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Variations in physicochemical properties, microbiological profiles, and nutrient dynamics in the Temi River, Arusha, Tanzania: Sources and implications

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Keywords

Physicochemical properties;
microbiological properties;
floodplain;
nutrients;
stable isotopes

Abstract

This study thoroughly investigates the physicochemical properties, microbiological profiles, and nutrient dynamics of the Temi River in Tanzania. The sources and implications of fluctuations in dissolved organic carbon (DOC) and nutrients during the wet and dry seasons are carefully analysed. Water samples were collected from various geographically referenced points along the river, and analyses were performed using the APHA Standard Methods for Water and Wastewater Testing. The results show that most parameters increased downstream in both seasons, with the highest DOC levels reaching 352.11 mg/L in the wet season, followed by a significant decrease to 126.00 mg/L during the dry season. Key ion concentrations, such as K^+, Na^+, Mg^{2+}, and Ca^{2+}, peaked at 114 mg/L during the wet season and dropped to 40.51 mg/L in the dry season. The floodplain area displayed higher biochemical oxygen demand (BOD) values, exceeding the WHO maximum permissible level of 10 mg/L, while other regions remained below this threshold. Stable isotope analysis indicated that DOC primarily originated from plant materials, with soil and wastewater sources contributing to fluctuations in nutrient concentrations. Notably, high levels of faecal coliforms (FC) were present in both seasons, indicating inadequate domestic sewage disposal and poor hygienic practices, which pose significant health risks. This comprehensive research provides a solid foundation for understanding the health risks linked to the Temi River for domestic use.

Introduction

The increase in the global human population has led to the pollution of most freshwater resources due to the disposal of sewage, industrial waste, and agricultural runoff, which impacts their physicochemical characteristics and microbiological quality, rendering them unsafe for consumption (Eastwood et al. 2025). Rivers serve as the most dependable freshwater sources for domestic use on Earth; therefore, understanding the hydro-physicochemical and biological properties of these water bodies is crucial for monitoring their pollution and overall health. Changes in the hydro-physicochemical and biological properties of rivers are inevitable, as the environment continues to evolve. Such changes are hypothesised by the River Continuum Concept, which posits that “a continuous gradient in the physical condition of water exists from the catchment headwaters to the mouth” (Vannote et al. 1980). Alterations in the physicochemical properties of water can result from either natural or anthropogenic activities, potentially compromising the safety of freshwater bodies and their surrounding environment (Al-Fanharawi and Al-Khafaji 2023).

The slopes of Mount Meru are home to several rivers that are crucial for the community's socioeconomic development, as their water is extensively used for domestic and irrigation purposes (Sima 2020). While increased urbanisation and agricultural activities along the Temi River have led to water pollution from various sources, little is known about the hydro-physicochemical status of the river (Kitalika et al. 2017). Several studies have examined the conditions of multiple rivers. For instance, Harun (2013) investigated the dynamics of Dissolved Organic Matter (DOM) in Malaysia’s lowland tropical catchment, specifically the lower Kinabatangan River. Furthermore, the dynamic nature of physicochemical properties in the Billabong Kinabatangan and Sungai Padas rivers has been researched (Jawan 2008). Investigations into the physicochemical parameters of the Tawi River revealed consistent increasing trends attributed to rising sewage contamination (Gandotra and Andotra 2008). The distribution of dissolved organic matter has been analysed in the Mackenzie River (Tamara et al. 2010), Potrero de los Funes River (San Luis, Argentina) (Almeida et al. 2007), River Ganga (Singh and Choudhary 2013), and nutrients in the Turag River (Meghla et al. 2013). A comparable study was conducted in the Yamuna River, Agra City (Gupta et al. 2013). Additionally, Lin et al. (2019) highlighted that urbanisation intensifies nitrogen discharge into river systems, thereby altering bacterial communities that can affect organic matter decomposition and overall water quality. Similarly, Zhang et al. (2021) examined the impact of various types of industrial wastewater on bacterial communities in urban rivers, thereby affecting their ecological functions.

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In Africa, such studies have been conducted on floodwaters in Nigeria (Ijoyah and Ogoko 2012) and the Nile River (Ali et al. 2014). Furthermore, earlier studies in Tanzania characterised the physicochemical properties of the Temi River (Lyimo et al. 2012) and those of the Msimbazi, Mzinga, and Kizinga rivers in Dar es Salaam (Napacho and Manyele 2010). Mihale (2021) stressed the concerning levels of metal pollution in the sediments of coastal rivers near Dar es Salaam, indicating that ongoing anthropogenic activities contribute to the degradation of marine and riverine ecosystems. This contamination poses risks to aquatic life and communities that rely on these water sources for domestic use. A study of the Mzinga River (Saria 2015) reported high bacterial contamination, with total coliform levels averaging far above established safety limits. Specifically, the total coliform count ranged from 14.17 to 486.80 CFU/100 mL, underscoring significant health risks for populations that depend on these waters for consumption and irrigation. Research in the Wami-Ruvu basin indicates that water quality fluctuates with the seasons and is influenced by agricultural runoff during the rainy periods (Miraji et al. 2019).

The establishment of sources for various pollutants in water has been effectively achieved by comparing and analysing the dual stable isotopes of the pollutant in question. While nitrogen isotopes have traditionally dominated nutrient-source tracking, stable-isotope techniques are increasingly recognised for their utility in tracing the origins of phosphorus and dissolved organic carbon (DOC) in aquatic environments. The use of oxygen isotopes in phosphate ($\delta^{18}O\text{-}PO_4$) allows researchers to distinguish between phosphorus inputs from synthetic fertilisers, wastewater effluents, and natural soil mineralisation processes (Davies et al. 2014). Similarly, carbon isotopes ($\delta^{13}C$) in DOC provide insight into the relative contributions of terrestrial vegetation, urban waste, and microbial decomposition to organic carbon pools in rivers and lakes (Cole et al. 2007). By applying these isotopic techniques to sediment and water samples, it becomes possible to distinguish between anthropogenic and natural sources, thereby informing targeted management strategies that mitigate nutrient pollution and promote ecosystem restoration. Numerous studies have been conducted to establish the origins of dissolved organic carbon and nitrate in water bodies such as Lake Peter, Paul, and Tuesday of the University of Notre Dame (USA), revealing that these sources originate from algae enrichment (Bade et al. 2007), the lower Mississippi River (Bianchi et al. 2004), groundwater (Heaton et al. 2012), and surface water (Nestler et al. 2011). Similarly, dual stable isotopes in Tanzania have been used to study the sources of nitrate pollution in groundwater aquifers (Alex et al. 2021, Zhou et al. 2022) highlighted the effectiveness of these methods in distinguishing contributions from various nitrogen sources, including agricultural runoff and domestic wastewater. This approach aligns well with research objectives for Tanzanian rivers, where farming activities and urban effluents significantly influence nutrient dynamics. In this study, similar methods were utilised to identify sources of DOC and nutrients in the Temi River. Additionally, the river's seasonal trends in physicochemical, nutrient, and microbiological characteristics, along with their implications for public health, were examined. The river's seasonal trends in physicochemical, nutrient, and microbial characteristics, along with their impact on public health, were also discussed.

