



Seasonal Variability in Physico-Chemical Attributes of Spring Water in Nagaland, India

Wati Temjen, Zhulika Aye¹, Mewekhro Mero¹, Jeolam¹, Imli Jamir¹ and Maibam Romeo Singh^{*}

Department of Botany, Fazl Ali College, Mokokchung-798 601, India

¹*Department of Botany, Nagaland University, Lumam-798 627, India*

^{*}*E-mail: romeomaibam@nagalanduniversity.ac.in*

Abstract: This study evaluated the seasonal variability of spring water quality across four districts of Nagaland, viz., Dimapur, Phek, Mokokchung, and Noklak. Forty sampling stations were investigated in rainy, summer, and winter seasons for key physico-chemical parameters such as pH, free CO₂, total alkalinity, chloride, conductivity and total dissolved solids (TDS). Results revealed distinct spatio-temporal differences. Mean pH values indicated higher alkalinity during rainy and summer months (up to 6.6 in Noklak) and lower in winter (5.2 in Mokokchung). Free CO₂ concentrations were consistently elevated in Noklak and Phek during winter (17. mg/l and 12.1 mg/l, respectively), reflecting increased solubility at low temperatures. Total alkalinity reached maximum levels in Mokokchung during the rainy season (53.8 mg/l) but declined sharply in winter (13.1 mg/l). Chloride concentrations peaked in Dimapur and Phek during the rainy season (>65 mg/l), while Noklak exhibited strong seasonal contrasts. Conductivity was highest in Mokokchung (125.0 µS/cm, rainy season), and TDS values were most elevated in Noklak (85.8 mg/l, rainy season). Across all districts, the general sequence was rainy > summer > winter for solute parameters, whereas free CO₂ peaked in winter. Despite these variations, all parameters except pH remained within BIS/ICMR/WHO permissible limits. These findings provide baseline data on spring water parameters in the hilly regions of Northeast India and emphasize the need for extended monitoring of additional physico-chemical, biological parameters and heavy metals contaminants to ensure long-term drinking water safety.

Keywords: Water quality, Physico-chemical parameters, Seasonal variation, Nagaland, Springs

Springs with their natural water quality are highly sensitive to pollution from human activities and changes in climate affecting surface run-off that replenishes groundwater (Saad et al., 2011). Additionally, the quality of these bodies of water can greatly differ based on their location and various environmental factors. Nagaland, situated in North-East India, faces significant challenges in water resource management due to its steep topography and heavy monsoonal rainfall. The state's rugged terrain contributes to rapid runoff, preventing effective rainwater harvesting and limiting water retention in the soil. Consequently, much of the rainwater is lost, resulting in minimal groundwater recharge (Lalmalsawmzauva et al., 2021). In addition to these natural challenges, human activities such as shifting cultivation which involves clearing forested areas for agricultural purposes, urban expansion, and infrastructure projects like road construction exacerbate the depletion of groundwater reserves. These factors have led to the drying up of natural springs, which are a crucial water source for many rural and urban communities in Nagaland (Lkr et al., 2020, Temjen et al., 2021) and this has become an pressing issue, particularly during the dry winter months when water shortages are most acute. Springs serve as lifelines for many communities, providing the primary source of drinking water and supporting agricultural activities. However, recent studies indicate a decline in spring discharge rates, further intensifying water scarcity in the

region (Dass et al., 2021). This uneven distribution poses challenges for water resource management, especially in rural areas where communities depend on natural springs and streams for domestic and agricultural use (Semy et al., 2022). Despite the critical reliance on these natural water sources, there has been limited research on the quality of spring water consumed by the local population. Most people rely on this water without any form of treatment, raising concerns about potential health risks, as poor water quality can lead to a host of waterborne diseases. Given the importance of springs for local communities, there is a critical need to understand the physical and chemical properties of spring water and assess whether it meets the standard permissible limits for safe drinking water. This study seeks to fill this gap by analyzing spring water from four districts in Nagaland, comparing its quality with permissible standard limits. The findings will help in rejuvenation of spring water and highlight the need for interventions, such as filtration and treatment systems, to ensure the safe consumption of spring water by local populations.

