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Stream water quality variation as a function of physical environmental conditions in an agriculturally dominated catchment

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Abstract: The aim of the present study was to investigate stream turbidity and water chemical parameters under varying environmental conditions. We analyzed a three-year-long (2021-2023) daily and bi-weekly dataset collected at six points (P1-P6) along a small stream. We measured stream water turbidity (FNU), total dissolved inorganic nitrogen (TDIN) content, water pH, and specific conductivity (SPC). Meteorological data were collected at the catchment outlet. Daily data showed a moderate positive correlation between FNU and precipitation ($r=0.42$, $p<0.001$), while weak negative connections were observed between SPC and FNU values ($r=-0.14$, $p=0.011$, $n=349$). The FNU values at the groundwater spring-fed sampling point (P3) were significantly different from the other sampling points on most parameters ($p<0.05$). The results of the cluster analysis revealed three main clusters based on daily turbidity data. These groups of daily precipitation totals were i) below 4.8 mm, ii) averaging 6.3 mm, and iii) averaging 23.7 mm. The clusters were most significantly separated along precipitation and FNU values. Turbidity values were strongly correlated with precipitation events for two days, after which stream water quality returned to baseline. Stream water quality was not significantly influenced by soil management or antecedent moisture content but rather by water origin (i.e., precipitation, groundwater).

Keywords: Turbidity; Suspended sediment; Antecedent soil moisture content; Small catchment.

1 INTRODUCTION

Assessing stream water quality in agricultural catchments is important for understanding the impact of agricultural practices on terrestrial and aquatic ecosystems. Agricultural activities often contribute to increased turbidity levels, and nitrogen and phosphorus concentrations in streams (Mateo-Sagasta et al., 2017) due to runoff from fertilizer amended lands and soil erosion following heavier rain events. This process can lead to eutrophication and water quality degradation (Pericherla et al., 2020; Qadri and Faiq, 2020). It is important to monitor these indicators and pollutants, particularly in relation to meteorological conditions such as rainfall, as weather events highly affect the amount and timing of runoff entering streams (Johnson et al., 2022). Seasonality also plays a key role, as different agricultural activities and weather patterns affect the concentration and transport of these pollutants.

The intensity and amount of precipitation can highly influence soil particle detachments and therefore the erosion rate and soil loss (Kinnell, 2020). Soil loss due to rainwater can result in a significant economic loss, as nutrients and fertile soil layers can be transported off from agricultural land, or weaken the soil structure needed for plant root stability and development. The date of the extreme precipitation events is also a crucial factor, as the bare soil is more vulnerable to soil erosion, especially after soil cultivation than soils covered with vegetation. However, to get a more precise estimation of sediment transport during peak discharge, frequent water sampling (e.g. every few minutes) is required (Lee et al., 2015). To understand catchment based hydrological response and to better model expected outcomes due to environmental changes, monitoring and assessing water quality and quantity of soil and surface water bodies are necessary (Farkas et al., 2013; Kása et al., 2017; Sheikh Goodarzi et al., 2021).

The climatic conditions can greatly affect stream hydrology and turbidity response to extreme precipitation events. A boreal study of a large river system found that local precipitation events did not significantly influence river discharge, rather catchment based precipitation totals were the main factors (Göransson et al., 2013). In tropical areas where cyclones can cause massive rainfalls and flooding, these tropical cyclones determine the majority of sediment transport (Ram and Terry, 2016). The source of soil moisture and runoff can also influence the concentration of suspended solids. For instance, snowmelt can lead to floods that increase sediment concentration in the stream, while summer rains often cause high runoff that generates suspended solids (Ciupa et al., 2021). In the Pannonian region under continental climate, most precipitation events occur during spring and fall seasons, ensuring favorable soil moisture conditions for winter cereals. During the last decades, several changes were noted between long-term and current precipitation amounts and intensities (Alexander, 2016; IPCC, 2022). Longer drought periods and sudden, high intensity rainfalls are becoming more common, which makes the cultivation and growing of certain crop types more challenging (Czigány et al., 2023; Horel et al., 2022a).

Along with a decrease in soil quality from the transport site, suspended solids can contaminate the surface water bodies. Turbidity mainly reflects soil particle transport and the concentration of suspended sediments, especially at higher volumes of stream discharge. The water quality can highly decrease as runoff of nutrients in dissolved and particle-attached forms enter the streams, which can further influence the entire ecosystem surrounding the streams. High river water turbidity can be related to important health issues for aquatic life. Contaminated waters entering larger water bodies such as lakes can cause eutrophication, lower oxygen content, or algal blooms, affecting the water habitats and the recreational activities around the water bodies (Bhateria and Abdullah, 2015; Brooks et al., 2016; Grosz et al., 2019). Nitrogen and phosphorus can enter small streams from nearby agricultural lands primarily through nutrient runoff. This process involves the movement of water carrying either dissolved or suspended nutrients. Some of the most important agricultural sources and environmental factors, influencing the load of soil particles and nutrients are i) fertilizer application in access, ii) runoff due to high precipitation events prior to the absorption by the crops, iii) sloping environment, iv) soil erosion, or v) poor soil physical parameters such as compaction. Hence, the entire catchment area and its land management systems and techniques influence stream water quality and its preservation or degradation. Therefore, evaluating water quality and its potential impacts on nearby ecosystems and sensitive areas is essential for making informed decisions about necessary mitigation measures.

