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# Investigating Physicochemical Properties of Rangazak and Challou River in Ukhrul District, Manipur

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**ABSTRACT:** Rivers are the primary source of surface water and are important for the conservation of ecological integrity, biodiversity, fisheries, agriculture and domestic needs. Ecologically important but one of the least studied freshwater systems are the hill streams of North-East India. The present study is the first comprehensive assessment of the physico-chemical properties of the Rangazak and Challou Rivers of Ukhrul district, Manipur which are two important tributaries of the Chindwin-Irrawaddy drainage system. Water quality was monitored for a period of one year (October 2024 to August 2025) at six sampling sites (three sites per river) for water temperature, pH, total dissolved solids (TDS), dissolved oxygen (DO) and total alkalinity using standard methods. Data were statistically analyzed using one way ANOVA ($p < 0.05$). The annual mean water temperature was found to be 18.6 ± 0.8°C in the Challou River and 19.2 ± 0.5°C in the Rangazak River with a clear seasonal pattern from the winter (January) with 4.3–4.6°C to the maximum of 30.4°C in August. The pH was weakly alkaline to neutral (annual mean 8.1 ± 0.4 and 8.3 ± 0.2, respectively). DO levels remained high throughout (6.15–9.2 mg/L) with a clear inverse relationship with temperature and TDS values (annual mean: 150.9 ± 14.1 and 148.1 ± 9.2 mg/L) far below the WHO permissible limit of 500 mg/L. Total alkalinity was low to moderate (29.2 ± 3.4 and 27.4 ± 3.2 mg/L as $CaCO_3$) and contributed primarily by $OH^-$ and $CO_3^{2-}$ ions with lowest values in April and highest in June. The seasonal variations in all parameters were typical of natural climatic and hydrological processes and not of human disturbance, suggesting that both rivers are relatively natural, healthy freshwater ecosystems. The results provide important baseline information for the conservation of fresh water biodiversity, habitat suitability assessment and sustainable river basin management in the region. Long-term monitoring and its integration with biological diversity studies is recommended.

## INTRODUCTION

The primary source of all surface waters in our planet is rivers. Among other water resources, they are play crucial role of supporting ecological integrity, biodiversity, fisheries, agriculture, domestic requirements, and electricity generation (Mirza et al 2014, Byod 2015, Eliku and Leta 2018, Byod 2019). However, rivers are vulnerable to pollutions from both human interventions and also natural phenomenon (Seth et al., 2016, Varol 2020, Mir et al., 2023). The indicators of a river ecosystem heath are defined by physico-chemical properties of the water flowing in the riverine system. The water quality parameters includes pH, Temperature, Dissolved Oxygen, Alkalinity, Nitrogenous load, Hardness, Turbidity, Total dissolved Solids, and Biological oxygen Demand. Therefore, water quality is been described as physical chemical and biological in nature (Spellman 2013, Alley 2013).

The North-Eastern region of India is a part of the Eastern Himalaya and Indo-Myanmar range endowed with numerous hill streams and rivers. The NE-region is principally drained by Brahmaputra and Barak river system (Bishwakarma et al., 2022). As stated in Chapter 1 and Chapter 3 of the present study, the Rangazak Kong and Challou Rivers situated within the eastern hill region of Manipur, an area marked by rugged terrain, steep slopes, dense forest cover, and relatively limited anthropogenic modification. The two rivers originate in the upland landscapes associated with the *Shirui-Kashong* range (2385 m asl) and drain ecologically significant catchment area which final merge into Chindwin-Irrawaddy river system. The rivers of these regions have been considered relatively pristine compared to its counterpart - the major Indian River Systems. The pristine nature of the rivers thus, sustains exceptionally high biodiversity particularly the aquatic faunal assemblage demonstrating a resilient ecosystem. The abundance or richness of aquatic faunal community is related to the adaptation of aquatic fauna especially fishes to its biotic and abiotic factors which contributes to the overall biodiversity and sustainable production (Samal et al., 2016, Lawal et al 2023).

The increasing anthropogenic pressure – rapid urbanization, intensification of farming, tourism, improper municipal waste disposals, deforestation, and detrimental activities of sand mining, gravels, etc., have posed challenges to the health of the river ecosystem (Ravichandran 2003, Mir et al., 2013, Pooja et al., 2013, Devi et al., 2016, Ustaoglu and Tepe 2019). The Hill streams and rivers of the NE regions experiences high rainfall and due to its steep topography, the river systems experiences pronounced seasonal fluctuation in the hydrological regime and water quality. The combined disturbances of seasonal variation and anthropogenic activities influences the nutrient enrichment, sediment load, dissolved oxygen, BOD, pH, and other water quality parameters affecting the biodiversity, species abundance, distribution and richness of aquatic fauna (Kumar and Padhy 2015, Kumari and Jangra 2023).

Evaluation of physiochemical characteristics forms the base for assessment of rivers health. This is from the fact that water quality parameters influences directly nutrient cycling, biological productivity, fish abundance and distribution, spawning success, nursery survival, propagation of species, niche and overall aquatic ecosystem. The baseline information and monitoring of physiochemical properties is important and particularly crucial for ecological sensitive regions such as North-East Region of India (Lemla et al., 2025) for comprehensive management strategies of the region ecosystem (Qadri et al., 2009, Tian et al., 2019, Nong et al., 2020). Hitherto, limited comprehensive investigation of the physiochemical characteristics of the many rivers, its tributaries, and hill streams of the North-East India are been done despite the ecological significance of the region.

