Physicochemical and microbial evaluation of water quality in the Tinau River Basin, Lumbini Province, Nepal

A. Mahat*, S, Katwal, S. Shakya*, B. T. Magar***, S. Poudel***, S. S. Kuinkel****, K. B. Pal*****, M. L. Sharma****** and R. R. Pant*****

*Patan Multiple Campus, Institute of Science and Technology, Tribhuvan University, Kathmandu, Nepal.
** Padma Kanya Multiple Campus, Tribhuvan University, Kathmandu, Nepal.
***Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.
****Department of Environmental Science and Engineering, Kathmandu University, Nepal.
***** Tri-Chandra Multiple Campus, Tribhuvan University, Kathmandu, Nepal.
******Central Department of Chemistry, Tribhuvan University, Kathmandu, Nepal.

Abstract: Monsoon runoff can dilute and degrade river water quality in Himalayan catchments by mobilizing sediments, organic matter, and fecal contaminants. The Tinau River in western Nepal supports domestic abstraction, irrigation and riparian livelihoods, yet its monsoon-season suitability for these uses remains insufficiently resolved. This study assessed the twenty-four sites (Tinau River Basin) spanning upstream (TR01-TR10), midstream (TR11-TR16) and downstream (TR17-TR24) reaches during the third week of September 2025 using physicochemical parameters, fecal indicator bacteria, a weighted arithmetic water quality index (WQI), and major-ion-based irrigation indices. Water was neutral to slightly alkaline (pH = 7.10-8.60) and moderately mineralized (EC = 212-503 µS/cm; TDS = 106-252 mg/L), but turbidity exceeded 5 NTU at 18 sites. BOD_5 and COD ranged from 8.11-40.54 and 10.0-52.4 mg/L, respectively, indicating notable organic loading. Total coliform and *Escherichia coli* ranged from 20-247 and 7-102 CFU/100 mL, respectively and *E. coli* occurred at every site. WQI classification identified 1 good site, 11 poor sites, 8 very poor sites and 4 unsuitable sites. Hydrochemical facies were dominated by $Ca\text{-}HCO_3$ water, consistent with carbonate weathering. Irrigation indices suggested low salinity and sodicity hazards, with 23 samples in C2-S1 and 1 in C1-S1, although RSC values of 1.76-2.96 meq/L indicated carbonate hazard at several locations. The Tinau River is therefore generally suitable for irrigation with drainage and soil management, but direct drinking use during the monsoon is not advisable without clarification and effective disinfection.

Keywords: Drinking water; *E. coli*; Irrigation suitability; Tinau river basin; Water quality index.

Introduction

Freshwater rivers underpin water security, agricultural production, ecosystem functioning, and public health. In monsoon-dominated catchments, short-lived runoff pulses can sharply alter river chemistry and microbiological quality by increasing land-river connectivity, suspended sediment transport and contaminant delivery.[1] Safe-use interpretation therefore requires evaluation against public-health guidance as well as local regulatory criteria.[2, 3]

Water quality indices (WQIs) are useful for condensing multi-parameter datasets into an interpretable screening value, but they are sensitive to parameter selection, weighting structure and the intended use of the water.[4,5] For

Author for correspondence: Ramesh Raj Pant, Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.
Email: rpant@cdes.edu.np; https://orchid.org/0000-0002-6170-0188

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surface waters that may be abstracted directly by nearby communities, chemically acceptable water cannot be assumed to be microbiologically safe.[2, 3]

Irrigation suitability must also be assessed independently from drinking-water suitability. Low-salinity water can still create infiltration or alkalinity problems when sodium, bicarbonate and carbonate interactions are unfavorable. Recent irrigation-water reviews and classical appraisal frameworks therefore recommend interpreting EC, SAR, Na%, KR, RSC, MAR, PI and PS together rather than in isolation.[6-10]