Materials and Methods

Description of the study area

The study area includes the Temi River, which originates in the typical sub-catchment foothills of Mount Meru and flows from the eastern to the southwestern parts of the mountain (Figure 1). The river flows downstream from the hill toward the southeast. The natural vegetation at the river's headwaters generally consists of tropical forest or savannah. The topography of the study region is shaped by the Mount Meru volcanic cone, which dates back to the Pleistocene Epoch and continues to the present day (Hijmans et al. 2005). The local climate of the area is a temperate Afro-Alpine, with annual precipitation of 450 mm (Hijmans et al. 2005). Additionally, the average minimum and maximum daily temperatures are 20.6 °C and 28.5 °C, respectively. Rainfall is unevenly distributed, with a main wet season from February to mid-May, accounting for 70% of the yearly precipitation, and a minor season from September to November, making up the rest, leading to a mean annual rainfall of 535.3 mm (Gea 2005, UNDP 2000). The river is divided into three regions based on land development: pristine (headwater) (3° 15' 00" S to 3° 20' 00" S), middle (3° 20' 00" S to 3° 25' 00" S), and floodplain (3° 25' 00" S to 3° 35' 00" S). The catchment area for the pristine part of the river features both artificial coniferous forests and conserved natural forests. At the same time, the middle region includes a mix of agriculture and urban settlements. The floodplain area is marked by bare land, intensive grazing, large-scale agriculture, treated municipal sewage disposal, and severe flooding during the wet season.

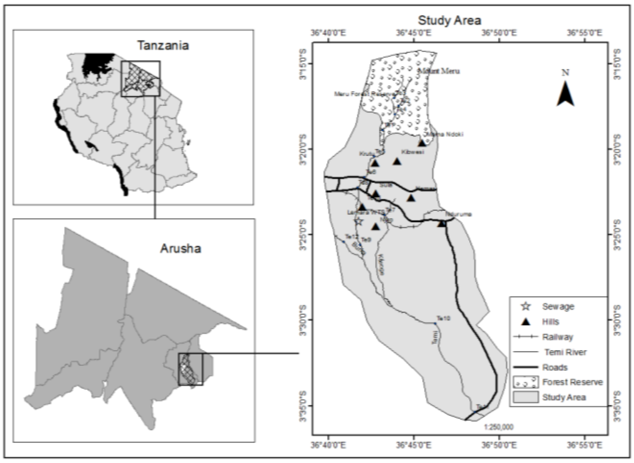

Figure 1: Location of the study area

Sampling

The georeferenced sampling points were selected based on confluence, accessibility, and pre-established monitoring stations. Two litres of water were collected at each point downstream from the river's source. One litre of each sample was used for chemical parameter analysis, while the other litre was reserved for microbiological and nutrient assessments. Samples for isotope analysis were collected in 100 mL High-Density Polyethene (HDPE) bottles with Teflon-lined caps and kept in cold boxes during transport. Sampling occurred during the wet season (mid-March to early April) and the dry season (August). In each season, 33 representative samples were collected for analysis. Additionally, soil composites, sewage effluents, manure, and commonly used industrial fertilisers were sampled within the study area.

Extraction, pretreatment, and clean-up of water samples

The extraction and treatment of soil organic matter, fertiliser samples, and manure followed the procedure outlined by Heaton et al. (2012). Additionally, soil samples were treated with 5% HCl to remove all inorganic carbonates before further processing. The resulting solution was filtered through a 0.45 µm Whatman membrane filter before preservation. Water samples for NO_3^-–analyses were acidified with concentrated H_2SO_4 to a pH of less than 2 and then frozen until analysis. Samples for stable isotope analysis of $\delta^{13}C$ and $\delta^{15}N$ were preserved with a few drops of $ZnCl_2(aq)$ to prevent biological activity. Samples for $\delta^{18}O$ and $\delta^{2}H$ analysis were cooled to 4 °C both before and during transport to the Stable Isotope Laboratory at the University of Waterloo in Canada.

Analysis and confirmation

Temperature, pH, total dissolved solids (TDS), dissolved oxygen (DO), and electrical conductivity (EC) were measured in situ using a HANNA multiparameter model HI9829. On the other hand, total hardness was determined by acid titrimetry. Other parameters, including BOD, faecal coliforms, and total suspended solids (TSS), were analysed using standard methods (APHA 2017). Additionally, total phosphates (TP), soluble phosphates (SP), sulfates, and chlorides were measured with the HACH 2800™. Turbidity and alkalinity were assessed using a 2100Q01 HACH portable turbidimeter, which employed a formazin turbidity standard of 4000 NTU in serial dilutions to meet concentration standards. Total alkalinity was measured with a HANNA alkalinity checker (HI 755). Chromophoric Dissolved Organic Matter (CDOM) was measured in situ with a submersible fluorometer, Turner™ Cyclops-7 (P/N-2100-000-U), integrated with a data logger. Samples for DOC were filtered through a 0.45 µm Whatman membrane filter, and their concentration was determined using a Shimadzu TOC-5000 analyser equipped with a non-dispersive CO_2 detector (Brooks et al. 2015). Analysis of $\delta^{13}C$ and $\delta^{15}N$ stable isotopes was performed using the Los Gatos Research Laser Processes Analyser with Integrated Cavity Output Spectroscopy (LGR®-ICOS). The Vienna Pee Dee Belemnite (V-PDB) and Vienna Standard Mean Ocean Water (VSMOW) international standards served as references for isotope analysis (IAEA 2000, De Troyer et al. 2010).

The $\delta^{13}C$ data analysis was reported in parts per thousand (‰), as indicated in Equation 1.

$$^{13}C \text{ or } \delta^{15}N = (\frac{Rs}{Rstd} - 1)1000 \tag{1}$$

where Rs- is the ratio of $\delta^{13}C/\delta^{12}C$ in the sample, Rstd- is the standard ratio (V-PDB), which equals 0.0112372. For $\delta^{15}N$, Rs- is the ratio of $\delta^{15}N/\delta^{14}N$ in the sample, and Rstd- is the standard ratio (VSMOW)

Results and Discussion

Physicochemical and microbiological changes in the river

The major cations and anions changed downstream, as shown in Figures 2 and 3. Generally, higher concentrations of cations and anions were observed during the wet season compared to the dry season. The highest concentrations of major cations and anions were found in the floodplain area of the river during the wet season at sampling points Te10 and Te11, while lower concentrations were recorded in the pristine and urban regions of the river. In the wet season, the HCO_3^- levels were 352.18 mg/L and 212.71 mg/L, respectively. These levels decreased during the dry season to 126.00 mg/L and 122.91 mg/L, respectively. Other ions (Cl^-, K^+, Na^+, Mg^{2+}, and Ca^{2+}) reached up to 114 mg/L and 40.51 mg/L in the wet and dry seasons, respectively (Figures 2 and 3). This trend is accelerated during the wet season by runoff, which likely collects dissolved ions from multiple sources along the river. Additionally, the low water velocity in the floodplain allows more time for interaction between the water and rocks, thereby increasing the dissolution of ions from the stones, which may be another contributing factor.