MATERIAL AND METHODS

Altogether 40 stations of springs were inventorized from the four districts of Nagaland (Table 1). Ten sites were selected from each district. The sites selected from each district were represented as D1 to D10 from Dimapur, P1 to P10 from Phek, M1 to M10 from Mokokchung and N1 to N10

from Noklak district. These districts were chosen to represent a diverse range of geographical and hydrological conditions within the state. Each sampling station was strategically located to capture water from critical springs and streams that are relied upon by the local population. This regional representation allows for a comprehensive assessment of water quality across different environments within Nagaland. The water quality parameters examined in this study include free CO₂, total alkalinity, chloride, conductivity and total dissolved solids (TDS), which are key indicators of water chemistry and suitability for consumption. These parameters were analyzed using standardized methods proposed by Trivedy and Goel (1986) and the American Public Health Association (APHA, 2005). The data obtained were compared to the drinking water quality standards (Table 2) set by the Bureau of Indian Standards (BIS 2003), the Indian Council of Medical Research (ICMR 1975) and World Health Organisation (WHO 1995). The water samples were collected from the selected springs during three distinct seasons: rainy season, spring and winter between 2021 and 2022. This seasonal approach was critical for capturing the variations in water quality that result from changing hydrological conditions throughout the year. All analysis was performed in triplicate for each water sample and the results are expressed as mean ± standard deviation.

RESULTS AND DISCUSSION

The seasonal variation in few selected physico-chemical parameters of spring water from 4 (four) districts of Nagaland is shown in Table 2. Results of each parameters are described as under.

pH: Spring water pH exhibited seasonal and spatial variability across the four districts. Lowest pH of 5.2 was during winter from the springs of Mokokchung district and highest of 6.6 in summer from the spring waters of Noklak district. The overall seasonal pattern indicated higher pH during summer and rainy months, while winter waters were nearly acidic, reflecting reduced buffering capacity under cooler conditions. Shah et al. (2019) also observed that in Himalayan springs where seasonal photosynthetic activity and dilution by monsoonal rainfall raised pH, whereas cooler winter conditions promoted acidification but were below the permissible limit.

Free CO₂: Free CO₂ concentrations demonstrated pronounced district-level differences. Maximum free CO₂ of 17.10 mg/l was in winter from the spring water samples of Noklak district and minimum from the Dimapur district during summer (4.30 mg/l). The district-wise pattern followed Noklak > Phek > Mokokchung > Dimapur, highlighting Noklak's distinct CO₂ enrichment. The values of Free CO₂

were within the permissible limits (Table 2). Elevated winter CO₂ concentrations can be attributed to enhanced solubility under low temperatures, reduced photosynthetic uptake in colder months, and restricted gas exchange in covered spring channels. Conversely, lower concentrations in summer reflect greater photosynthetic drawdown and increased atmospheric exchange. This seasonal solubility-driven pattern is consistent with hydrological observations in cold-water spring systems (Orr et al., 2022).

Total alkalinity: Both the highest and lowest values of the Alkalinity of spring water samples from various sites was in the district of Mokokchung. Highest value of 53.80 mg/l was during rainy season and lowest value of 13.10 mg/l was reported from the water samples during winter month. All values were below the permissible limit of 120 mg/l set by BIS (2003), ICMR (1975) and WHO (1995). The consistent reduction in winter alkalinity across districts reflects lower biological activity and decreased carbonate input, while rainy-season enrichment is linked to monsoonal runoff and organic matter leaching. Such monsoonal enhancement of bicarbonate has been well-documented in hilly watersheds (Li et al., 2020).

Chloride: Chloride concentrations fluctuated considerably both spatially and temporally. Maximum chloride content of 66.70 mg/l was during rainy season from the spring water samples of Dimapur district and minimum reported from the spring water samples of Noklak district (23.60 mg/l). but were within the permissible limit (Table 2). Overall, chloride followed the sequence rainy > summer > winter across all districts, reflecting increased leaching and surface runoff during the monsoon. The consistently higher values in Dimapur and Phek may also indicate anthropogenic influence from agriculture and residential activities. These results align with earlier studies that highlighted rainfall and human-induced runoff as key drivers of chloride variability in spring-fed systems (Haake et al., 2019).