The Tinau River originates in the Mahabharat hills, traverses the geomorphically fragile Chure range, and enters the Terai plain of western Nepal. The watershed is exposed to slope instability, bank erosion, intense monsoon runoff, riverbed extraction and growing settlement pressure.[11-13] Recent and earlier Tinau River studies have reported seasonal physicochemical variation and bacteriological contamination, indicating that local water use can be constrained even when several chemical variables remain within acceptable limits.[14, 15] However, a longitudinal monsoon-season appraisal that integrates physicochemical condition, microbial contamination, drinking-water screening, and irrigation suitability has remained limited. The present study therefore aimed to: (i) characterize spatial patterns in physicochemical and microbial contamination; (ii) assess drinking-water suitability using a weighted arithmetic WQI supported by guideline comparison; and (iii) evaluate irrigation suitability using major-ion-based indices.

Materials and Methods

Study area and sampling design

The Tinau watershed covers approximately 562 km² and extends from about 85 to 1,940 m above sea level in western Nepal (Figure 1).[11] Sampling was conducted in the third week of September, immediately after a week of high-flow or flood conditions, at 24 sites coded TR01-TR24 from upstream to downstream. For reach-wise comparison, the sites were grouped into upstream (TR01-TR10), midstream (TR11-TR16), and downstream (TR17-TR24) reaches. The watershed setting and sampling corridor are presented in Figure 1.

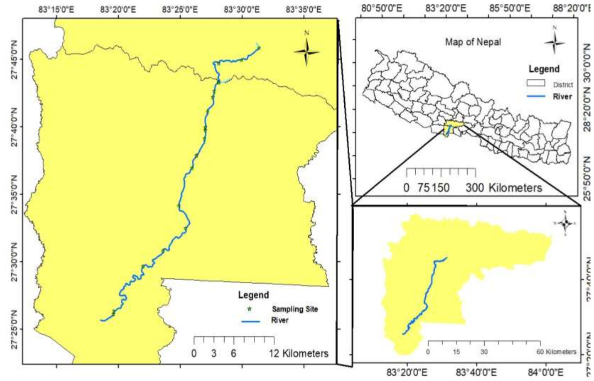

Figure 1: Location map of the Tinau River

Sampling, laboratory analysis, and data verification

Surface-water samples were collected in clean high-density polyethylene bottles. In-situ measurements included temperature, pH, EC, total dissolved solids (TDS), and dissolved oxygen (DO). Samples for laboratory analysis were transported on ice and stored at 4 °C before processing. Turbidity, alkalinity, total hardness, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), nitrate, ammonia, phosphate, iron, and total suspended solids (TSS) were analyzed using procedures described in Standard Methods for the Examination of Water and Wastewater.[16] Total coliform and *E. coli* were enumerated by membrane filtration and reported as CFU/100 mL.[16] Temperature, alkalinity, total hardness, and TSS were retained in the full analytical dataset as supporting variables for hydrological and statistical interpretation, whereas the main drinking-water summary emphasizes the principal WQI, organic-load, and microbial variables.

Water-quality assessment and statistics

The drinking-water WQI was evaluated using the weighted arithmetic framework.[5] The index combined pH, EC, TDS, turbidity, DO, BOD_5, COD, nitrate, ammonia, phosphate, and iron. Quality ratings were computed as $Qi = 100 \times (V_i - V_0)/(S_i - V_0)$, where V_i is the measured value, S_i is the adopted standard, and V_0 is the ideal value; unit weights were assigned as $W_i = K/S_i$, where $K = 1 / \Sigma(1/S_i)$; and total

WQI was obtained as $\Sigma(Q_iW_i)$.[5] WHO and Nepal drinking-water criteria were used as the principal screening references.[2,3] WQI classes were interpreted as good (26-50), poor (51-75), very poor (76-100), and unsuitable (>100).[5] Iron was retained in the WQI because it is included in drinking-water acceptability and operational screening criteria and allows direct comparison with guideline based assessment.[2,3] Its near-static concentration (0.250-0.251 mg/L) contributed little to site-to-site WQI variation; therefore, the interpretation emphasizes the more variable and risk-relevant parameters, particularly turbidity, organic-load indicators and microbial contamination[4,5].

Table 1: Summary statistics of the principal physicochemical and microbial variables (n = 24).