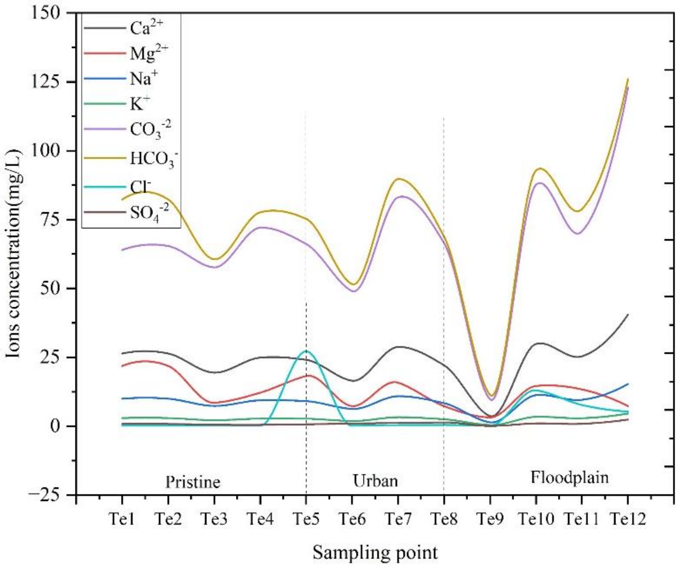

Figure 2: Major ions concentration during the dry season in the Temi River

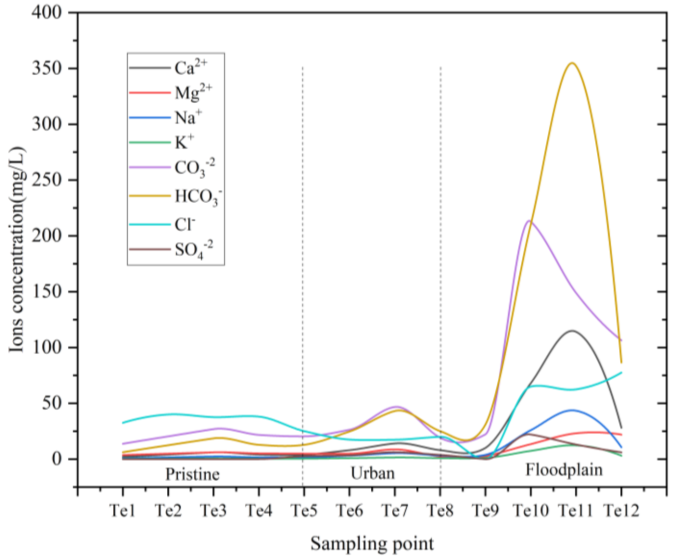

Figure 3: Major ions concentration during the wet season in the Temi River

The correlation matrix of major ions in the Temi River (Table 1) shows consistently strong positive relationships among cations such as Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}, with correlation coefficients often exceeding 0.80 (e.g., Mg^{2+}–Na^{+}: 0.81, Mg^{2+}–K^{+}: 0.81). These high correlations suggest a common geochemical origin, likely due to the dissolution of typical soluble salts, such as halides, carbonates, and sulfates, resulting from the weathering of local rocks or human activities. The strong correlation between Cl^{-} and Mg^{2+} (0.83) further supports the idea of co-mobilisation through runoff or groundwater movement, especially during the wet season when hydrological connectivity increases.

The elevated ionic concentrations observed during the wet season correspond to increased terrestrial runoff, which enhances the transport of soluble salts into the river system. This seasonal influx not only increases the absolute concentrations of major ions but also enhances their co-occurrence patterns, as indicated by the consistent correlation values across wet-season samples. The matrix further indicates ionic stability and conservative behaviour in the aquatic environment, with minimal ion exchange or selective retention, especially for monovalent cations such as Na^{+} and K^{+}, which exhibit a perfect correlation (r^2 = 1.00). This suggests similar transport dynamics and low reactivity.

Table 1: Correlation matrix for major ions in the Temi River

	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
Ca^{2+}	1							

Mg^{2+}	0.8071*	1						
Na^+	1*	0.8067*	1					
K^+	1*	0.8066*	1	1				
CO_3^{2-}	0.855*	0.7815*	0.8548*	0.8548*	1			
HCO_3^-	1*	0.8069*	1*	1*	0.8549*	1		
Cl^-	0.6122*	0.8319*	0.6118*	0.6118*	0.7415*	0.6122*	1	
SO_4^{2-}	0.8056*	0.6398*	0.8058*	0.8058*	0.9549*	0.8055*	0.5783*	1

*Correlation is significant at $p \geq 0.05$

The water temperature ranged from 14.95°C in the pristine environment during the wet season to 26.17 °C in the floodplain during the dry season (Figure 4). High temperature fluctuations in the river are due to variations in vegetation cover along the riparian environment, causing some areas to be colder. In contrast, areas directly hit by sunlight are hot.

The salinity ranged from 0.04 mg/L to 275.99 mg/L. Salinity levels were very low during the wet season, likely due to dilution from runoff. However, during the dry season, the floodplain experienced an increase in salinity, likely due to low water velocity, which increased the interaction time between water and rocks containing different soluble salts (Figure 5). Despite the fluctuation in salinity within the river, their values remained below the WHO acceptable levels of 100 mg/L in the pristine environment, which is used as one of the water sources for the Arusha municipality (WHO 2017).