Antecedent soil moisture can influence the rate of soil transport from erosion prone agricultural areas. The land use types in a given catchment are a major factor in runoff generation, as agricultural land can have significantly higher runoff compared to forest or rangeland (Sheikh et al., 2016). The aspect and slope of the land use types can also influence the rate of erosion and soil moisture retention (Nagy et al., 2020), however, this rate can be highly site dependent (Regüés and Gallart, 2004; Sheikh et al., 2016).

There are various methods for measuring total suspended solids (TSS) in waterways. The most traditional approach involves collecting water samples, filtering them through a filter, and determining the weight of TSS per volume of water. Although this method is highly accurate, it can be time-consuming and labor-intensive (Packman et al., 1999). To replace or reduce the use of the filtering method, alternative approaches have been developed, one of them is the use of optical turbidity sensors. By using these sensors, a quick and reliable estimation of water quality can be achieved after they are calibrated to the specific river or stream where they will be used, particularly in small-scale water systems (Potyó et al., 2017). New technologies, such as satellite data (MODIS) retrieval, are becoming more common for turbidity estimations. However, these techniques cannot be used for small streams due to its current spatial resolution. In the meantime, daily turbidity measurements are still rare in current literature, especially when full years can be considered. As most related papers investigate seasonal changes, the present paper provides a baseline from stream turbidity and chemistry based on a comprehensive data collection at the catchment scale. Our dataset can be used for further evaluations, particularly for small-scale water retention measures, such as those implemented at the farm level. Therefore, in this paper, we aimed at assessing stream water turbidity values in an agriculturally dominated catchment. Our focus was to study (i) the changes in soil turbidity and water chemistry over time and at different locations along a small stream, and (ii) the influence of different meteorological and other environmental conditions to provide a baseline for the study catchment. We hypothesized that a correlation can be drawn not only with the precipitation intensities and amounts but also with the antecedent soil moisture conditions of nearby lands.

2 MATERIALS AND METHODS

2.1 Site description

The study was conducted on a small (21 km^2) agricultural catchment, where the Csorsza stream enters Lake Balaton, Hungary, a highly touristic area. Most of the land use types in the catchment consist of arable lands with crop rotation (typically maize, sunflower, winter wheat, barley, etc.), grasslands and meadows, vineyards, and forests (Figure 1). The lower lying areas (stream valley) are the most affected by soil management such as tillage and fertilization, increasing the possibilities of soil erosion and stream pollution. The length of the Csorsza stream is approximately 7.5 km, with its highest point being at 240 m above sea level and the lowest at 115 m above sea level. The stream bed is mostly naturally shaped by water erosion. However, around urban areas, many artificial concrete channels with straight bottoms and angled sides can be found. In the natural areas of the stream bed, the sediment texture is mostly silt or silty loam, with no gravel present. Around streambed sites, the following plants can often be seen: *Trifolium repens* L., *Trifolium pratense* L., *Convolvulus arvensis* L., *Calystegia sepium* L., *Achillea millefolium* L., *Securigera varia* L., *Bellis perennis* L., *Brunnera macrophylla* L., *Taraxacum officinale* L., all common to this area.

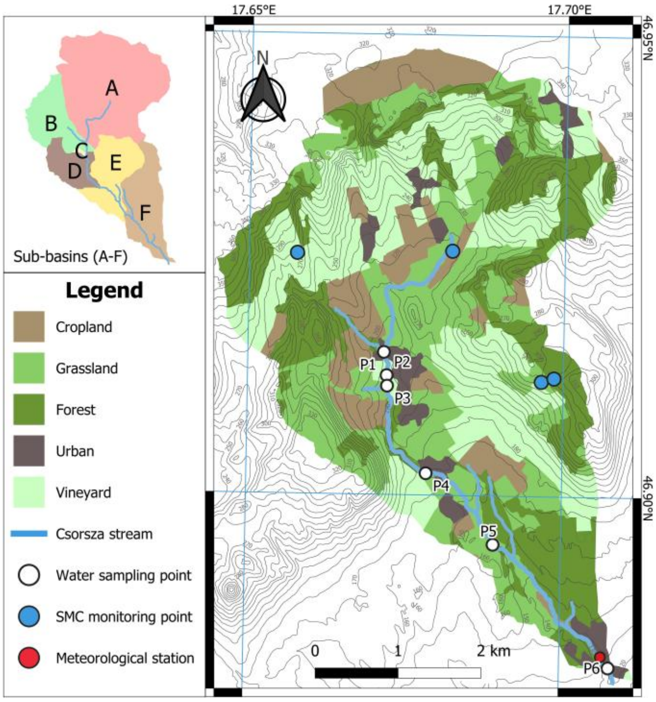

Fig. 1. Area of the Csorsza study catchment showing locations for daily water sampling points (empty circle at P6), bi-weekly water sampling locations along the stream (empty circles at P1-P6) with corresponding sub-basins (A-F; upper left map), location of the soil moisture and temperature monitoring sensors at different land use types (blue circles), and the main meteorological station (filled red circle).