The two river systems in this present study 'Rangazak Kong' and 'Challou Kong' of Ukhrul district, Manipur is an important drainage system (Zimik and Pyal 2021) of the Northern part of the District. The region is locally referred as "Raphei" reflecting its association with abundant water resources and productive riverine landscape. Despite their ecological and socio-economic role, they remain among the least explored river systems in Manipur. The earliest scientific data on freshwater ecosystem was the documentation of icthyofaunal records of fishes from the broader Ukhrul region by Chaudhuri (1912) and Hora (1937), who documented fish species from the upper Chindwin drainage. More specifically information on the ichthyofauna of northern Ukhrul was later provided by Laishram and Vishwanath (2005). Till date, no concrete work related to freshwater ecosystem for the two river system has been investigated. Hence, the present was undertaken to evaluate the physicochemical properties of Rangazak and Challou River of different seasons. The present work would serve as invaluable baseline information for conservation of fresh water biodiversity, identifying emerging threats and habitat suitability, ensuring ecological integrity of the river and scientific data for river basin management strategies.

## MATERIALS & METHODS

The physico-chemical properties of the study site were evaluated for a period of one complete year for a comprehensive understanding of the water quality dynamics of the region. The current research work was undertaken to generate a baseline data of the following physico-chemical parameters in the study area. They are namely; flow rate, temperature, pH, turbidity, dissolved oxygen, alkalinity, total dissolved solid.

**Study Area & Sampling Site**

This present study was carried out in two important hill-streams of Northern Ukhrul District, Manipur—the Rangazak River and the Challou River. The Rangazak River, located at 25.5364356° N and 95.709655° E with an elevation of about 586 m, stretches for nearly 100 km. and Challou River located at 25°14'19.14"N and 94°37'48" and flows for about 91 km through the northern part of Ukhrul. The Rangazak River (Tizu River) and Challou River (Thetsu River) flow northward, merging near Mercy Bridge at Melluri District, Nagaland, becoming a key tributary of the Chindwin-Irrawaddy drainage system.

In this present thesis work, a total of six sites were chosen, with three sites designated for each river system namely Rangazak and Challou River and its tributaries (Fig. 1).

**Rangazak River:**

Sampling site 1= 25°38'25.61"N & 94°35'1.24"E

Sampling site 2 = 25°21'19.99"N & 94°22'30.08"E

Sampling site 3= 25°10'26.50"N & 94°24'15.06"E

**Challou River:**

Sampling site 1 = 25°38'2.40"N & 94°35'8.56"E

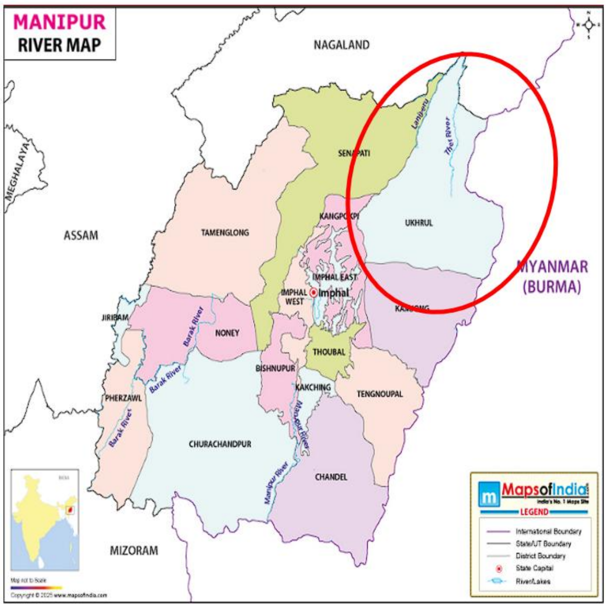
Sampling site 2 = 25°17'24.96"N & 94°31'17.35"E

Sampling site 3 = 25°14'19.14"N & 94°31'43.80"E

**Physico-chemical Parameters Studied:**

**Temperature**

Temperature of the sampling sites were recorded using an analog mercury thermometer (USA, AI Tech Comp) having a scale marked for every 0.1$^0$C. During each sampling test, temperature was immediately measured and recorded on-site as the first parameter, prior to the assessment of other water quality characteristics.



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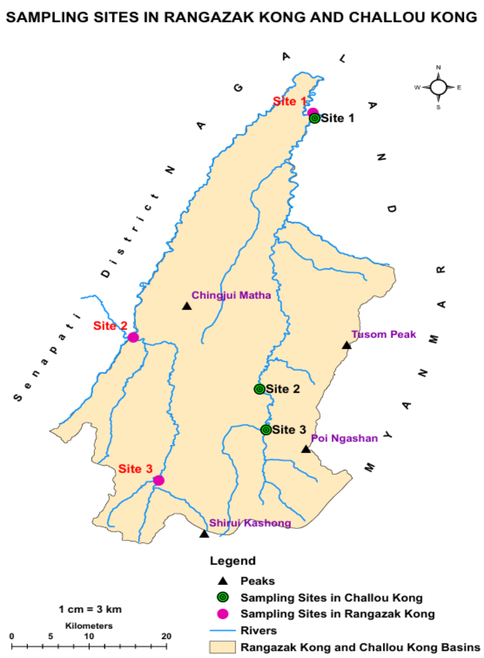


**Fig 1.** Map showing the study area and sampling site for the present research work (Courtesy Map of India Manipur River Map).

A water sample of 30 litres was scooped from the sampling site with a bucket. then a 300cc subsample was transferred to a BOD bottle. The thermometer was immersed up to the designated mark specified by the manufacturer and allowed to equilibrate before taking the reading. Once the mercury level reached a steady state, indicating thermal equilibrium, the temperature reading was noted.

**pH**

The pH of all the sampling sites was measured using an electronic probe (Konvio NEER, India). In this assay the water from the flowing rivers were collected in a 300cc subsampling container and the probe was inserted in the water for measuring the pH. The stable reading of pH values displayed on the monitor of the probe was recorded. This process was repeated for 3 times from the same sampling site and the values obtained were expressed as mean ± SE. The pH meter was calibrated before use.