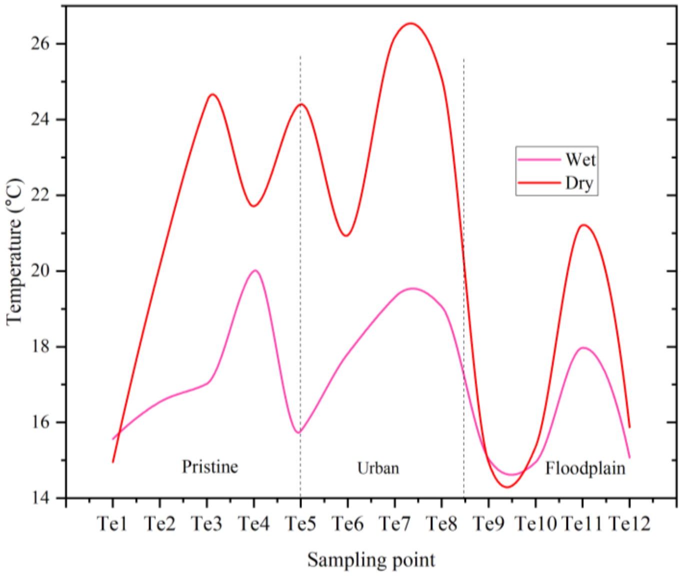

Figure 4: Water temperature during the wet and dry seasons

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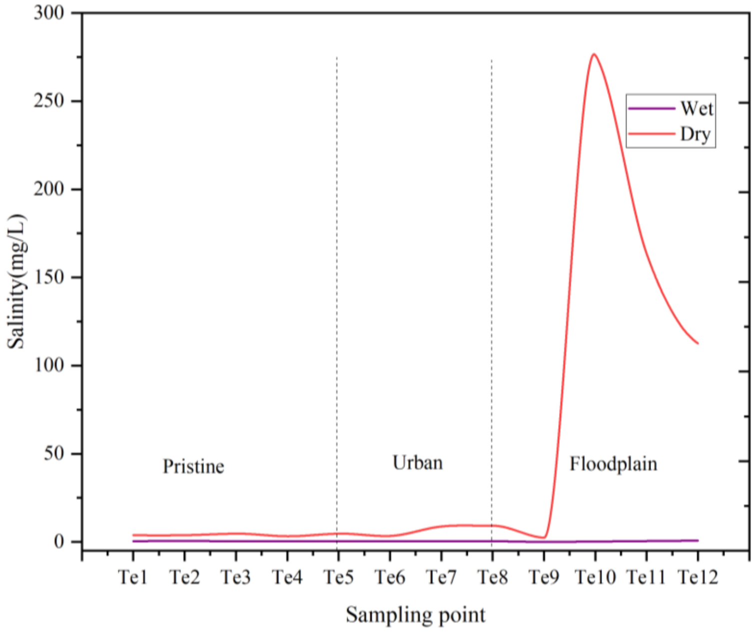
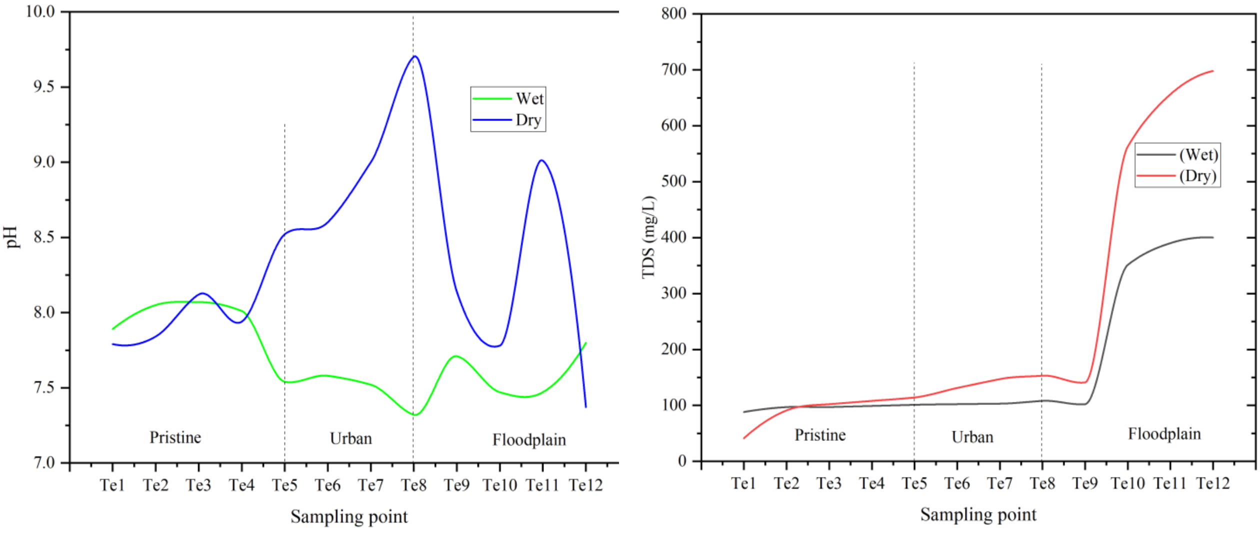


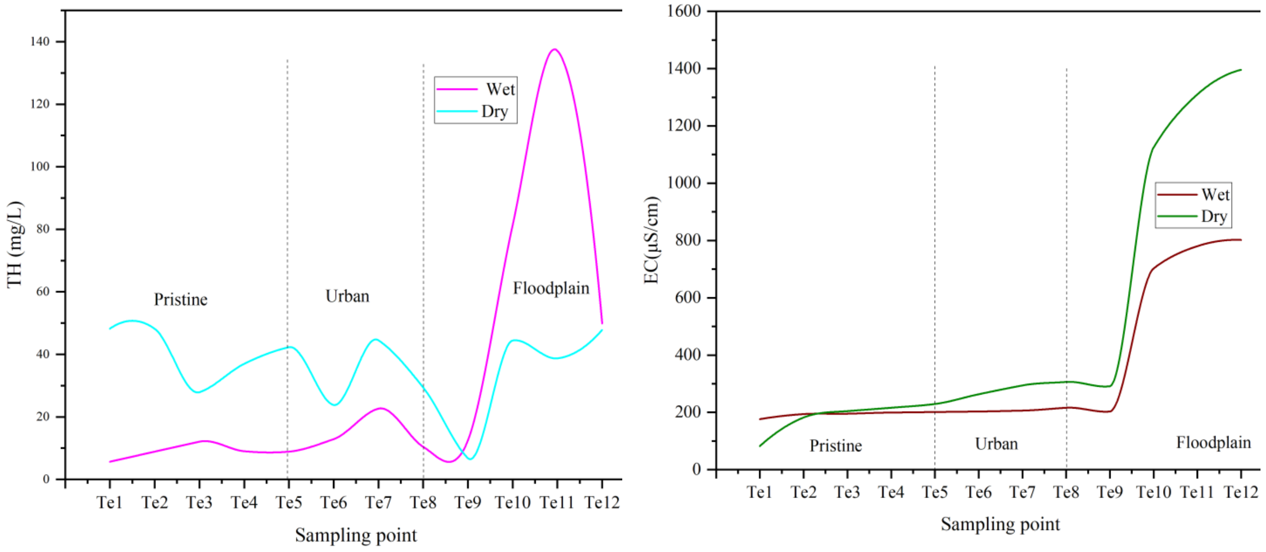
Figure 5: Salinity of the Temi River in wet and dry seasons

The pH ranged between 7.32 and 9.70 in both seasons, but they were within the acceptable levels of 6.5-9.2 in both seasons, respectively (WHO 2017) , except at Te8, where the pH reached 9.7 (Figure 6a). This sampling point is located within the urban area, where most of the City's domestic effluent discharges occur. The effluents are likely to contain alkaline effluents.

The total dissolved solids (TDS), total hardness (TH), and electrical conductivity (EC) in both seasons were also within the acceptable levels for drinking water of 200-1200 mg/L, 200 mg/L, and 2500 µS/cm, respectively (Figures 6b, c, d) (WHO 2017). The increase in levels of the three parameters in the floodplain is due to their dependence on dissolved salts, which are embedded in the rocks. The river spends more time in the floodplain, causing more interactions between water and the rocks, which, in turn, are accelerated by high temperatures, as discussed earlier.



(a) (b)



(c) (d)

Figure 6: Variations in pH, TDS, TH, and EC in the Temi River during the wet and dry seasons

The FC levels were a concerning parameter in both seasons, as no water sample was found to be free from FC. Higher FC levels occurred during the wet season, as runoff transported faeces-contaminated waste into the river. The highest FC level was 10,200 FCU/100 mL at Te12, recorded at the floodplain, and 4,800 FCU/100 mL at Te6, located in the urban section of the river during both seasons. The lowest level in the wet season was 500 FCU/100 mL at Te4, in a pristine environment. During the dry season, these values slightly decreased to 300 FCU/100 mL at the same point in the pristine environment (Figure 7). The presence of FC, even in untouched areas, underscores the need to treat potable water before use, regardless of its source. Despite the recovery at Te7 and Te8 due to natural vegetation and sand filtration, there is an unusual increase in FC in the floodplain caused by the discharge of effluents from the Lemara wastewater treatment system (WTS) into the river. This implies that the system is not efficiently treating the wastewater to reduce the contaminants to acceptable levels. Thus, it is crucial to modify the system to more effectively capture microorganisms and reduce their numbers downstream.