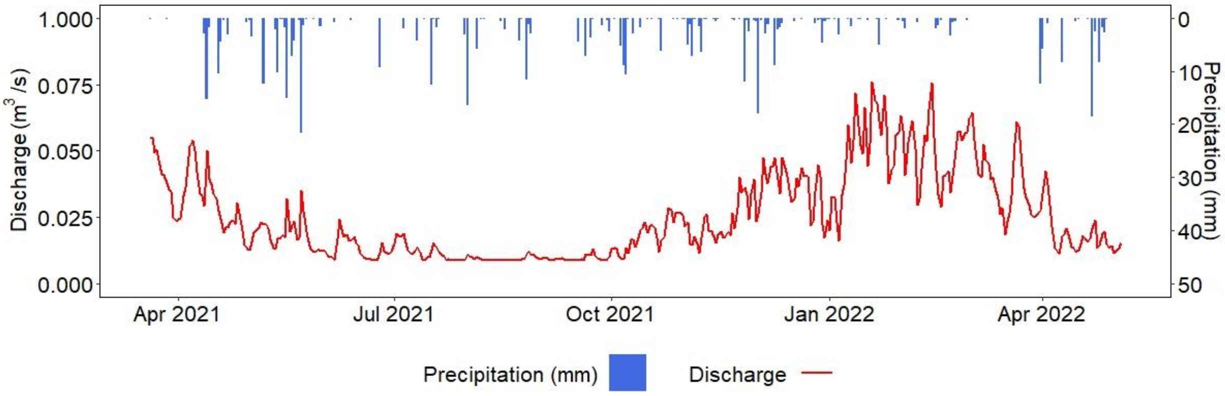

Fig. 2. Discharge and precipitation dynamics over time for the Csorsza stream.

Table 1. Measurement locations, types, and number of data collected. The numbers in frequent measurements along the stream represent occasion numbers and the numbers in parenthesis represent the amount of collected data. SPC refers to electrical conductivity of the stream water (µS cm^{-1}), TDIN is the total dissolved inorganic nitrogen content ($mg.l^{-1}$), SMC is the soil moisture content at the cropland site (as volumetric water content), and Precip refers to precipitation (mm).

Measurement locations	Turbidity	SPC	TDIN	pH	SMC	Precip
Daily (P6)						
2021	193	193	174	157	155	365
2022	61	61	0	61	254	364
2023	280	278	163	255	260	296
Total	534	532	337	473	669	1025
Frequent (P1-P6)						
2021	12 (64)	12 (64)	9 (49)	8 (20)	12	12
2022	3 (17)	3 (17)	0 (0)	3 (17)	3	3
2023	8 (39)	8 (39)	8 (37)	8 (26)	8	8
Total	23 (120)	23 (120)	17 (86)	19 (63)	23	23

The area is dominated by continental climate with high Mediterranean influence. The summer seasons are hot and dry, and cold winters with higher precipitation amounts are typical. The catchment is moderately rain deficient with annual precipitation of around 600 mm (Dövényi, 2010), while precipitation patterns show a decreasing trend often below 600 mm (Horel et al., 2022b). During the investigated years (2021–2023) the average yearly precipitation totals were 451.7 mm, which is substantially below the long-term averages. Meanwhile, the average air temperatures showed a gradual increase, with values of 10.6, 11.3, and 11.5 °C in 2021, 2022, and 2023, respectively. Winter months also experienced fewer precipitation totals during the study years compared to long-term averages. Due to rain deficiency in this area, the Csorsza stream has low water discharge amounts (0.025 m^3/s; Figure 2), while it is a relatively fast flowing stream due to high elevation changes.

The soil types vary across the catchment; detailed descriptions of different areas can be found in Horel et al. (2022b). Briefly, the dominant soil types of the agricultural areas are Cambisols and Calcisols (IUSS Working Group, 2015). At the highest elevations, with outcropping limestones, Leptosol is the typical soil (IUSS Working Group, 2015). This soil type is typical for the grassland and forest soil moisture monitoring sites. Around the Csorsza-stream valley mainly Epileptic Cambisols can be found, where the loessy sediment thickness increases. The texture of the cropland SMC measurement site is silty clay, while the grassland, forest, and vineyard sites have silt loam or silty clay loam textures.