**Alkalinity:**

Alkalinity of all the sampling sites was analysed following phenolphthalein and methyl orange method through titration (APHA, Braid and Bridgewater 2017). In this assay, river water was collected from the intended site in bucket, and a 300cc portion was poured into a bottle to serve as the sample. Following the standard protocol prescribed by the above method, where, 20ml of sample was taken in a conical flask and 2% phenolphthalein indicator (2 to 3 drops) were added to check the presence of free $CO_2$. The appearance of pink colour in the conical flask was taken to be the absence of free $CO_2$. In such cases, the alkalinity assay was performed. The burette reading of reagent (1N HCl) was noted for phenolphthalein indicator titration – change from pink to colourless solution, was noted as phenolphthalein alkalinity. After which methyl orange was added in the same conical flask and titration was continued till the appearance of pink colour was observed. The total volume of 1N HCl volume was noted and the total alkalinity was determined from the same.

In instances, if addition of phenolphthalein indicator in the water sample showed no pink colouration; it indicates the presence of free $CO_2$. Free $CO_2$ concentration was evaluated by titrating with N/44 NaOH where the end point of the titration was taken to be the appearance of pink colour solution. In this particular case where free $CO_2$ is present, the alkalinity of the water was evaluated for total alkalinity.

The concentration of free $CO_2$, P- alkalinity and T- alkalinity was determined by using the following formula:

$$\textbf{Conc. of free } \mathbf{CO_2} = \frac{\text{Volume of titrant used } \times 1000}{\text{Volume of sample used}}$$

The concentration of free $CO_2$ and alkalinity were expressed in mg/L as $CaCO_3$. Further, the contribution of alkalinity by the carbonate system was determined by following the standard protocol of alkalinity relationship shown in the table below.

**Table 1:** Relationship table of alkalinity

| Result of Titration | OH- | CO2-3 | HCO3- |
|---|---|---|---|
| P = 0 | 0 | 0 | M |
| P = M | P or M | 0 | 0 |
| P = M/2 | 0 | 2P | 0 |
| P>M/2 | 2P – M | 2(M-P) | 0 |
| P<M/2 | 0 | 2P | M – 2P |

**TDS Analysis:**

The TDS of all the sampling sites were measured using TDS digital probe (Konvio, NEER, India). In this assay the water from the flowing river were collected using bucket and transferred to 300cc container and finally the probe was inserted in the water for measuring the TDS. The stable reading of TDS values displayed on the monitor of the probe was recorded. The stable reading of TDS value was displayed on the monitor of the probe. This process was repeated for 3 times from the same sampling site and the values obtained were expressed as mean ± SE.

**Dissolved oxygen**

Dissolved oxygen of the sampling site was determined using Test Kit (AEDO8, AQUASOL, India) with LOD of 0.5 mg/L. Samples were collected in a 300 cc BOD bottle from the site of collection following the methods prescribed by Strickland and Parsons (1968). Three readings were taken for each sampling sites.

**Statistical Analysis:**

Data were analyzed using one-way analysis of variance (*ANOVA*) and significance was accepted at $p < 0.05$.

**RESULT**

**Temperature**

The water temperature profile of the two river system is observed to be influenced by seasonal variation of temperature. Significant difference ($P< 0.5$) in mean water temperature was observed from autumn (Oct'2025) to winter (Jan'2025) and spring (April'2025) to monsoon season (June'2025) after which no significant difference was recorded till the summer (Aug'2025) season. This pattern was found to be similar in the waters of the two river system in the present study (Table 2). The annual mean temperature of Challou River was observed to be 18.6 ± 0.8°C and Rangazak River was 19.2 ± 0.5°C.

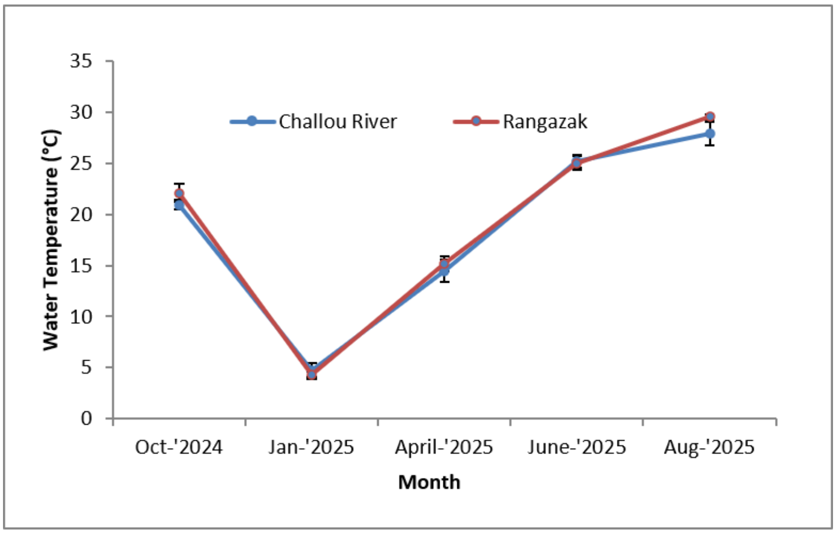


**Fig 2.** Water temperature profile of two river system Challou River and Rangazak River over 12 months (October 2024 to August 2025)

In the present study, a steep drop in water temperature was observed from 20.9±0.4°C in the month of Oct'2024 to 4.6±0.78°C in Jan' 2025 at Challou River while Rangazak River from 22.1±0.86°C to 4.3±0.29°C (Fig. 2). The lowest water temperature was recorded at 3°C in site 3 of Challou River while in Rangazak River the lowest was recorded at 4°C in site 2 & 3. Significant ($p<0.05$) increase in water temperature was observed from Jan'2025 to April'2025 in both the river system. An increase from of 3-5°C to 14.4±1.1°C in Challou River and 15.1±0.73°C in Rangazak River was recorded. The highest water temperature was observed in the month of Aug'2025 at 30.4°C in site 1 of Challou River. However, the mean water temperature during the month of Aug'2025 was observed to be higher for Rangazak River at 29.5±0.30°C while it was 27.9±1.1°C for Challou River.