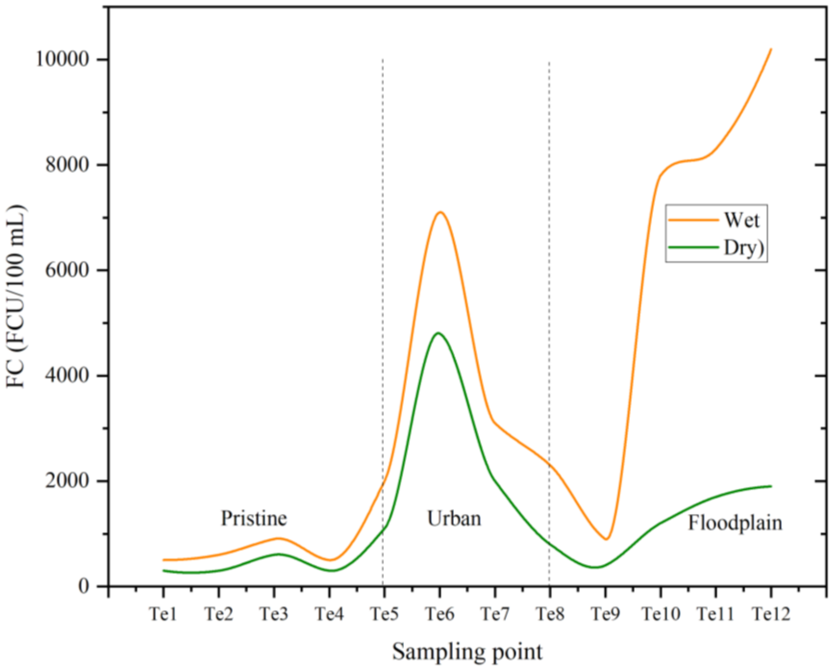


Figure 7: Variations of FC in the Temi River during the wet and dry seasons

The nutrient flow for this river in both seasons is illustrated in Figures 8 and 9. Nutrient levels rose after mixing with wastewater from Lemara WTS, with nitrates being the most prominent in both seasons. The highest levels were 97 mg/L at Te10 and 82 mg/L at Te11, while the minimum levels were below 0.23 mg/L and below the detection limit (bdl) in the dry and wet seasons, respectively (Figures 3a and b). In both seasons, some sampling points exceeded the WHO-recommended maximum limit of 50 mg/L for drinking water (WHO

2017). The river's water levels were higher during the dry season than in the wet season. This is expected because the floodplain is a lowland dominated by pastoralists with large herds of animals that depend on the same river for water, especially during the dry season. When animals stay in one area all day, they increase the nitrogenous waste in the water through excretion. Other parts of the river showed low levels in both seasons; however, during the dry season, levels were slightly higher in pristine environments (Te1 and Te4). The rise in nitrates in this area is due to excretory waste from wild animals, which use this river as their primary water source, since most streams in the area dry up during drought. Nitrate transformation at all points followed similar patterns based on the nitrates present, as shown in Figures 3a and 3b. Correlation studies of transformations revealed a strong positive relationship between them, indicating that different compounds can be converted into one another under certain pH conditions (Table 2). Overall, nitrate levels in pristine environments remained below the maximum permissible levels set by the World Health Organisation.

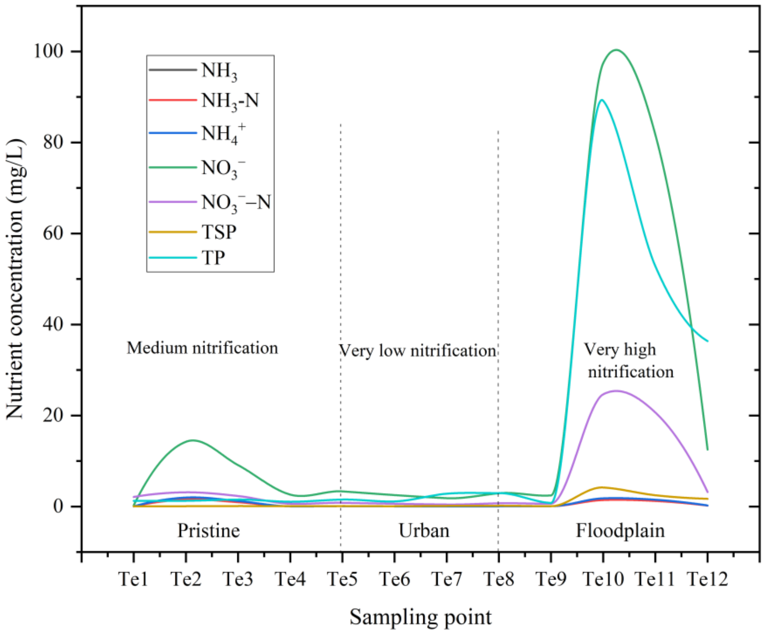


Figure 8: Nutrient variations in the Temi River during the wet seasons

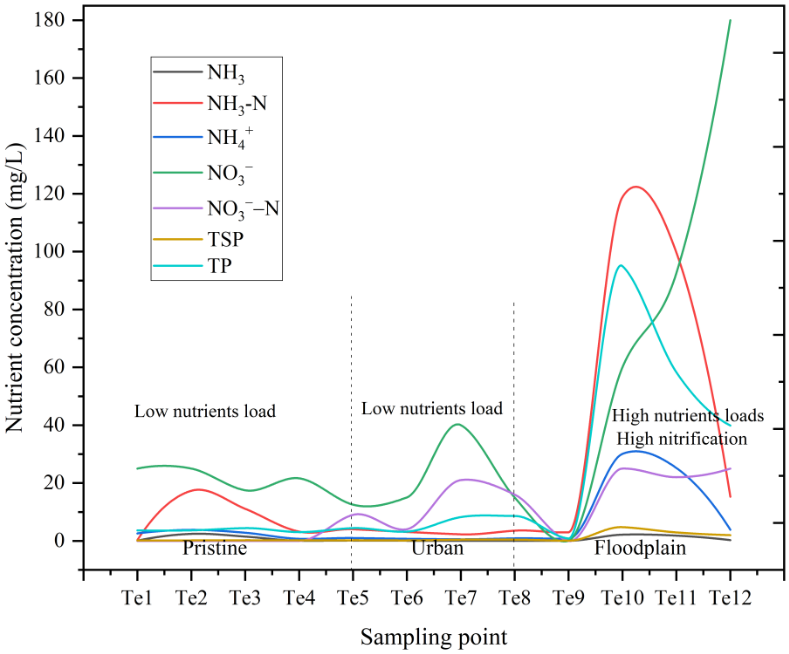


Figure 9: Nutrient variations in the Temi River during wet seasons

Phosphate nutrients were also detected in areas similar to those with nitrates, as shown in Figures 8 and 9. In this study, the highest total suspended phosphorus (TSP) concentration during the wet season was 4.16 mg/L at Te10, while total phosphate (TP) reached 89.15 mg/L. At the same site during the dry season, the TSP concentration was 4.74 mg/L, while the TP concentration reached 94.94 mg/L. This abnormal increase in phosphate indicates point-source pollution from the discharge to the receiving river, as well as from improperly treated wastewater from

Lemara WTS. However, such sewage is also used for downstream vegetable irrigation, providing water and nutrients simultaneously, posing a significant health risk because the water has been found to contain high levels of FCs. The river's floodplain area exhibited phosphate concentrations exceeding 0.1 mg/L in both seasons, suggesting improperly treated effluents from the Lemara wastewater treatment system, a point source of pollution. Under normal conditions, a river not flowing into a lake should have a total soluble phosphate (TSP) not exceeding 0.1 mg/L (Wang 2020).

The correlation matrix (Table 2) shows a perfect positive correlation between TSP and TP (r = 1.00), indicating that TSP is a reliable indicator of the soluble portion of TP and reflects contributions from both organic and inorganic phosphate species (Sharpley et al. 2013). This strong linear relationship suggests that the phosphorus pool in the river is mainly in soluble forms, which are readily mobilised under dry-season hydrological conditions (Withers et al. 2001).