The majority of the catchment area (approximately 78%) consists of gentle slopes ranging from 1% to 10%. Slopes between 10% and 15% account for approximately 9.8% of the total catchment area, while slopes exceeding 15% constitute less than 6%. In terms of aspect distribution, the predominant orientations of the catchment are toward the east, southeast, south, and southwest, collectively representing more than 72% of the total area. The most dominant land use types are forest, grassland, vineyard and cropland, which occupy approximately 85% of the total catchment area. After the catchment was divided into 6 sub-basins (Figure 1 A–F) based on water sampling points, sub-basins A and E had vineyards, B and F forests, and C and D grasslands as the most dominant land use types. These sub-basins were determined after delineation of the area to the water sampling points. At this catchment livestock farming is rare, with only a few sheep and cattle farms present, while organic manure application at croplands and vineyards is common. Hence, nutrient pollution might occur from nearby grazing (most likely at sub-basin F) or after high rainfall events from nearby water runoff.

2.2 Stream water sampling method

Water samples were collected daily at the outlet (P6) whenever water flow was present in the stream (Figure 1). Water was collected in 1 Liter clean plastic bottles, which were rinsed with stream water three times prior to water collection. These samples were used to measure turbidity (FNU) values of the stream entering Lake Balaton (n = 366). Additional sampling locations (P1–P5) along the stream (Figure 1) were also selected and water samples were collected bi-weekly (n = 61) to determine the turbidity (FNU), specific conductivity (µS cm^{-1}), and ammonium (NH_4^+) and nitrate (NO_3^-) ion concentrations ($mg.l^{-1}$).

2.3 Stream water sampling locations, time intervals, and measurement types

There were two types of water collection methods. Table 1 summarizes the data collected from both daily and frequent measurement occasions. The first measurement type was a daily water sample collection at the catchment outlet (P6). The samples from the outlet (P6) were measured for turbidity and electrical conductivity using a handheld instrument (ProDSS, YSI Instruments). This instrument was calibrated to TSS estimation from FNU data as Potyó et al. (2017) described in detail. Selected samples (random one sample per week with additional samples when high turbidity was observed) were measured for TDIN (as the sum of NO_3^--N + NO_2^--N and NH_4^+-N) and pH with a Multi 350i pH meter (WTW). We also collected water samples bi-weekly from various locations along the stream (P1-P6) to represent different parts of the water sources feeding into the main stream. We had 10 measurement points over the years, however, due to extreme drought conditions, some points were often drying out, inhibiting sample collections, therefore for the purpose of this study, we analyzed 6 points with the most collected data. These water samples were measured for TDIN concentration, FNU, SPC, and pH.

The main purpose of the daily measurements was to gather data on the quantity of suspended sediments leaving or relocated within the catchment. We analyzed the daily precipitation totals and the turbidity values. However, water samples were often collected before rainfall events, leading to inconsistencies in our analyses. To address this issue, we used the three-day sums of the precipitation events and compared them to the peak turbidity values.

2.4 Meteorological data

A meteorological station collecting data on air temperature, atmospheric pressure, precipitation, wind speed and direction, relative humidity, and radiation was installed at the outlet of the Csorsza catchment (Figure 1). An additional rain gauge (ECRN-100, Decagon Devices) with 0.2 mm resolution collected in 10-minute intervals was placed at the cropland location to minimize discrepancies in local rain events along the stream, next to the cropland SMC monitoring point. Because there were no additional rain gauges between these two points of the water sampling sites, we interpolated data along the stream for data analyses.

2.5 Soil moisture and temperature monitoring

Soil moisture and temperature sensors (Teros 12 or 5TM, Meter Group, Germany) were installed 15 cm below the soil surface at four land use types, with the closest to the stream being the cropland site (Figure 1). The other three measurement sites included a vineyard, a grassland, and a forest site. In this study, we used soil monitoring data recorded between 2021 and 2023 with a measurement frequency of 10 minutes, and daily averages were used for analyses. The 15 cm soil layer represents the topsoil, which is the most vulnerable soil layer for soil particle detachment and water erosion toward the stream. For data analyses, we used the data from those specific days when also stream water sampling occurred.

2.6 Statistical analysis

The effects of precipitation intensity, amount, and antecedent water contents on stream turbidity values were analyzed using nonparametric statistical analyses of the Wilcoxon rank sum test and Kruskal–Wallis for the non-normally distributed datasets. The descriptive multivariate statistical analysis of hierarchical Cluster Analysis (CA, Eucladean distance) and the Principal Component Analysis (PCA) were applied to explore the factor pattern of the selected stream water, soil, and meteorological parameters. All statistical calculations were performed using the software package R (R Core Team, Version 4.0.2). The statistical significance of the data sets was determined at $p < 0.05$. The same small letters in Figures and Tables indicate no significant differences, while different letters indicate significant differences among the investigated parameters at $p < 0.05$.