**Table 2**: Mean temperature of Challou River and Rangazak River measured across three different sites at various months for a period of one year.

| Month | Challou River Water Temperature (°C) | | | | Rangazak River Water Temperature (°C) | | | |
|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | Mean ± SE | Sampling Sites | | | Mean ± SE |
| | Site 1 | Site 2 | Site 3 | | Site 1 | Site 2 | Site 3 | |
| Oct-'2024 | 22°C | 20.3°C | 20.6°C | 20.9±0.4°C | 24°C | 21.5°C | 20.8°C | 22.1±0.86°C |
| Jan-'2025 | 5°C | 6°C | 3°C | 4.6±0.78°C | 5°C | 4°C | 4°C | 4.3±0.29°C |
| April-'2025 | 15.4°C | 16°C | 12°C | 14.4±1.1°C | 16.1°C | 15.8°C | 13.5°C | 15.1±0.73°C |
| June-'2025 | 26.4°C | 25.1°C | 24°C | 25.1±0.6°C | 25°C | 26.3°C | 23.8°C | 25.03±0.64°C |
| Aug-'2025 | 30.4°C | 27.4°C | 26°C | 27.9±1.1°C | 30°C | 29.1°C | 27.3°C | 29.5±0.30°C |

**pH**

The pH of river water in the present study showed a slight inclination towards basic side throughout the observation period. The highest pH value was recorded for the month of June 2025 with a mean value of 9.06±0.2 in Rangazak River while for Challou River it was observed in the month of April with 8.6±0.3 (Fig 3). The annual average pH of the two rivers, Challou and Rangazak was recorded at 8.1±0.4 and 8.3±0.2, respectively.

In the present study it was observed that site specific differences in pH values were not consistent but varies across different months of observation. A high pH value of 9.1 was observed for site 2 in Rangazak River in the month of June 2025 while for the month of April 2025 it recorded pH value of 7.6 which was second lowest recorded in this river system during the entire study period (Table 3). In Challou River, the lowest pH value of 6.8 was recorded in site 2 for the month of August 2025 and October 2024. But then, the highest pH of 9.1 was also observed for same site in April and June 2025.

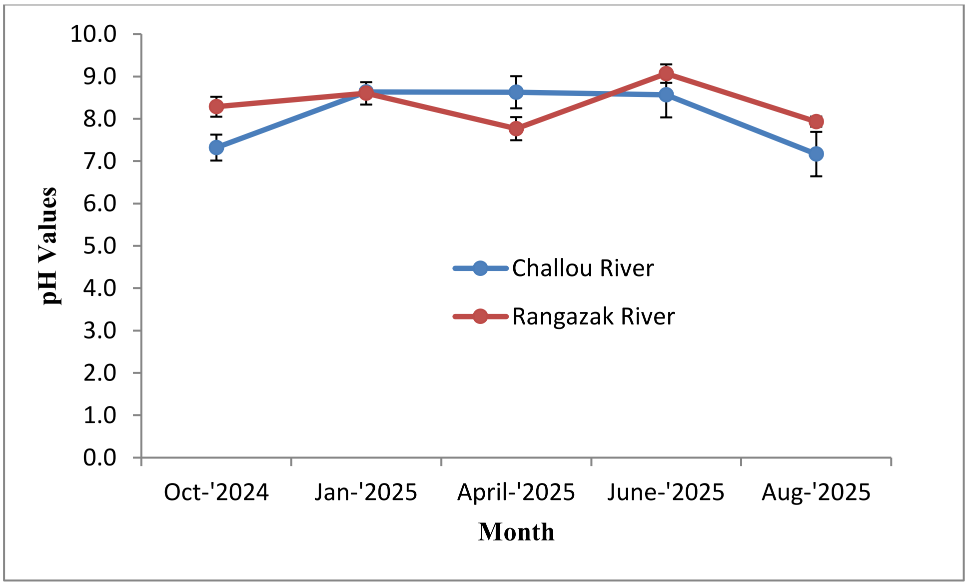


**Fig 3.** pH profile of two river system Challou River and Rangazak River over 12 months (October 2024 to August 2025)

**Table 3**: pH of Challou River and Rangazak River measured across three different sites at various months for a period of one year.

| Month | pH of Challou River | | | | pH of Rangazak River | | | |
|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | Mean ± SE | Sampling Sites | | | Mean ± SE |
| | Site 1 | Site 2 | Site 3 | | Site 1 | Site 2 | Site 3 | |
| Oct-'2024 | 7.8 | 6.8 | 7.3 | 7.3±0.3 | 8.7 | 8.1 | 8 | 8.2±0.2 |
| Jan-'2025 | 8.8 | 8.6 | 8.5 | 8.6±0.08 | 8.2 | 8.5 | 9.1 | 8.6±0.2 |
| April-'2025 | 7.9 | 9.1 | 8.8 | 8.6±0.3 | 8.3 | 7.6 | 7.4 | 7.7±0.2 |
| June-'2025 | 9.1 | 9.1 | 8.5 | 8.5±0.5 | 8.9 | 9.5 | 8.8 | 9.06±0.2 |
| Aug-'2025 | 8.2 | 6.8 | 7.5 | 7.1±0.5 | 8 | 7.7 | 8.1 | 7.9±0.1 |

**Total Dissolved Solids (TDS)**

The TDS of the two river system showed values well below the range of 300 mg/L which is considered as accepted level for good water quality. The annual TDS profile indicated the poorest quality during the month of June and August 2025. June. Annual mean TDS of Challou and Rangazak River was recorded at 150.9±14.1 mg/L and 148.1±9.2 mg/L, respectively.