Parameter	Unit	Mean ± SD	Range	NDWQS guideline, 2022	Sites exceeding
pH	-	7.82 ± 0.32	7.10-8.60	6.5-8.5	1
EC	µS/cm	403.25 ± 64.93	212-503	1500	0
TDS	mg/L	201.79 ± 32.44	106-252	1000	0
Turbidity	NTU	13.93 ± 11.86	0.4-47.2	5	18
DO	mg/L	8.53 ± 1.16	4.34-10.26	5*	1*
BOD_5	mg/L	21.28 ± 11.67	8.11-40.54	5*	24*
COD	mg/L	30.88 ± 12.11	10.0-52.4	-	-
Nitrate	mg/L	0.23 ± 0.17	0.013-0.684	50	0
Ammonia	mg/L	0.09 ± 0.01	0.081-0.112	1.5	0
Phosphate	mg/L	0.012 ± 0.006	0.001-0.022	-	-
Iron	mg/L	0.250 ± 0.001	0.250-0.251	0.3	0
Total coliform	CFU/100 mL	94.25 ± 63.78	20-247	-	-
E. coli	CFU/100 mL	40.08 ± 27.86	7-102	0	24

** DO and BOD_5 are reported as screening indicators of river condition; they are not formal NDWQS potability limits Temperature, alkalinity, total hardness, and TSS were measured as supporting variables and are included in the underlying dataset.*

For irrigation appraisal, major-ion concentrations were converted to milliequivalents per liter (meq/L). The principal indices were $SAR = Na / \sqrt{((Ca + Mg) / 2)}$, $Na\% = (Na + K) \times 100 / (Ca + Mg + Na + K)$, $KR = Na / (Ca + Mg)$, and $RSC = (HCO_3 + CO_3) - (Ca + Mg)$.[6-10] EC-SAR relationships were interpreted using the USSL framework, Na%-EC relationships using the Wilcox criterion, and RSC classes according to classical irrigation-water guidance.[7-10] MAR, PI, and PS were also reviewed to strengthen the irrigation interpretation.[6] Descriptive statistics were used for summary reporting, and Kruskal-Wallis tests were applied to evaluate reach-wise differences among river reaches.

Results and Discussion

Physicochemical and microbiological condition

The physicochemical and microbiological characteristics of the Tinau River (Table 1; Figures 2 and 3) show a circumneutral to slightly alkaline system (pH 7.10-8.60; mean 7.82). Such buffering is consistent with carbonate weathering and alluvial interaction reported from Himalayan river systems.[17,18] EC and TDS values (212-503 µS/cm and 106-252 mg/L) indicate low to moderate mineralization indicating that river chemistry is primarily controlled by natural geogenic processes remain an important control on dissolved ions, although localized agricultural return flows and domestic inputs may also contribute.[19]

Turbidity varied markedly (0.4-47.2 NTU), and 18 sites exceeded the 5 NTU drinking-water guideline. This pattern indicates strong sediment input during the monsoon, probably associated with catchment erosion, surface runoff, riverbank disturbance, and suspended-particle transport. Elevated suspended solids can degrade water quality, increase treatment difficulty, and facilitate contaminant and pathogen transport. [20]

Elevated BOD_5 (8.11-40.54 mg/L) and COD (10.0-52.4 mg/L) showed significant organic pollution, with maxima at TR09, TR11, TR20, and TR23. These values point to biodegradable and oxidizable organic matter inputs during runoff conditions, which may originate from untreated sewage, solid-waste disposal, livestock activity, and diffuse agricultural sources. [21] Although DO was generally adequate (mean 8.53 mg/L), high BOD_5 shows that the river receives substantial oxygen-demanding material.