3 RESULTS

3.1 Water turbidity and precipitation amounts at the catchment outlet

The daily measured FNU values over time are shown in Figure 3. Our results showed a moderate correlation between FNU and precipitation ($r = 0.42$, $p < 0.001$, $n = 366$; Pearson), due to high FNU values from low water levels. This mainly occurred during drought conditions with low water levels and velocity. A weak negative and significant connection was observed between SPC and FNU values ($r = –0.14$, $p = 0.011$, $n = 349$; Pearson), showing that high precipitation amounts lower water conductivities and, therefore, dilute dissolved ions. In 2022, an extreme drought event caused the stream to dry out and disabled our water collection. Also, some low water levels resulted in high turbidity values in our measurements such as data collected at the end of the 2023 vegetation period (from late July to September), when very low water flow and high air temperatures enabled the water to lose its clarity resulting in higher turbidity values without precipitation event occurring.

We found the highest FNU value to be around 6400, which occurred on a day with 37.2 mm of precipitation in 2022. To reach this high FNU value, the prior days included additional precipitation events, summing to 55.6 mm of precipitation within one week. We observed 19 days when the precipitation totals were higher than 20 mm (measured at the cropland rain gauge). Unfortunately, water samples could not be collected from all of those events, therefore, our analysis of higher precipitation totals versus FNU is limited.

To see if there are any seasonal trends, we have divided the collected daily FNU data into fall, spring, summer, and winter months. We then compared the amount of precipitation to the stream FNU values for each season. We found moderate correlations between precipitation amounts and FNU values for the summer and fall data ($r = 0.50$ and $r = 0.58$, respectively; Pearson), however, no correlation between data for the spring and winter seasons was observed.

3.2 Water parameter changes along the stream

When we analyzed the data from different sampling points along the stream (Figure 1), we found that P3 had the lowest turbidity values (Figure 4a; $p < 0.001$; Wilcoxon), which significantly differed from the other sampling points. The origin of P3 is unique, as it is the only point along the stream that is fed by underground spring water. Consequently, therefore, its chemistry and turbidity are more related to groundwater quality than runoffs from rain events. However, this is the only point where substantially high NO_3^- concentrations were consistently measured at all sampling events, hence we also observed significantly higher TDIN concentrations ($p < 0.05$; Wilcoxon; Figure 4c) compared to the other points. We observed some high overall TDIN values over time, however, these were event-based extremes, such as higher precipitation at specific times of the year resulting in increased water pollution, whereas at P3 all measurement points had consistently higher TDIN values than the other points along the stream. While some of these values seem high for statistical evaluations, we opted to keep these values as they are not true outliers. The SPC values continuously decreased toward the catchment outlet, resulting in the lowest values observed around P6 and the highest at P1–P3. This pattern (e.g., significant differences between P3 and P5 or P6 with $p < 0.001$; Wilcoxon) indicates a reduction in dissolved ions as the water moves toward the catchment outlet. The water pH at P5 was significantly higher than at all other points except for P4 (Figure 4d).

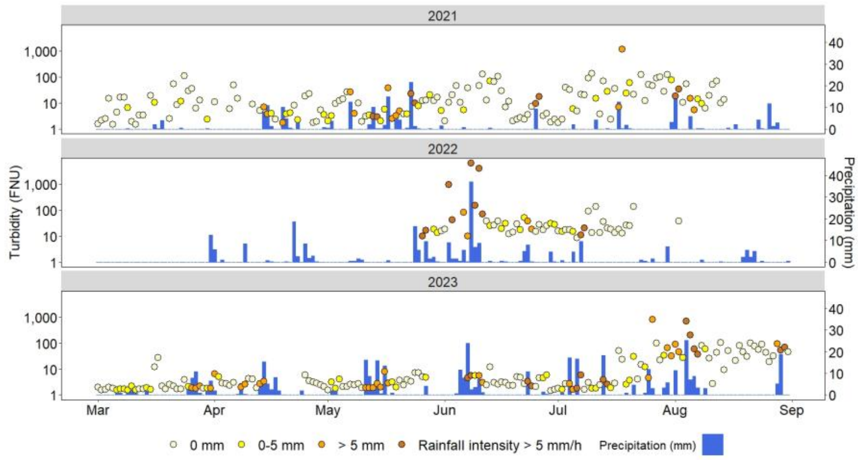

Fig. 3 Three-day averages of precipitation totals (mm; blue bars) and the corresponding peak turbidity measurements (FNU) for the Csorsza catchment during the study years based on daily sample collection; n = 534. Circles show the FNU values linking to the specific amount of precipitation totals, and the shades of yellow to light brown dots represent FNU values at different rainfall intensity categories. Precipitation intensities of higher than 5 mm precipitation total within an hour are separately highlighted (n = 23).