Conductivity: Higher value of conductivity was from the spring water of Mokokchung district during rainy season (125.0 µS/cm) whereas lower was during winter from water samples of spring from various sites of Dimapur district (59.90 µS/cm). Overall district wise average values confirmed the overall pattern in the trend of rainy > summer > winter. All the values were fall within the permissible limit. Elevated rainy conductivity reflects enhanced ion leaching, soil erosion, and domestic inputs, particularly in steep terrains of Mokokchung district. Similar seasonal enrichment of conductivity due to monsoonal hydrology was observed in hilly watersheds (Longchar et al., 2023).

Total Dissolved Solids (TDS): TDS showed strong spatial and seasonal differences. Maximum was recorded during rainy season from the spring water samples of Noklak (85.0

Table 1. Study sites with their geo-coordinates

Sampling station	Latitude	Longitude	Altitude (above msl)
Station (D1): Chumukedima 1	25° 47' 7.8924"N	93°48' 13.0032"E	178m
Station (D 2): Chumukedima 2	5°46'53.79531"N	93°48'5.83856"E	468m
Station (D 3): Medziphema 1	25° 45' 3.6788"N	93° 52' 53.2596"E	438m
Station (D 4): Medziphema 2	25° 45' 42.174"N	93° 53' 9.9024"E	440m
Station (D 5): Niuland Town 1	25°56'3.15412"N	93°58'39.81943"E	179m
Station (D 6): Niuland Town 2	5°56'13.98312"N	94°0'21.12033"E	273m
Station (D 7): Hovishe 1	25°56'3.08925"N	93°58'39.81430"E	184m
Station (D 8): Hovishe 2	25°56'0.76126"N	93°59'54.43218"E	192m
Station (D 9): Ghotovi 1	25°56'3.19024"N	94°0'4.98154"E	273m
Station (D 10): Ghotovi 2	25°55'59.34457"N	93°59'50.39632"E	220 m
Station (P1): Pfutsero 1	25°34'5.8764"N	94°17'42.0972"E	1941m
Station (P2): Pfutsero 2	25°34'11.5572"N	94°17'40.686"E	1942m
Station (P3): Kami 1	25°31'40.6164"N	94°16'10.5132"E	1742m
Station (P4): Kami 2	25°31'58.6056"N	94°16'11.676"E	1813m
Station (P5): Zapami 1	25°31'26.8284"N	94°15'25.668"E	1703m
Station (P6): Zapami 2	25°31'20.2476"N	94°15'51.534"E	1686m
Station (P7): Lasumi 1	25°32'2.382"N	94°14'23.0244"E	1696m
Station (P8): Lasumi 2	25°32'3.6492"N	94°14'19.1904"E	1666m
Station (P9): Leshemi 1	25°32'19.986"N	94°14'3.3612"E	1665m
Station (P10): Leshemi 2	25°32'11.7024"N	94°13'57.6804"E	1638m
Station (N1): Shim pokdom	26° 12'33.7"N	95° 59'43.4"E	1565m
Station (N2): Timpulang 1	26° 12'41.0"N	95° 00'00.9"E	1563m
Station (N3): Timpulang 2	26° 12'39.1"N	94° 59'59.3"E	1616m
Station (N4): Longshitso	26° 13'07.0"N	95° 00'18.6"E	1649m
Station (N5): Laakhkham	26° 12'36.4"N	95° 01'57.5"E	1235m
Station (N6): Kutongshae	26° 12'57.0"N	95° 01'32.6"E	1524m
Station (N7): Jin jit	26° 12'53.1"N	94° 59'43.4"E	1514m
Station (N8): Thangkham	26° 12'55.1"N	95° 00'37.1"E	1552m
Station (N9): Lunghing	26° 12'51.0"N	95° 01'30.8"E	1505m
Station (N10): Laapha	26° 13'10.9"N	95° 01'34.5"E	1638m
Station (M1):Kinunger 1	26°36'51.242"N	4°41'81.705"E	563m
Station (M2): Kinunger 2	26°36'24.932"N	94°38'86.382"E	404m
Station (M3): Longkhum 1	26°40'65.639"N	94°40'55.104"E	1436m
Station (M4): Longkhum 2	26°26'12.858"N	94°40'64.125"E	1489m
Station (M5): Ungma 1	26°29'41.139"N	94°50'55.722"E	1265m
Station (M6): Ungma 2	26°30'21.648"N	94°50'71.824"E	1133m
Station (M7): Mokokchung Village 1	26°33'31.756"N	94°53'97.194"E	1316m
Station (M8): Mokokchung Village 2	26°32'90.318"N	94°53'10.195"E	1322m
Station (M9): Chuchuyimpang 1	26°33'40.256"N	94°54'77.762"E	1394m
Station(M10):Chuchuyimpang 2	26°33'15.637"N	94°55'27.695"E	1387m