Nutrient concentrations remained below drinking-water limits, with nitrate, ammonia, and phosphate ranging from 0.013-0.684, 0.081-0.112, and 0.001-0.022 mg/L, respectively. These low measured concentrations do not rule out event-based nutrient pulses, because agricultural and urban nonpoint sources often vary strongly with rainfall and land-river connectivity. [1,22]

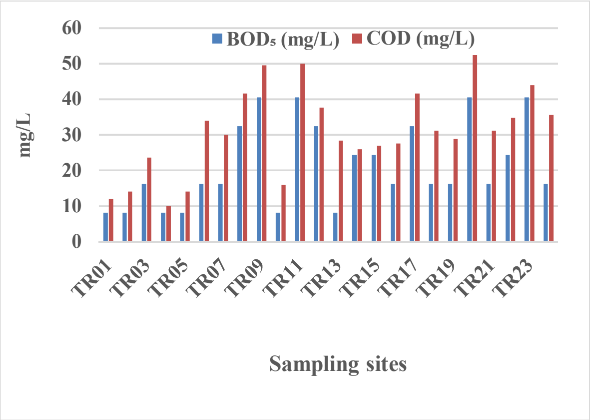

Figure 2: Site-wise BOD_5 and COD concentrations along the Tinau River.

Microbiological contamination was widespread. Total coliform and *E. coli* ranged from 20 to 247 and 7 to 102 CFU/100 mL, respectively. *E. coli* occurred at every site and exceeded the zero-detection criterion for drinking water, indicating recent fecal contamination from human or animal sources. [2,3,23] The combined presence of turbidity and fecal indicator bacteria indicates that direct domestic use during the monsoon presents a public-health risk unless the water is effectively clarified and disinfected.

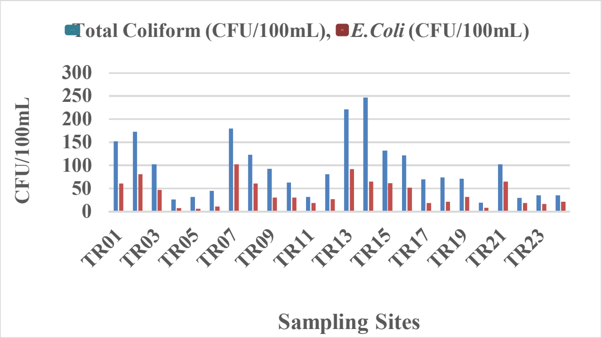

Figure 3: Site-wise total coliform and *E. coli* counts along the Tinau River.

Spatial patterns along the river continuum

Reach-wise patterns were evident along the Tinau River (Table 2; Figures 2 and 3). EC and TDS increased from upstream to downstream, from 372.50 to 450.12 µS/cm and from 186.40 to 225.00 mg/L, respectively. This downstream increase indicates progressive enrichment of dissolved ions through water-rock interaction, agricultural return flow, settlement inputs, and cumulative catchment effects, a pattern commonly reported in river water-quality studies. [18,25]

Turbidity also increased downstream, from 7.36 NTU upstream to 24.90 NTU downstream, indicating greater sediment loading in lower reaches where bank disturbance, land-use pressure, and surface runoff are more pronounced. Similar suspended-sediment effects have been reported as major contributors to river-water degradation and contaminant transport. [20]

Kruskal-Wallis results showed significant reach-wise differences for temperature ($p < 0.001$), EC ($p = 0.020$), TDS ($p = 0.020$), turbidity ($p = 0.018$), ammonia ($p = 0.012$), phosphate ($p = 0.005$), and TSS ($p = 0.002$). COD, DO, BOD_5, total coliform, and *E. coli* did not differ significantly among reaches at $p < 0.05$; therefore, their longitudinal tendencies are described cautiously rather than interpreted as statistically distinct reach effects.

COD mean values increased from upstream to downstream (24.48-37.45 mg/L), whereas microbial contamination peaked in the midstream reach, where total coliform and *E. coli* averaged 139.17 ± 81.90 and 52.83 ± 26.75 CFU/100 mL, respectively. The midstream microbial peak suggests localized inputs from settlements, drainage channels, livestock access, and sanitation pressures superimposed on monsoon runoff. These findings agree with earlier Tinau River evidence that bacteriological contamination remains a persistent management concern. [15]

Drinking-water suitability during the monsoon

The WQI evaluation (Figure 4) indicates that most Tinau River sites were poor to unsuitable for drinking during the monsoon; only TR01 fell into the good category. The poorest physicochemical conditions occurred at TR09, TR11, TR20, and TR23, which also showed high organic loading and sediment influence.