Table 2. Pearson's correlation analysis (r) and p-value (p) between precipitation and the investigated soil and water quality parameters. SPC: electrical conductivity, TDIN: total dissolved inorganic nitrogen, FNU: turbidity, Precip: precipitation, SMC: soil moisture content, C: cropland, G: grassland, V: vineyard, F: forest. Correlation is significant at the 0.05 level. n = 61.

p \ r	SPC	TDIN	FNU	pH	Precip	SMC_C	SMC_G	SMC_V	SMC_F
SPC		0.18	–0.22	–0.34	–0.16	–0.09	0.00	–0.15	–0.03
TDIN	0.161		0.36	–0.05	0.37	0.45	0.14	–0.22	0.20
FNU	0.088	0.005		–0.02	0.23	–0.01	–0.28	–0.23	–0.23
pH	0.007	0.709	0.90		0.11	–0.08	–0.17	–0.29	–0.10
Precip	0.215	0.004	0.07	0.384		0.29	0.18	–0.12	0.24
SMC_C	0.475	0.000	0.94	0.519	0.022		0.78	0.50	0.76
SMC_G	0.978	0.271	0.03	0.191	0.164	0.000		0.71	0.92
SMC_V	0.254	0.090	0.08	0.022	0.361	0.000	0.000		0.59
SMC_F	0.813	0.123	0.07	0.460	0.068	0.000	0.000	0.000	

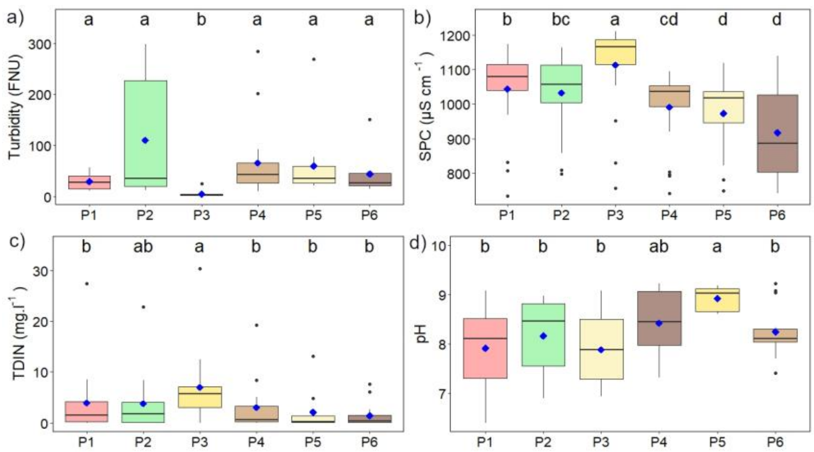

Fig. 4. Box plots of average stream water parameters of a) turbidity (n = 120), b) specific conductivity (n = 120), c) total dissolved inorganic nitrogen (TDIN; n = 86), and d) pH (n = 63) for the different sample collection points along the stream. Each data point represents the median (solid black line), the mean (blue diamond), the upper and lower quartiles, and the minimum and maximum values (whiskers; data ±1.5 interquartile range). Different letters indicate statistically significant differences (Wilcoxon test) between the measurement points.

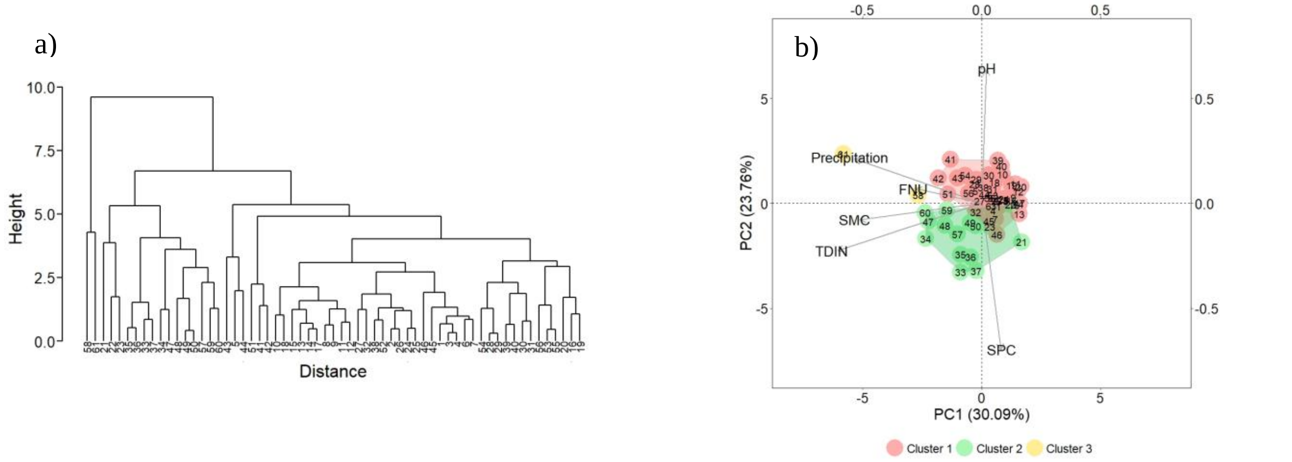

Fig. 5. a) Hierarchical dendrogram and b) principal component analysis (PCA) ordination biplot for the three clusters with selected environmental variables (water chemistry and precipitation) represented as vectors (n = 61). SMC: soil moisture content; SPC: Electrical conductivity of the stream water; TDIN: total dissolved inorganic nitrogen content.