D = Dimapur, P = Phek, M = Mokokchung, N = Noklak

Table 2. Seasonal variation in few selected physico-chemical parameters of spring water of Nagaland

Parameters	Sites	Rainy	Winter	Summer	BIS/ICMR/WHO
pH	D1 to D10	6.2 ± 0.7	5.7 ± 0.8	6.0 ± 0.6	6.5-8.5
	P1 to P10	6.2 ± 0.2	5.7 ± 0.3	6.3 ± 0.4	
	N1 to N10	6.3 ± 0.5	5.9 ± 0.5	6.6 ± 0.5	
	M1 to M10	5.7 ± 0.6	5.2 ± 0.2	6.4 ± 0.8	
Free CO ₂ (mg/l)	D1 to D10	4.3 ± 1.4	5.4 ± 1.5	4.3 ± 1.4	22 mg/l
	P1 to P10	10.2 ± 3.9	12.1 ± 4.6	9.1 ± 3.4	
	N1 to N10	12.6 ± 5.3	17.1 ± 5.3	12.1 ± 4.9	
	M1 to M10	5.4 ± 1.9	9.4 ± 3.6	5.1 ± 2.6	
Total alkalinity (mg/l)	D1 to D10	44.8 ± 11.9	26.5 ± 13.4	32.3 ± 11.6	120 mg/l
	P1 to P10	39.0 ± 13.4	22.6 ± 5.0	40.8 ± 13.4	
	N1 to N10	39.3 ± 12.7	23.0 ± 5.0	34.5 ± 18.7	
	M1 to M10	53.8 ± 16.3	13.1 ± 3.5	31.2 ± 10.7	
Chloride (mg/l)	D1 to D10	66.7 ± 13.2	45.6 ± 14.9	47.3 ± 10.2	250 mg/l
	P1 to P10	65.8 ± 9.3	42.9 ± 15.8	48.9 ± 9.7	
	N1 to N10	52.5 ± 6.0	23.6 ± 7.7	31.3 ± 9.5	
	M1 to M10	56.3 ± 9.3	42.8 ± 8.8	46.4 ± 9.2	
Conductivity (µS/cm)	D1 to D10	96.6 ± 30.7	59.9 ± 21.0	70.8 ± 18.1	300 µS/cm
	P1 to P10	98.9 ± 24.7	77.6 ± 13.8	90.5 ± 19.5	
	N1 to N10	100.8 ± 29.0	82.6 ± 22.0	88.8 ± 21.7	
	M1 to M10	125.0 ± 38.3	78.9 ± 39.1	116.0 ± 40.5	
Total dissolved solid (mg/l)	D1 to D10	52.7 ± 13.9	32.3 ± 5.1	32.3 ± 5.1	500 mg/l
	P1 to P10	65.2 ± 21.4	45.7 ± 18.1	77.5 ± 75.4	
	N1 to N10	85.8 ± 20.1	56.9 ± 19.0	68.5 ± 20.0	
	M1 to M10	54.1 ± 13.6	31.8 ± 14.0	44.7 ± 17.7	

All values are expressed as mean ± SD of all the sites from each district

mg/l) whereas the minimum was from Mokokchung district during winter month (31.80 mg/l). All the values lie far below the permissible limit of 500 mg/l (Table 2). The general seasonal sequence was rainy > summer > winter, corresponding to enhanced erosion and runoff during monsoon periods. Khadka et al. (2023) also reported monsoon-driven increases in TDS in spring systems due to soil and agricultural runoff.