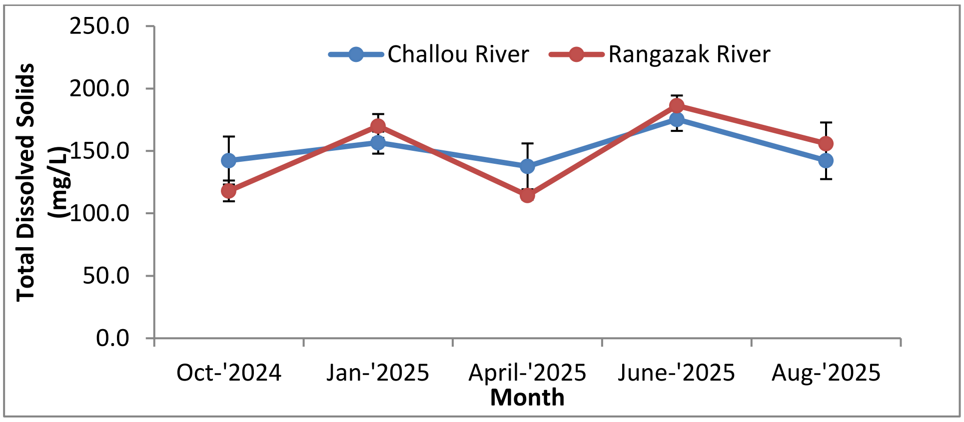


**Fig 4**. TDS profile of two river system Challou River and Rangazak River over 12 months (October 2024 to August 2025)

A Significant ($p<0.05$) differences in TDS was observed at various period of measurements for Ranazak River where the the highest mean TDS was recorded at 186.3±8.09 mg/L in June while the lowest data was recorded at 114.3±3.3 mg/L in April (Fig 4). Such significant difference was not observed in Challou River which recorded the highest TDS at 175.33±9.2 in June and the lowest at 137.67±18.3 mg/L in April.

The TDS at various sites do not show a distinct pattern during various months of evaluation. The highest TDS recorded was 200 mg/L at Rangazak River in June month while for Challou River it was recorded at 192 mg/L in site 1 for the same month. The lowest TDS reading was recorded at102 mg/L in Ranazak River site 1 during October 2024 and 101 mg/L for Challou River at site 3 in the month of April (Table 4).

**Table 4**: TDS of Challou River and Rangazak River measured across three different sites at various months for a period of one year.

| Month | TDS of Challou River (mg/L) | | | | TDS of Rangazak River (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | Mean ± SE | Sampling Sites | | | Mean ± SE |
| | Site 1 | Site 2 | Site 3 | | Site 1 | Site 2 | Site 3 | |
| Oct-'2024 | 117 | 130 | 180 | 142.33±19.2 | 102 | 122 | 130 | 118±8.3 |

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|---|---|---|---|---|---|---|---|---|
| Jan-'2025 | 160 | 170 | 140 | 156.67±8.8 | 153 | 186 | 171 | 170±9.5 |
| April-'2025 | 158 | 154 | 101 | 137.67±18.3 | 112 | 110 | 121 | 114.3±3.3 |
| June-'2025 | 192 | 160 | 174 | 175.33±9.2 | 187 | 200 | 172 | 186.3±8.09 |
| Aug-'2025 | 170 | 138 | 119 | 142.33±14.8 | 178 | 167 | 123 | 156±16.8 |

**Dissolved Oxygen (DO)**

The dissolved oxygen profile across various seasons was observed to be high throughout the observation period. The highest DO level was observed in the month of January for both the Challou and Rangazak River at 8.40±0.04 mg/L and 8.86±0.33 mg/L respectively. The lowest DO content was recorded in the month of June for both the rivers with a minimum level of 6.59±0.25 mg/L in Rangazak River (Fig. 5). It was further observed that no significant variation in DO level was recorded during the period of evaluation in both the river system.

In the present study, the two river system displayed a gradual decrease of dissolved oxygen level from the month of January. Site specific DO content showed the highest value at 9.2 mg/L in site 3 followed by site 1 at 9.17 mg/L for Challou River (Table 5). In the month of June both the rivers showed the lowest level of DO content. The lowest DO level recorded in the present study was recorded at 6.15 mg/L in site 1 of Challou and Rangazak River, respectively. Annual mean DO of Challou and Rangazak River suggest no significant difference with 7.5±0.18 mg/L and 7.49±0.35 mg/L, respectively.