3.3 Environmental parameter correlations

To better understand the catchment's dynamics, we first used a cluster analysis of our dataset. We found that three main clusters could be identified (Figure 5). The first two clusters encompassed most of our data, while the third covered only the extreme precipitation events. We further analyzed the three clusters to investigate the correlations between turbidity values and other studied environmental parameters (e.g., SMC, TDIN, pH, SPC, and precipitation). The cluster analysis results showed that three main clusters can be distinguished based on the daily sample data, which divided our dataset into three groups of daily precipitation amounts with precipitation totals i) below 4.8 mm, ii) averaging 6.3 mm, and iii) averaging 23.7 mm. The three clusters, especially the extreme events are most significantly separated based on precipitation and FNU values. Due to the limited number of extreme turbidity events, the PCA analysis showed a clear separation between the clusters of data and samples from extreme days (yellow points; Figure 5b). The correlation data of the different environmental parameters are summarized in Table 2. We found a weak correlation between FNU and precipitation totals ($r = 0.16$, $p = 0.21$, $n = 61$; Pearson), and a negative correlation between SPC and precipitation amounts. However, these correlations are based only on the days when all five investigated parameters were available for analysis (n = 61), which differs from the analysis of all daily data with FNU values.

While the SMCs from the four land use types were considered for the analyses, the moderate correlation to stream water quality was observed only for the cropland site (TDIN: $r = 0.45$, $p = 0.0003$). The SMC data from forest, grassland, and vineyard sites had weak correlations to stream TDIN values (e.g., forest: $r = 0.20$, $p = 0.12$), hence, for the PCA analysis we opted to present only the cropland data. We did not find any correlations between the turbidity values and the SMC data from the different land use types.

4 DISCUSSION

In the present study, data from selected stream water chemical and physical measurements recorded for three years are presented. The connections between meteorological and water parameters were substituted with nearby soil moisture content data to further investigate the effect of antecedent soil moisture on stream water turbidity. We found that changes in turbidity values can be closely related to both precipitation amounts and antecedent SMC, while water chemistry is more likely related to precipitation amount and the origin of the water source (e.g., spring water or runoff water from agricultural lands near the stream). In our study, however, besides water origin, the most influential water quality indicators are the water pH and specific conductivity.

4.1 Environmental and meteorological factors affecting water quality

The relationship between stream water turbidity and precipitation or water flow should be apparent, especially in erosion prone environments. However, the threshold of precipitation amount that causes a significant increase in water turbidity is unique to each stream or river, and depends on surrounding environmental characteristics, such as soil textures, land uses, or inclination levels. While high precipitation often results in a quick response in water turbidity levels, the lag time between receiving precipitation at a site and corresponding changes in turbidity can vary. This can result in turbidity changes being observed in samples collected the next day or even persisting for over a week (Göransson et al., 2013). We also observed at our research site a high sensitivity to precipitation and sampling times, with varying lag phases required to capture turbidity changes following a single precipitation event, consistent with the findings of Hamilton and Luffman (2009) or Chen and Chang (2019). In our study, we found that turbidity values were highly correlated during the first two days of precipitation events, and later this correlation substantially decreased, indicating the maximum of two days for high levels of suspended solids affecting the stream water. The correlation between water discharge and turbidity can also be highly site specific, as some catchments might have moderate, others might show only weak correlations between these variables (Huey and Meyer, 2010). Another environmental parameter likely affecting water turbidity and dissolved ion levels is the antecedent soil moisture content at a given site (Rostami et al., 2018). Outram et al. (2016) showed that a wetter year can significantly raise NO_3-N and total phosphorus fluxes in streams compared to a drier year. In our study, SPC also correlated (negatively) with precipitation amounts, as the more precipitation totals entered the catchment the less the measured SPC values of the stream water were. We did note some positive correlation between turbidity and SMC, mainly precipitation amounts that affected water turbidity, as higher water flow can be associated with low SPC (Kobayashi et al., 1999).