CONCLUSION

This study highlights significant seasonal variability in the physico-chemical attributes of spring water across four districts of Nagaland. Although all measured parameters except pH were within the permissible limits of BIS/ICMR/WHO standards. During the rainy season, pH, alkalinity, chloride, conductivity and TDS increased, largely due to surface runoff, soil leaching, and anthropogenic inputs. In contrast, winter samples showed elevated free CO₂ and reduced alkalinity, reflecting the influence of cooler water temperatures and diminished biological buffering. Spatial

variation was also apparent in Noklak and Phek districts consistently exhibited higher CO₂ and TDS concentrations, while Mokokchung district displayed the widest seasonal fluctuations. These findings provide a valuable baseline data for assessing spring water quality in Nagaland and emphasize the need for further analysis of others remaining physico-chemical parameters along with biological parameters and minerals composition in order to check the suitability of spring water benefit for human health.

AUTHORS CONTRIBUTION

Wati Temjen, Zhulika Aye, Mewkhro, Jeolam and Imlu Jamir prepared the initial manuscript draft, assisted in the collection of water samples, laboratory analysis, and compilation of manuscript. All authors contributed to data entry, statistical analysis and figure preparation. Maibam Romeo Singh supervised the overall research work, conceptualized the study design, provided guidance in methodology and interpretation, and revised the manuscript for intellectual content..

REFERENCES

- APHA 2005. *Standard methods for the examination of water and wastewater, Method 1020*. American Public Health Association, Washington, DC, USA.
- Bureau of Indian Standards 2003. *BIS 10500*, Manak Bhavan, New Delhi.
- Dass B, Sen S, Bamola V, Sharma A and Sen D 2021. Assessment of spring flows in Indian Himalayan micro-watersheds: A hydro-geological approach. *Journal of Hydrology* **598**: 126354.
- Haake DM and Knauf JH 2019. Comparison of contributions to chloride in urban stormwater from winter brine and rock salt application. *Environmental Science & Technology* **53**(20): 11888-11895.
- Indian Council of Medical Research 1975. *Manuals of standards of quality for drinking water supplies*. ICMR, New Delhi.
- Khadka K, Rijal ML and Gyawali R 2023. Factors controlling the variation in physicochemical parameters of springs in Malachy area, Nepal. *Journal of Nepal Geological Society* **66**(1): 1-12.
- Lalmalsawmzauva KC, Chatterjee U, Dutta RA, Koley B, Bhunia GS and Shit PK 2021. Rainwater harvesting potential in Nagaland, India. *Modern Cartography Series* **10**: 641-657.
- Li X, Bellerby RG, Wallhead P, Ge J, Liu J and Yang A 2020. A neural network-based analysis of the seasonal variability of surface total alkalinity on the East China Sea shelf. *Frontiers in Marine Science* **7**: 505780.
- Lkr A, Singh MR and Puro N 2020. Assessment of water quality status of Doyang River, Nagaland, India, using water quality index. *Applied Water Science* **10**: 46.
- Longchar L, Wati T, Semy K and Wati L 2023. Estimation of water quality of Dikhu River of Nagaland through a combination of water quality index and principal component analysis techniques. *Karbala International Journal of Modern Science* **9**(4): 4.
- Orr JC, Kwiatkowski L and Pörtner O 2022. Arctic Ocean annual high in CO₂ could shift from winter to summer. *Nature* **610**(7930): 94
- Saad E, Saad I, Hourri K, Jaghror H, Hamman C, Zidane L, Douira A and Fadli M 2011. Physico-chemical approach to the main water sources of the Middle Atlas piedmont, Beni Mellal, Morocco. *Morocco Journal* **3**(110605): 5.
- Semy K, Singh MR, Walling M, Wati T, Jangir A and Mishra G 2022. Qualitative soil assessment of coal mine disturbed and undisturbed tropical forest in Nagaland, India. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences* **92**(2): 275-280.
- Shah JA, Pandit AK and Shah GM 2019. Physico-chemical limnology of a shallow lake in the floodplains of western Himalaya from last four decades: present status. *Environmental Systems Research* **8**(1): 9.
- Temjen W, Singh MR and Jungla T 2021. Impact of fallow on soil health in Mokokchung district, Nagaland, India. *Journal of Environmental Engineering and Landscape Management* **29**(4): 410-417.
- Trivedy RK and Goel PK 1986. *Chemical and biological methods for water pollution studies*. Environmental Publication, Karad (India)
- WHO 1995. *Guidelines for drinking water quality*. World Health Organization, Geneva.

Received 14 June, 2025; Accepted 02 September, 2025