Importantly, WQI alone cannot fully represent public-health risk when microbial indicators are excluded or treated only indirectly. Even the good WQI site contained 61 CFU/100 mL of *E. coli,* demonstrating that physicochemical screening can underestimate fecal contamination hazards. This interpretation is consistent with WQI-method reviews and microbial drinking-water guidance, which emphasize that index values should be supported by pathogen or fecal-indicator evidence when assessing water intended for direct use. [2,4,23,24]

When physicochemical and microbiological results are combined, none of the 24 sites should be considered safe for direct consumption during the monsoon without adequate treatment. At minimum, direct use would require clarification or filtration to address turbidity and effective disinfection to remove microbial risk. Similar monsoon and urban-river studies in South Asia show that rainfall-driven runoff and land-use connectivity can increase pollutant delivery and reduce drinking-water suitability. [1,25,28]

Hydrochemistry and irrigation suitability

The irrigation-water interpretation is summarized in Table 3, and the EC-SAR classification is shown in Figure 5. The Tinau River displays a Ca-HCO_3 dominated hydrochemical signature, indicating carbonate weathering as the main geogenic control on water composition. Similar hydrochemical facies have been reported for other Himalayan river systems, including the Gandaki and Seti basins. [26, 27, 29, 30]

Relatively low ECw (212-503 µS/m) and low SAR (0.40-0.56) place 23 samples in C2-S1 and one sample in C1-S1 on the USSL diagram (Figure 5), indicating low salinity and very low sodicity hazards. [8] Na% and Kelly's ratio (KR) also remained within acceptable ranges, supporting the interpretation that sodium-related irrigation hazards are low throughout the basin. [9,10]

However, residual carbonate-related alkalinity risks require attention. RSC values ranged from 1.76 to 2.96 meq/L, placing 17 sites in the marginal class and 7 sites in the unsuitable class for this specific index. This means that repeated use on poorly drained soils could promote alkalinity build-up even where salinity and sodicity hazards are otherwise low. [7,8] Other indices, including MAR, PI, and PS, indicated low magnesium, permeability, and chloride-related salinity risks under normal agronomic management.[6,7, 29,30]

Conclusion

The Tinau River showed a combine influence of geogenic.

Table 2: Reach-wise mean ± SD for selected parameters and Kruskal-Wallis p-values.

Parameter	Unit	Upstream	Midstream	Downstream	p-value
EC	µS/cm	372.50 ± 75.28	392.00 ± 56.53	450.12 ± 17.68	0.020
TDS	mg/L	186.40 ± 37.83	196.50 ± 27.88	225.00 ± 9.13	0.020
Turbidity	NTU	7.36 ± 7.16	10.27 ± 3.41	24.90 ± 13.31	0.018
DO	mg/L	8.96 ± 1.07	8.62 ± 0.30	7.94 ± 1.50	0.172
BOD_5	mg/L	16.22 ± 11.47	24.32 ± 11.47	25.34 ± 11.00	0.112
COD	mg/L	24.48 ± 13.76	32.77 ± 9.44	37.45 ± 7.99	0.058
Total coliform	CFU/100 mL	98.90 ± 57.25	139.17 ± 81.90	54.75 ± 28.62	0.070
E. coli	CFU/100 mL	44.00 ± 32.34	52.83 ± 26.75	25.62 ± 17.14	0.215

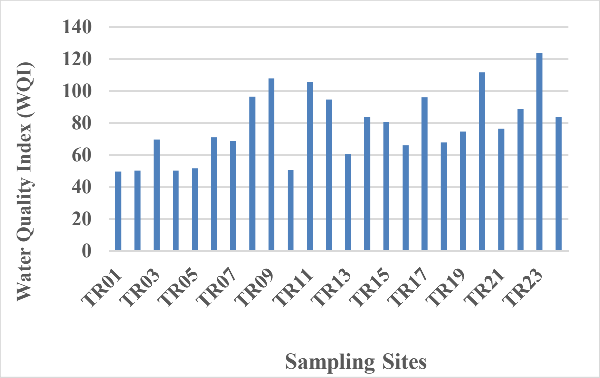

Figure 4: Site-wise Water Quality Index (WQI) along the Tinau River.