The high TP value compared to TSP suggests that a large part of phosphorus exists in particulate or colloidal forms, possibly attached to suspended sediments or organic matter. However, the perfect correlation shows that fluctuations in TSP are closely linked with changes in TP, supporting the idea that both fractions originate from similar sources and undergo identical transformations. These sources may include agricultural runoff, wastewater discharge, and sediment resuspension, all of which influence the balance between dissolved and particulate phosphorus (Sharpley et al. 2013).

Table 2: Correlation matrix for nutrients in the Temi River

	NH_3	NH_3-N	NH_4^+	NO_3^-	NO_3^- -N	TSP	TP
NH_3	1						
NH_3-N	0.9999*	1					
NH_4^+	0.9997*	0.9997*	1				
NO_3^-	0.7248*	0.7228*	0.7091*	1			
NO_3^--N	0.7166*	0.7146*	0.7007*	**0.9998***	1		
TSP	0.5815*	0.5794*	0.5643	**0.9359***	0.9379*	1	
TP	0.5815*	0.5794*	0.5643	**0.9359***	0.9379*	1	1

*Correlation is significant at $p \geq 0.05$

Furthermore, the strong correlations between TSP and nitrogen species, such as NO_3^- (r = 0.9359) and NO_3^-–N (r = 0.9379), indicate simultaneous nutrient loading events, likely caused by similar land-use pressures and hydrological transport processes. This simultaneous mobilisation of nitrogen and phosphorus compounds emphasises the risk of eutrophication, especially during periods of low flow and high nutrient retention.

Seasonal patterns and spatial distribution of oxygen-intensive pollutants in the river system

A quantitative assessment of oxygen-demanding pollutants revealed an apparent seasonal variation, with notably higher concentrations during the wet season than during the dry season (Figures 10 and 11). The headwaters (Te1) remained low in pollutants, reflecting minimal human activity and limited runoff. At sampling site Te10, near the confluence of the WTS and Temi River, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) peaked at 34.1 mg/L and 52.0 mg/L, respectively, during the wet season. These levels decreased to 24.7 mg/L and 37.0 mg/L in the dry season, indicating less pollutant input. The higher levels during the wet season are linked not only to the discharge of oxygen-demanding waste but also to increased terrestrial runoff, which carries organic and chemical waste into the river, thereby boosting microbial activity and oxygen consumption. This sharp increase in these values indicates inefficiencies in the wastewater treatment system (WTS), which fails to remove oxygen-demanding substances before the effluent is released effectively. Significantly, these levels exceed the Tanzania Bureau of Standards (TBS) maximum allowable limit of 30 mg/L for wastewater discharge (TBS 2021), posing potential ecological risks. In both seasons, there was a considerable decrease in such values at one sampling point (Te9) because, before reaching this area, self-purification (sand filtrations due to sedimentation and low water velocity) occurs, which in turn reduces the waste.

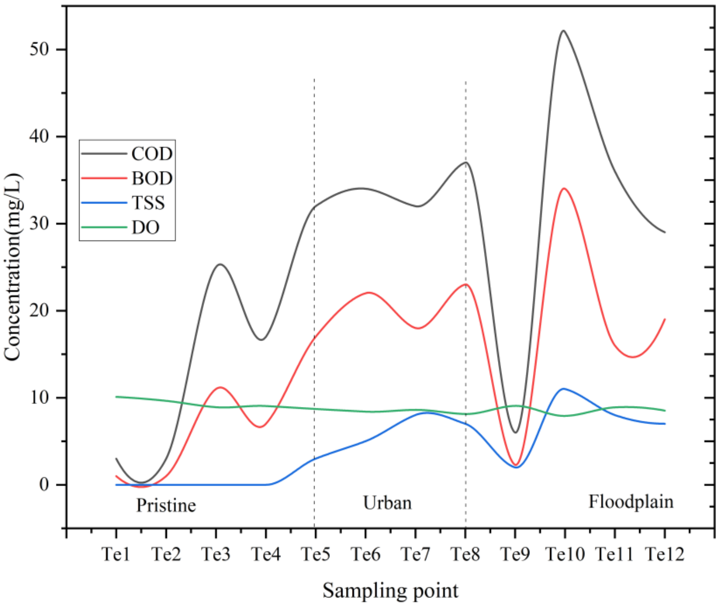


Figure 10: Variations in oxygen-demanding wastes in the dry season

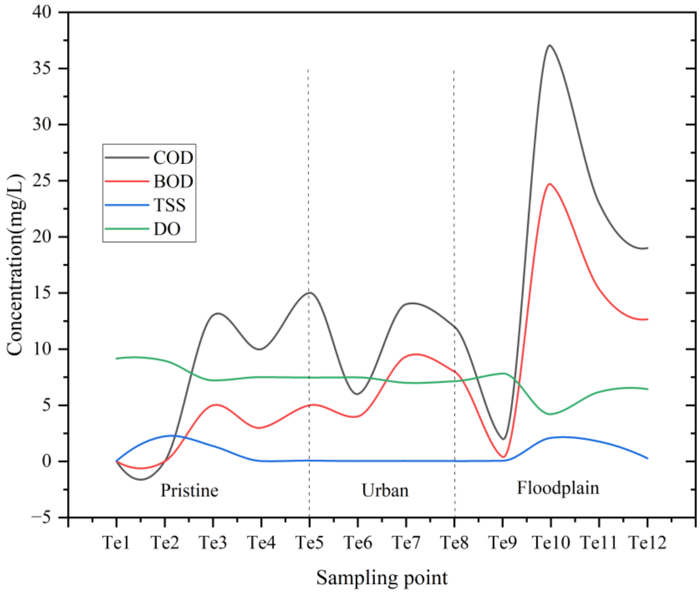


Figure 11: Variations in oxygen-demanding wastes in the dry season

A proportional relationship was observed between BOD and COD across sampling points, indicating that the waste components have similar oxidative effects on both parameters. Despite higher levels at Lemara, downstream sites Te11 and Te12 exhibited decreasing BOD and COD values, indicating natural attenuation and self-purification processes within the river system.

Dissolved Oxygen (DO) concentrations showed an inverse relationship with BOD and COD, indicating biological oxygen consumption by organic matter. DO levels were highest at Te1, reaching 10.10 mg/L during the wet season and 9.16 mg/L during the dry season, while Te10 showed lower values of 7.91 mg/L and 4.20 mg/L. These results are consistent with ecological standards, as DO levels between 4–7 mg/L are generally sufficient to support aquatic life, and levels above 8 mg/L indicate a healthy aquatic environment (Baker & Kearney, 2016). Additionally, the recorded DO levels meet TBS standards for drinking water quality (TBS 2019).

Additionally, Total Suspended Solids (TSS) showed a positive correlation with COD, highlighting the role of particulate matter in increasing oxygen demand. This relationship emphasises the importance of integrated management strategies that address both dissolved and suspended pollutants to protect river health and ecological balance.

Fluorescence signatures of dissolved organic carbon and turbidity in the river system

Chromophoric dissolved organic matter serves as a proxy for oxidised dissolved organic carbon (DOC) in aquatic environments, with its optical properties, particularly fluorescence, providing insight into the concentration and composition of total organic carbon (TOC). In this study, fluorescence intensity was measured in relative fluorescence units (RFU), indicating the presence of organic compounds such as fulvic and humic acids, as reported by Massi et al. (2020 and Tian et al. (2012).