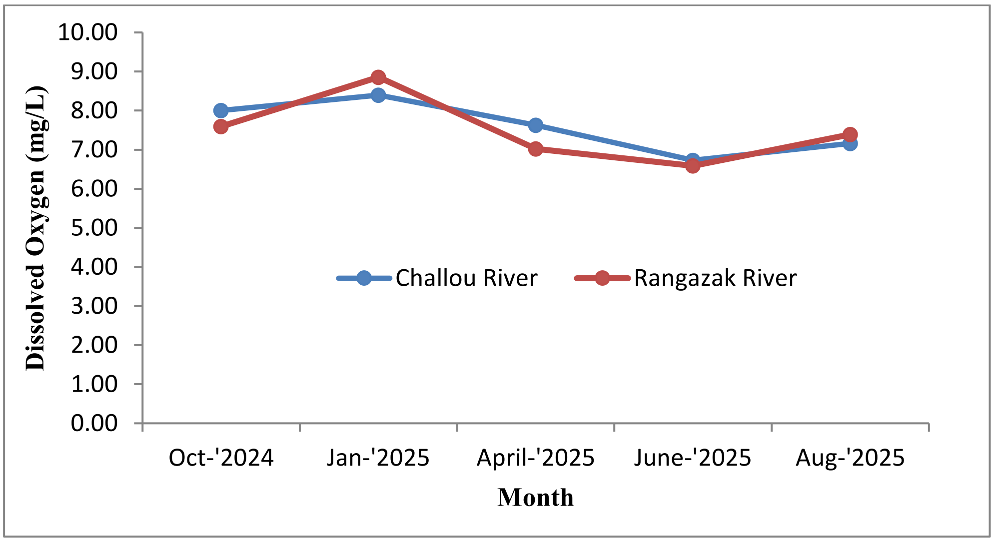


**Fig 5**. DO profile of two river system Challou River and Rangazak River over 12 months (October 2024 to August 2025)

**Table 5**: Dissolved Oxygen profile of Challou River and Rangazak River measured across three different sites at various months for a period of one year.

| Month | DO of Challou River (mg/L) | | | | DO of Rangazak River (mg/L) | | | |
|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | Mean ± SE | Sampling Sites | | | Mean ± SE |
| | Site 1 | Site 2 | Site 3 | | Site 1 | Site 2 | Site 3 | |
| Oct-'2024 | 7.82 | 7.88 | 8.31 | 8.00±0.15 | 8.74 | 7.02 | 7.02 | 7.59±0.57 |
| Jan-'2025 | 8.31 | 8.44 | 8.44 | 8.40±0.04 | 9.17 | 8.2 | 9.2 | 8.86±0.33 |
| April-'2025 | 7.88 | 7.5 | 7.5 | 7.63±0.13 | 6.59 | 7.02 | 7.45 | 7.02±0.25 |
| June-'2025 | 6.15 | 7.3 | 7.02 | 6.73±0.29 | 6.15 | 6.59 | 7.02 | 6.59±0.25 |
| Aug-'2025 | 6.59 | 7.45 | 7.45 | 7.16±0.29 | 7.12 | 7.05 | 8.13 | 7.39±0.37 |

**Total Alkalinity**

The Challou and Rangazak Rivers in the study presented an annual mean total alkalinity of 29.2 ± 3.4 mg/L as $CaCO_3$ and 27.4 ± 3.2 mg/L as $CaCO_3$, respectively. The highest total alkalinity was recorded in the month of June at 41.7 ±4.2 mg/L as $CaCO_3$ for Challou River, while in Rangazak River was recorded at 35 ±5.8 mg/L as $CaCO_3$. The month of April showed the lowest alkalinity for both the rivers Challou and Rangazak at 21.0±3.8 mg/L as $CaCO_3$ and 23±3.2 mg/L as $CaCO_3$, respectively (Fig 6).

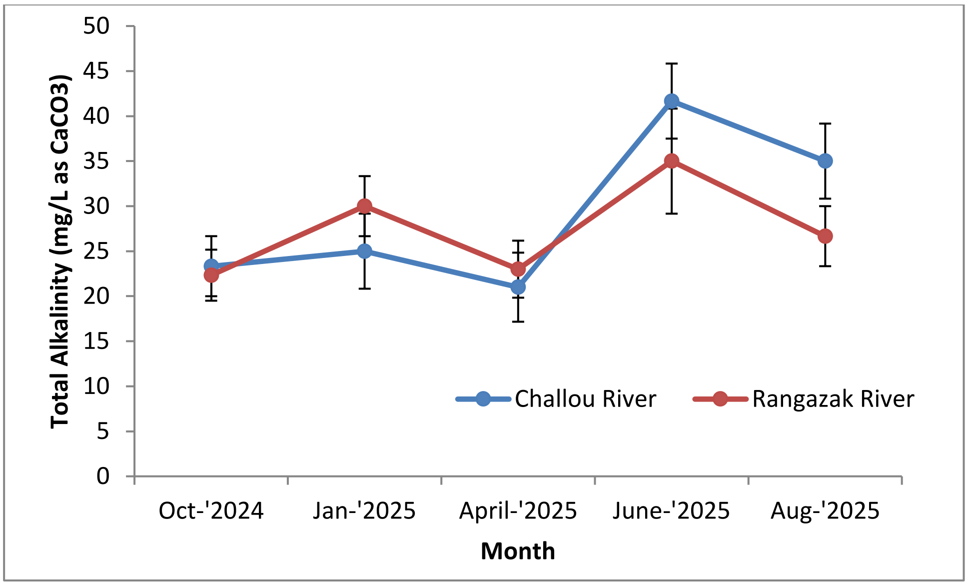


**Fig 6.** DO profile of two river system Challou River and Rangazak River over 12 months (October 2024 to August 2025)

The total alkalinity of Challou River is predominantly contributed $HO^-$ and $CO_3^{2-}$ during the period of study. The highest value of $CO_3^{2-}$ was recorded for the month of June reaching up to 16.8±2.1 mg/L as $CaCO_3$ for Challou River. In the month of April, contribution of $OH^-$ was the highest which was recorded at 28.6±3.1 mg/L as $CaCO_3$. However, in the month of June the lowest contribution of $OH^-$ was observed at 1.7± 0.2 mg/L as $CaCO_3$. The contribution to alkalinity by $HCO_3^-$ alkalinity was (7.7±0.6 mg/L as $CaCO_3$) observed only for the month April in the entire study (Table 6).

