. In: Gilmore M.S., Clewell D.B., Ike Y., Shankar N. (Eds) *Enterococci: From commensals to leading causes of drug-resistant infection*. Massachusetts Eye and Ear Infirmary, Boston.

Byamukama D., Mach R.L., Kansiime F., Manafi M., Farnleitner A.H., 2005 – Discrimination efficacy of fecal pollution detection in different aquatic habitats of a high-altitude tropical country. *Applied and Environmental Microbiology* **71**: 65-71.

Çullaj A., Hasko A., Miho A., Schanz F., Brandl H., Bachofen R., 2005 – The quality of Albanian natural waters and the human impact. *Environment International* **31**: 133-146.

Çullaj A., Lazo P., Baraj B., 2007 – Assessment of the environmental situation of Albanian rivers based on physico-chemical analyses. In: *Rivers and citizens: Cross-border experiences in environmental protection and sustainable development*.

Davies-Colley R.J., Smith D.G., 2001 – Turbidity, suspended sediment, and water clarity: A review. *Journal of the American Water Resources Association* **37**: 1085-1101.

Edge T.A., Boehm A.B., 2010 – Classical and molecular methods to measure fecal bacteria. In: Sadowsky M.J., Whitman R.L. (Eds) *The fecal bacteria*.

Farnleitner A.H., Wilhartitz I., Ryzinska G., Kirschner A.K., Stadler H., Burtscher M.M., Hornek R., Szewzyk U., Herndl G., Mach R.L., 2005 – Bacterial dynamics in spring water of alpine karst aquifers. *Environmental Microbiology* **7**: 1248-1259.

Goblirsch, T., Mayer, T., Penzel, S., Rudolph, M., Borsdorf, H. – 2023). In Situ Water Quality Monitoring Using an Optical Multiparameter Sensor Probe. Sensors, 23(23), 9545.

Herrig I., Seis W., Fischer H., et al., 2019 – Prediction of fecal indicator organism concentrations in rivers. *Environmental Sciences Europe* **31**: 59.

Iso, 2006 – Water quality - Sampling for microbiological analysis. International Organization for Standardization, Geneva.

Iso, 2014 – Water quality-Enumeration of *Escherichia coli* and coliform bacteria. International Organization for Standardization, Geneva.

Jamieson R., Gordon R., Sharples K., Stratton G., Madani A., 2002 – Movement and persistence of fecal bacteria in agricultural soils. *Canadian Biosystems Engineering* **44**: 1-9.

Kay D., Stapleton C.M., Wyer M.D., et al., 2005 – Decay of intestinal enterococci concentrations in estuarine waters. *Water Research* **39**: 655-667.

Miho A., Çullaj A., Lazo P., Hasko A., Kupe L., Schanz F., Brandl H., Bachofen R., 2006 – Assessment of water quality of some Albanian rivers using diatom-based monitoring. *Albanian Journal of Natural and Technical Sciences* **19**: 94-105.

Liu L., Phanikumar M., Molloy S., Whitman R., Shively D., Nevers M.B., Schwab D., Rose J., 2006 – Modeling the transport and inactivation of *Escherichia coli* and enterococci. *Environmental Science and Technology* **40**: 5022-5028.

Pruden A., Pei R., Storteboom H., Carlson K.H., 2006 – Antibiotic resistance genes as emerging contaminants. *Environmental Science and Technology* **40**: 7445-7450.

Servais P., Garcia-Armisen T., George I., Billen G., 2007 – Fecal bacteria in the rivers of the Seine drainage network. *Science of the Total Environment* **375**: 152-167.

Solo-Gabriele H., Wolfert M.A., Desmarais T.R., Palmer C.J., 2000 – Sources of *Escherichia coli* in a coastal subtropical environment. *Applied and Environmental Microbiology* **66**: 230-237.

Who, 2017 – Guidelines for drinking-water quality. World Health Organization, Geneva.