controls and monsoon-amplified anthropogenic pressures. of natural geogenic processes and anthropogenic pressures that shape its water quality. Physicochemical parameters such as pH, EC, and TDS generally remained within WHO and Nepalese drinking-water guideline values, consistent with carbonate-weathering control on dissolved ions. In contrast, turbidity, BOD_5, COD and fecal indicator bacteria showed substantial contamination during the monsoon period.

E. coli occurred at all sites, confirming recent fecal contamination and making the river unsuitable for direct drinking use without treatment. WQI results classified most sites as poor to unsuitable, but the microbial results show that WQI must be interpreted together with fecal indicators when public-health risk is assessed.

Reach-wise analysis showed downstream increases in turbidity and dissolved ions, whereas microbial contamination peaked in the midstream reach, indicating localized settlement and drainage impacts. For irrigation, the river was generally suitable because salinity and sodicity hazards were low; however, elevated RSC values indicate a need for drainage management and periodic monitoring to avoid soil alkalinization under repeated irrigation.

Effective management should therefore combine erosion control, improved sanitation and wastewater management, seasonal monitoring of physicochemical and microbial variables, and targeted irrigation-risk surveillance to protect public health and sustain agricultural use of the Tinau River.

Data Availability Statement

The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request.

Table 3: Summary of irrigation-water quality indices and interpretive significance.

Index	Unit	Mean ± SD	Range	Interpretation
ECw	μS/m	0.40 ± 0.06	212-503	Low salinity hazard; 23 samples C2-S1 and 1 sample C1-S1
SAR	-	0.50 ± 0.04	0.40-0.56	Very low sodicity hazard; all samples in S1
Na%	%	28.73 ± 2.95	21.58-32.81	Good by Wilcox criterion at all sites
KR	-	0.35 ± 0.05	0.22-0.42	Acceptable throughout (all values <1)
RSC	meq/L	2.38 ± 0.26	1.76-2.96	17 marginal and 7 unsuitable sites; main irrigation caution
MAR	%	14.83 ± 9.88	7.28-47.62	All values <50; no magnesium hazard indicated
PI	%	141.74 ± 16.16	104.04-163.00	Class I permeability throughout
PS	meq/L	0.51 ± 0.09	0.27-0.65	Low potential salinity across the basin

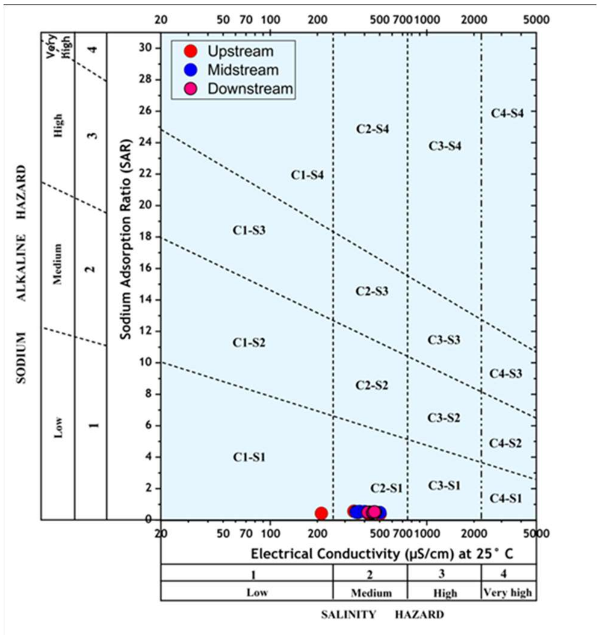

Figure 5: USSL diagram (EC versus SAR) for irrigation water suitability.

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