Spatial and seasonal variations in fluorescence were observed across sampling sites. During the wet season, the highest fluorescence was recorded at Te12 (441 RFU), while the lowest was at Te1 (-160 RFU). In the dry season, Te11 showed the highest fluorescence (19.4 RFU), whereas Te2 exhibited the lowest fluorescence (-162 RFU) (Figure 12). Negative RFU values, especially in upstream or minimally impacted sites like Te1 and Te2, indicate negligible dissolved organic matter (DOM), with any carbon likely existing in inorganic forms such as bicarbonates or carbonates. Conversely, positive RFU values in downstream floodplain sites suggest the presence of DOM, probably from terrestrial inputs, microbial activity, and human sources.

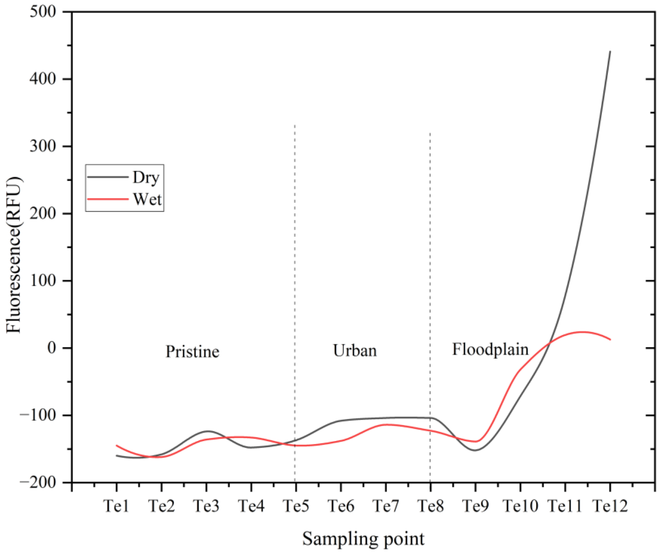


Figure 12: Variations in fluorescent organic matter in the Temi River during the wet and dry seasons

The distribution of fluorescence values matches the stable isotope analysis discussed in the following section, which further clarifies the origin and transformation pathways of organic carbon within the river system. These results highlight the usefulness of fluorescence spectroscopy as a non-invasive method for evaluating organic matter dynamics in freshwater ecosystems.

On the other hand, most parts of the river were turbid, with higher turbidity being more pronounced during the wet season than during the dry season (Figure 13). The high turbidity in the wet season is attributed to surface runoff, which carries waste containing colloids, mostly clay particles. Low turbidity in the dry season is attributed to the absence of runoff.

Spatial distribution and drivers of dissolved organic carbon in the river

Dissolved Organic Carbon (DOC) concentrations showed a clear spatial pattern along the Temi River, increasing gradually from the pristine upper catchment toward the lowland floodplain. The lowest DOC levels, measured at 0.2 mg/L, were recorded at upstream sites Te1 and Te3, which have minimal human impact and limited terrestrial runoff. In contrast, the highest DOC concentration of 1.97 mg/L was found at Te10, located within the river's floodplain area (Figure 14).

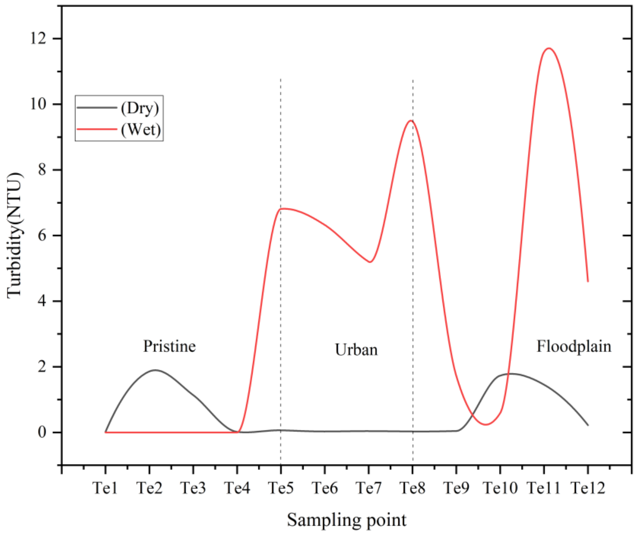


Figure 13: Turbidity trends in the Temi River during the wet and dry seasons

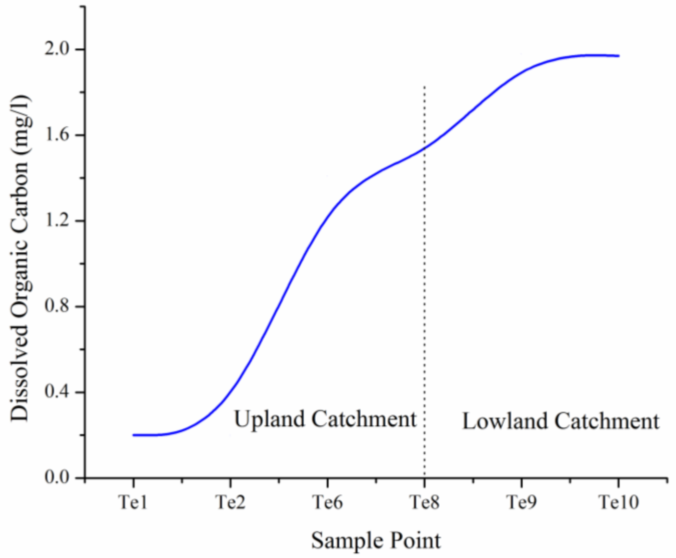


Figure 14: Trend of dissolved organic carbon in the Temi River

The high DOC levels in the floodplain are likely due to several factors. First, increased nutrient input from surface runoff and municipal wastewater discharge, especially from the Lemara treatment facility, brings significant amounts of organic material into the river system. Second, microbial breakdown of organic substrates in warmer, nutrient-rich floodplain waters further raises DOC levels. Together, these processes increase the concentration of oxidised organic compounds downstream (Zang et al. 2025).

Previous research has demonstrated that DOC in riverine environments predominantly originates from terrestrial vegetation, especially in relatively undisturbed systems (Zang et al. 2025). In such contexts, DOC serves as a key component of the natural carbon cycle, influencing microbial activity, nutrient dynamics, and light attenuation (Xia et al. 2025). The observed DOC patterns in the Temi River are consistent with these findings, highlighting the interplay between land use, hydrology, and biogeochemical processes in shaping the distribution of organic carbon (Dittmar and Stubbins 2013, Perdue 2003).

Stable isotope analysis of dissolved organic carbon sources in the river

Given the Temi River's flow through diverse ecological and human-influenced landscapes, pinpointing the sources of dissolved organic carbon (DOC) is vital for understanding its biogeochemical processes. This study used stable carbon isotope analysis to compare the $\delta^{13}C$ signatures of riverine DOC with those of potential source materials, as shown in Table 4 and Scheme 1 (Mook 1980a, Mook 1986a).