In Rangazak River, alkalinity was contributed exclusively by $OH^-$ and $CO_3^{2-}$. Major contribution to alkalinity was from OH- with the maximum value recorded at 23.9 ±1.2 mg/L as $CaCO_3$ during the month of June. The lowest reading of OH- was recorded for October with 1.6±0.1 mg/L as $CaCO_3$. The highest alkalinity contributed by $CO_3^{2-}$ was observed for the month of August with 13.4±1.1 mg/L as $CaCO_3$ followed by October month. The lowest contribution was observed in the month of June with 3.2±0.3 mg/L as $CaCO_3$ followed by April month with 12.8±1.3 mg/L as $CaCO_3$ (Table 7).

**Table 6**: Alkalinity profile of Challou River measured across three different sites at various months for a period of one year.

| Month | P-Alkalinity (mg/L as CaCO3) | | | | M-Alkalinity (mg/L as CaCO3) | | | | Total Alkalinity In mg/L as CaCO3 (Mean ± SE) |
|---|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | Mean ± SE | Sampling Sites | | | Mean ± SE | |
| | Site 1 | Site 2 | Site 3 | | Site 1 | Site 2 | Site 3 | | |
| Oct-'2024 | 10 | 10 | 5 | 8.33±1.3 | 15 | 20 | 10 | 15±2.4 | 23.3±3.3 |
| Jan-'2025 | 10 | 10 | 5 | 8.33±1.2 | 20 | 15 | 15 | 16.7±1.4 | 25.0±4.2 |
| April-'2025 | 5 | 5 | 10 | 6.67±1.4 | 15 | 13 | 15 | 14.3±0.5 | 21.0±3.8 |
| June-'2025 | 20 | 15 | 15 | 16.67±1.1 | 30 | 25 | 20 | 25±2.4 | 41.7±4.2 |
| Aug-'2025 | 15 | 15 | 10 | 13.33±1.2 | 25 | 20 | 20 | 21.7±1.4 | 35.0±4.2 |

**Table 7**: Alkalinity profile of Rangazak River measured across three different sites at various months for a period of one year.

| Month | P-Alkalinity (mg/L as $CaCO_3$) | | | | M-Alkalinity (mg/L as $CaCO_3$) | | | | Total Alkalinity In mg/L as $CaCO_3$ (Mean ± SE) |
|---|---|---|---|---|---|---|---|---|---|
| | Sampling Sites | | | Mean ± SE | Sampling Sites | | | Mean ± SE | |
| | Site 1 | Site 2 | Site 3 | | Site 1 | Site 2 | Site 3 | | |
| Oct-'2024 | 10 | 10 | 5 | 8.3±1.4 | 14 | 15 | 15 | 15±0.2 | 22.3±2.8 |
| Jan-'2025 | 15 | 15 | 5 | 11.7±2.7 | 20 | 25 | 10 | 18.3±3.6 | 30±3.3 |
| April-'2025 | 10 | 10 | 5 | 8.3±1.4 | 15 | 15 | 14 | 14.7±0.3 | 23±3.2 |
| June-'2025 | 15 | 10 | 10 | 11.7±1,4 | 30 | 20 | 20 | 23.3±2.7 | 35±5.8 |
| Aug-'2025 | 15 | 10 | 5 | 10±2.4 | 15 | 15 | 20 | 16.7±1.4 | 26.6±3.3 |

## DISCUSSION

The assessment of physicochemical properties of Ranazak and Challou River reveals seasonal variation in the water quality parameters were influenced by combined factors of climatic conditions, watershed geology, hydrological processes, and natural ecological dynamics. Water temperature is considered master of all abiotic factors as it influences physical, chemical and biological processes of river ecosystem regulating the concentration of dissolved oxygen, nutrient cycle and metabolic activity of aquatic fauna, its distribution and reproductive biology (Boyd and Tucker 1998, Wetzel 2001, Van Vliet et al., 2011, Beechie et al 2013, Tank and Chippa 2013). The water temperature profile of both Ranazak and Challou River exhibited a distinct seasonal pattern with the lowest record 4.3 ± 0.2 °C and 4.6 ± 0.7 °C respectively in Winter season (January) and highest in August (29.5±0.3 °C). This variation of temperature resembles closely with the seasonal change in air temperature and solar radiation characteristics of hill-stream ecosystem. The observed seasonal pattern of water temperature is in conformity with the studies of Singh and Ao, (2026) in River of Nagaland, Singh et al., (2010) in Manipur River System, Manna and Sarkar (2008) in Brahmaputra River of the North-East Region. The observed spatial variation amongst the sampling sites within each river may be attributed to differences in the vegetation cover, ground water inputs, channel morphology, stream depth or water velocity. However, these variations are relatively not significant which indicates that the two river system of the present study maintains a homogenous thermal regime. The observed temperature of the present study is observed to be suitable for tropical and subtropical freshwater fishes – typically falling under coldwater fisheries.

The physicochemical parameter that governs the ecological health of freshwater ecosystem is the dissolved oxygen that acts as an important indicator of the overall water quality of the river (APHA 2017, Lone et al., 2021). It also plays as important role in influencing the metabolism of aquatic organisms (Yang et al., 2007, Eliku and Leta 2018). The concentration of DO is influenced by temperature, velocity of water flow, decomposition of organic matter and BOD (Mir et al., 2023). In the present study, the concentration of DO remained consistently high throughout the study period ranging from 6.3 mg/L to 9.2 mg/L. The level of dissolved oxygen above the threshold minimum of 5 mg/L is considered necessary for sustenance of health freshwater ecosystem (CPCB 2008, WHO 2017). The elevated value of dissolved oxygen in the present study area demonstrates good aeration capacity of the fast flowing hill streams indicating the absence of significant organic pollutants. In this present study, the demonstration of higher during January (winter) and gradual decrease during April (spring) and lowest level in June (monsoon) followed by partial recovery in August month (Fig 4.4) showed a clear inverse relationship between dissolved oxygen and water temperature. This inverse relationship is well established in freshwater system wherein temperature fundamentally influences solubility of oxygen (Chapman 1996, Byod and Tucker 1998, Wetzel 2001, APHA 2017). The observed pattern of dissolved oxygen in Rangazak and Challou River have been reported for other North-East Indian and Himalayan rivers (Khan et al., 2003, Manna and Sarkar 2008, Singh et al., 2010, Khound et al., 2018, Manzoor and Igbal 2020, Bhat et al., 2021).