Another important aspect of turbidity is the seasonality of samplings. During summer, when air and water temperatures are high, flow rates might be low, and an increase in algal blooms can be expected, resulting in a higher level of turbidity levels without an increased amount of TSS. In contrast, during winter in a continental climate, algal blooms are less likely, and data retrieved from optical sensors more reliably estimate TSS. High seasonal variability in water TSS concentrations can be due to differences in other meteorological conditions, such as higher wind conditions (Zhang et al., 2023), hence, the time of water sampling can further influence the results without significant runoff related soil erosion processes due to high precipitation events. However, during winter, biogenic material accumulation might occur, and during snowmelt these organic material pieces can enter the streams in excess, (Tananaev and Debolskiy, 2014) causing higher turbidites.

4.2 Stream water chemical parameters as water quality indicators

Water pH is an important indicator of water quality, as it influences water chemical reactions and the health of aquatic life. Changes in pH can interrupt the water and surrounding soil ecosystems. Different precipitation events can result in different hydrological responses from a catchment (Lynch et al., 1986), influencing the rate of change in most investigated parameters. Atmospheric acid and nitrogen deposition can be still a great threat to the soil and aquatic systems, however, with stricter air quality standards its rates are generally decreasing (Benish et al., 2022). Meteorological, seasonal, and local environmental conditions can greatly influence the rate of acid wet deposition (Luo et al., 2016). Zhu et al. (2021) studied catchment-based nitrogen deposition and emission rates and found that atmospheric nitrogen deposition was smaller than the emission rates, while forest sites are strong reactive nitrogen sinks. We found moderate negative and weak negative relationships between the water TDIN concentrations and pH values for larger (>10 mm) rain events. P5 had significantly higher pH values compared to P1-P4. This point, however, is located in the only major area in the catchment where livestock (mainly cattle and sheep) grazing is common. An increase in water pH due to cattle presence might occur as a result of increased animal waste, especially NH_4^+ from ammonia, which can raise water pH by exceeding its buffering capacity. Another negative influence of grazing near water bodies is the reduced vegetation cover that allows faster water runoff to enter streams from adjacent agricultural lands. The increased runoff can enhance the organic matter and different nitrogen compounds that lead to nutrient enrichment in the water. Hence, reaching the water’s buffering capacity can further result in increased water pH. At this measurement point (P5), the average water pH was close to 9, making the water slightly alkaline and potentially decreasing the solubility of inorganic phosphorus (Diaz et al., 1994). This can directly and indirectly influence water chemistry. Our data showed a moderate, positive, and significant correlation between TDIN and water turbidity or precipitation. Stronger connections between nitrate, nitrite, and phosphate were noted by Joseph et al. (2022), however, the authors could not find any correlations between turbidity and precipitation.

Another key water quality indicator is specific conductivity, which reflects the collective concentration of ions in the stream water and provides information on the dissolved materials in the water. We noted that specific conductivity values gradually decreased toward the catchment outlet, which might result from the lack of underground spring waters feeding the stream in the area between measurement points, as our P3 point with underground water intrusion had significantly higher SPC values compared to other points. Seasonal changes in SPC can be expected, as sharp drops in winter months were noted by Indivero et al. (2021) compared to summer months, however in our study a negligible increase was detected (1.4%).

Water discharge can also influence the amount of suspended solids, as a lower amount of water might decrease the TSS (Wilcock et al., 2006). However, our study showed the opposite results due to extremely low water flows during prolonged drought conditions. High air and water temperatures in summer, slow water velocity, and high plant growth around the streams can provide an environmental condition for algal blooms and high biological, such as microbial, activities that might increase water turbidity without having any major precipitation events (Coffey et al., 2019; Shi et al., 2022). Therefore, water turbidity under a certain threshold of precipitation amounts can provide misleading information on rainfall and turbidity correlations. In our catchment, we found that below 4.8 mm daily precipitation totals, the turbidity values were related to specific environmental (microbial, water chemical, air temperature, etc.) rather than rainfall events. Hence, our study demonstrated and highlighted the importance of site-specific monitoring in mitigating negative effects arising from future climate change related precipitation patterns and amount alterations.

5 CONCLUSIONS

Our study emphasizes the importance of water quality monitoring not only for public health but primarily as a method for studying soil and the surrounding ecosystem health. This approach helps in better preparing for mitigation measures. The threat of climate change related shifts in precipitation pattern along with land use conversions, can contribute to flash floods and extreme soil erosion events. These events not only affect the fertility of catchment lands but also impact larger water bodies and have direct and indirect effects on areas outside a specific catchment. Our three-year long monitoring data enabled us to investigate how physical-chemical indicators of stream water quality correlate with different environmental indicators. We found that daily precipitation totals above 23.7 mm pose a high soil erosion threat, while daily precipitation totals below 4.8 mm indicate that water turbidity is more related to biological, physical, and chemical characteristics of the stream water rather than rainfalls or lack thereof. Our study also highlights the importance of antecedent soil moisture as another influencing factor of water quality changes. Hence, further investigation is needed prior to implementing land use changes in sloped environments to prevent the degradation of soil and water systems, concurrently keeping the ecosystem and its services healthy and intact.

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