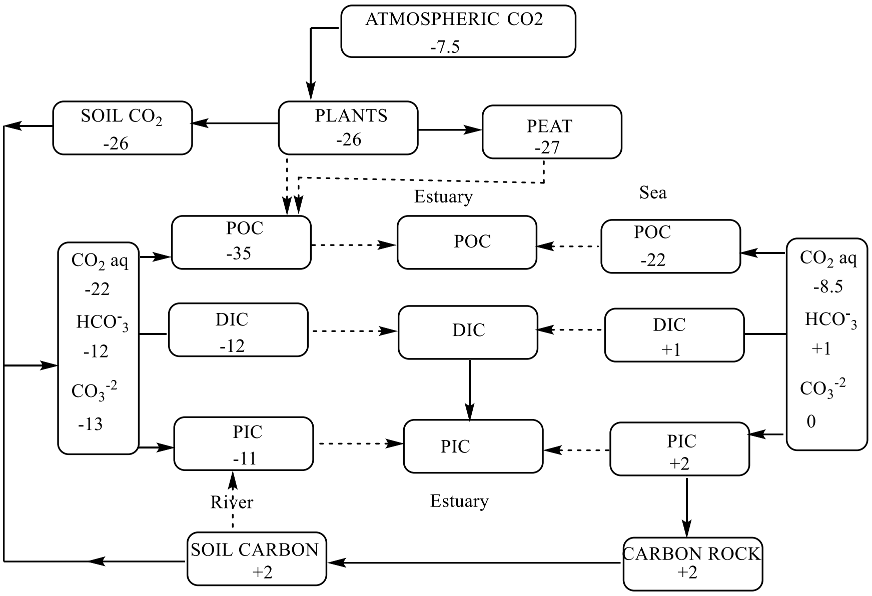
At the headwaters (Te1), $\delta^{13}C$ values averaged -13.01‰, closely matching the isotopic signature of groundwater (-13.11‰). This similarity suggests that DOC in the upper catchment primarily originates from inorganic carbonates, likely due to the mixing of groundwater with surface water. In contrast, $\delta^{13}C$ values in the middle and floodplain of the river ranged from -21.30‰ to -22.82‰. These values match the isotopic signatures of manure (-21.25‰) and terrestrial plant material (-22.1‰), indicating that the DOC in these areas primarily originates from organic sources, such as wastewater effluents and decaying vegetation.

Since manure mainly consists of plant-derived organic matter, the isotopic evidence supports the conclusion that terrestrial vegetation is the primary source of DOC in the downstream sections of the river. This interpretation aligns with previous research demonstrating that DOC in river systems often originates from allochthonous plant material, especially in areas impacted by agricultural and urban runoff (Dittmar and Stubbins 2013, Mook 1980a, Mook 1986a, Perdue 2003).

Table 4: Stable isotope signatures and dissolved organic carbon levels for the Temi River.

SP	Te1	Te3	Te5	Te6	Te8	Te9	Te10	M	SC	GW	WW	CAN/NPK	PM
DOC (mg/L)	0.20	0.20	-	1.41	1.46	1.98	1.97	-	-	-	-	-	-
$\delta^{13}C$ (‰)	-13.01	-	-	-	-21.30	-22.82	-22.50	-21.25	-17.4	-13.11	-20.07	-24.81	-22.1
$\delta^{15}N$ (‰)	-6.82	-	-	-	8.08	10.11	10.36	6.77	9.47	-2.59	10.19	-6.91	-
$\delta^{2}H$ (‰)	-24.71	-	-22.31	-20.36	-	-17.42	-14.50	-	-	-	-	-	-
$\delta^{18}O$ (‰)	-5.08	-	-4.70	-4.45	-	-3.77	-3.01	-	-	-	-	-	-

SP- Sampling Point; M- Manure; CAN- Calcium Ammonium Nitrate; NPK- Nitrogen Phosphorus Potassium; SC- Soil Composite; GW- Groundwater, WW- Wastewater; PM- Plant Materials



Scheme 1: Schematic diagram showing the sources of dissolved inorganic carbon (DIC), suspended particulate organic carbon (POC), and particulate inorganic carbon (PIC) in rivers and estuaries(Mook 1980a, 1986a).

Tracing nitrogen sources in the river using $\delta^{15}N$ stable isotope fractionation

Stable nitrogen isotope analysis ($\delta^{15}N$) offers a reliable method for identifying and distinguishing nitrogen sources in river systems affected by agricultural activities and wastewater discharge (Qiu et al. 2024, Xia et al. 2018, Zhang et al. 2019). This method enables the characterisation of nitrogen input routes and their interactions within aquatic ecosystems (Anornu et al. 2017).

In the pristine upper catchment of the Temi River, $\delta^{15}N$ values averaged -6.82‰, closely matching the isotopic signature of commonly used inorganic nitrogen fertilisers (-6.91‰; Table 4). This suggests that nitrogen input in this area is primarily human-made and originates from fertiliser runoff (Heaton et al. 2012a, Xia et al. 2018, Zhang et al. 2019). This supports the idea that small-scale farming in the surrounding catchment adds nitrogen to the river through surface runoff. In contrast, $\delta^{15}N$ values in the middle and lower parts of the river ranged from 8.08‰ to 10.36‰, indicating a shift in nitrogen sources toward organic forms. These values match the isotopic signatures of soil-derived nitrogen (9.47‰) and effluent from the Lemara wastewater stabilisation system (10.19‰), indicating that the nitrate in these sections originates from both natural soil processes and human wastewater inputs. The increase in nitrate levels downstream of the Lemara discharge point further supports the idea that the stabilisation pond is not fully effective at removing nitrogen compounds before they are released.

Together, these isotopic patterns reveal the spatial differences in nitrogen sources in the Temi River, highlighting the importance of land use and wastewater management in shaping nutrient behaviour in freshwater ecosystems.

Policy implications and recommendations

The findings of this study emphasise the urgent need for integrated water resource management policies that address both point and non-point sources of pollution in the Temi River catchment. Elevated levels of dissolved organic carbon (DOC), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and nitrate concentrations, particularly downstream of wastewater discharge points, highlight the ineffectiveness of the current wastewater treatment infrastructure at Lemara. Policymakers should focus on upgrading and monitoring wastewater stabilisation systems to ensure they meet the thresholds set by TBS. Additionally, regulating agricultural runoff through buffer zones, promoting sustainable fertiliser use, and implementing community-based watershed stewardship programs can help reduce nutrient loading. Incorporating stable isotope monitoring into routine water quality assessments would improve source attribution and guide targeted interventions. Ultimately, a multi-sectoral approach involving environmental agencies, local governments, and community stakeholders is essential to protect aquatic ecosystems and maintain long-term water quality sustainability.

Conclusions

A comprehensive study of the Temi River in Tanzania highlighted notable variations in its physicochemical properties, microbiological quality, and nutrient dynamics between the wet and dry seasons. The findings showed that water quality deteriorated downstream, primarily due to human activities associated with urbanisation and agriculture. High levels of faecal coliforms and other pollutants raised serious concerns about public health and water safety for both households and aquatic life.

During the wet season, the river showed higher levels of dissolved organic carbon (DOC) and major ions, including K^+, Na^+, Mg^{2+}, and Ca^{2+}. These levels dropped significantly during the dry season, indicating that runoff during heavy rains is a key factor in carrying pollutants into the river. The link between the river and the nearby Lemara wastewater treatment plant was clear: high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) levels downstream indicated inefficiencies in effluent management, often exceeding health authorities' limits. Additionally, the stable isotope analyses revealed that the DOC primarily originated from plant materials. At the same time, significant nutrient inputs from soil and wastewater emphasised the urgent need for better waste management practices.

These findings have significant implications, highlighting the need for comprehensive water quality management. Actions should be taken to rehabilitate and upgrade existing wastewater treatment plants to ensure contaminants are removed before they enter the river. Educational initiatives focused on increasing community awareness about pollution reduction and water conservation can encourage local participation in environmental stewardship.

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Conflict of Interest

The author has no competing interests to disclose.

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