pH also referred to as Hydrogen ion concentration is a fundamental physicochemical parameter that influences the chemical composition of water, microbial activity, nutrient availability, photosynthesis, respiration, survival and reproduction of aquatic organism (Liong 1984, Hamid et al 2020). The optimal pH of water is considered to range from 6.5 to 8.5 (BIS 2012). The pH value of Ranazak and Challou Rivers during the four seasons of the year remained within the neutral to moderate alkaline rage

7.1±0.5 to 9.06±0.2 (fig 4.2) indicating a stable water for adequate buffering capacity. In earlier studies of Himalayan hill streams, pH range of the present study was found follow similar pattern (Singh et al 2012, Talukdar et al., 2016, Sarmah et al 2023). The slight alkaline nature of the pH values observed in both the river system could be influence of rich minerals geological formation. The relative seasonal variation of pH during January and April may be attributed to the lower river discharge, increased photosynthesis activity, and greater accumulation of carbonate and bicarbonates from limestone. However, the lower level of pH values during monsoon may likely be due to dilution by rainfall, increased surface runoff transporting organic matter and enhanced decomposition (Wetzel 2001, APHA 2017).

The presence of bicarbonates, carbonates, and hydroxyl ions which imparts buffering capacity to water is derived from the rocks and soil within the watershed. This buffering capacity or alkalinity plays an important role in chemical stability of freshwater ecosystem by regulating acid-base balance, nutrient availability and biological productivity. Total alkalinity contributed by $HCO_3^-$, $CO_3^{2-}$ and $OH^-$ ions (Mir et al., 2023, Kang et al., 2001, APHA 2017) exhibits inverse relationship with pH (Rebsdorf et al., 1991, Chapman 1996, Arafat et al., 2022). The recorded value of annual total alkalinity across different seasons for Rangazak and Challou River in the present study (refer Table 4.6 & 4.7) are well below the desirable limit of 200mg/L as $CaCO_3$ recommended by Bureau of Indian Standards IS 10500:2012 (2012) and also within the acceptable limit set by World Health Organization (2017) for use as drinking water. The recorded mean total alkalinity of both the rivers (21.0 to 41.7 mg/L as $CaCO_3$) indicates low to moderate alkalinity. Such moderate alkalinity indicates low mineralization and characteristics of hill stream ecology draining relatively undisturbed forested catchments reflecting pristine nature of the river system.

The seasonal variation of alkalinity in both the rivers is evident with lowest alkalinity during April (spring) and highest alkalinity in June (monsoon). During these periods the dominance of carbonate alkalinity was observed. This could be due to the conversion of bicarbonates into carbonates. Coherently, the pH values recorded during these months ranged between 7.1 and 9.1 which suggest major contribution of alkalinity by carbonates (APHA 2017). Accordingly, the increased alkalinity during the monsoon (June) was likely associated with monsoon rainfall that accelerated the chemical weathering and transport of HCO3- and CO32- from rocks and soil into river channels. Conversely the lower alkalinity during the month of April can be opined to be from limited mineral dissolution, reduced surface runoff, lower ground water contribution, and intense photosynthesis. Such observations are documented by several workers (Trivedy and Goel 1986, Kannel et al., 2007, Dodds and Whiles 2020).

Total dissolved solids is the total concentration of organic and inorganic substances dissolved in specific volume of water which includes salts, minerals ions such as bicarbonates, chlorides, sulphates, sodium, magnesium, calcium and potassium. TDS is regarded to be an important indicator of water quality as it reflects the transparency of water, degree of mineralization, conductivity, and suitability for aquatic fauna and also domestic use (APHA 2017, Dar et al., 2019). In freshwater ecosystem, TDS is influenced by surface runoff, groundwater inflow, geological weathering, precipitation, soil erosion, and human interference in the form of mining, domestic disposal, and agriculture (Wetzel et al., 2001, Mirza et al., 2014, APHA 2017, Mir and Gani 2019, Manzoor and Iqbal 2020). These findings were found to be relevant to the present study for the seasonal variation in TDS concentration. In both the rivers, the concentration of TDS was observed to increase during the monsoon period (June) and gradually lowered during the other months. However, the value of TDS of Rangazak and Challou River recorded (114.3 – 186.3 mg/L, respectively) was observed to be significantly ($P<0.05$) lower than the recommended limit of 500mg/L for drinking water (WHO, 2017, BIS ISI 10500: 2012). Occurrence of spatial variation within the sampling site (refer Table 4.4) may be associated with the local geological formation, ground water contribution, stream flow characteristics or localized anthropogenic activities. The TDS concentration observed for Rangazak and Challou River in the present study indicates moderate mineralization and less affected by excess dissolved solids. The observed values of TDS in the present study are characteristic features of relatively unpolluted hill streams.

The present study demonstrates that the evaluated physicochemical quality of Rangazak and Challou Rivers falls within the limit of a health freshwater ecosystem. The seasonal variation observed for the water quality parameters reflects a natural climatic and hydrological process rather than anthropogenic intervention. The findings obtained in the present study can be used as baseline information for future ecological and conservational planning. A long-term regular monitoring is recommended for detection of thread and changes that may affect the integrity of the two river system. For future research, an integrated physicochemical monitoring with biological diversity study especially fish and macroinvertebrate communities would provide comprehensive information on the river ecosystem health for sustainable management of freshwater resources for the region.

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