REPORT OF WATER QUALITY OF FRESH WATER BODIES IN MUNNAR LANDSCAPE

Conducted as part of:

PROTECTION OF FRESH WATER ECOSYSTEMS FOR THE CONSERVATION OF THREATENED SPECIES IN MUNNAR, WESTERN GHATS, INDIA.
Project Code: 2023A-41

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Disclaimer: The findings and conclusions presented are generalized insights derived from the collective responses of the community members who participated in the survey. The information is used solely for the purpose of understanding and improving community conditions and should not be construed as reflecting the views or conditions of any specific individual or group.

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1. Introduction

Water is essential for all life, fueling everything from the food we eat to the energy we consumed. It is one of the most valuable yet limited resources on Earth. Despite covering 71% of the planet's surface, less than 1% of Earth's water is both fresh and accessible for human and ecological needs. This limited resource is under increasing pressure from population growth, industrial expansion and climate change, making freshwater ecosystems such as lakes, rivers, wetlands and aquifers highly vulnerable. Alarmingly, over 10% of all known animal species and more than 50% of all fish species rely on freshwater systems, highlighting their ecological importance (Balian et al., 2008).

Fresh water habitats are among the most threatened ecosystems on the planet, facing more significant biodiversity declines than their terrestrial counterparts (Sala et al., 2000). These environments, which make up less than 1% of Earth's surface, are home to an estimated 126,000 plant and animal species- approximately 10% of all species globally (Balian et al., 2008). However, their rich biodiversity is at risk due to pollution, water extraction, habitat destruction and invasive species. Such stressors often lead to a higher extinction risk for freshwater species compared to terrestrial organisms (Belgrano et al., 2015; Collen et al., 2014).

Aquatic ecosystems are particularly fragile because pollutants from urban, industrial and agricultural activities often accumulate in freshwater systems. For instance, agricultural runoff introduces harmful chemicals like pesticides and heavy metals, which disrupt the ecological balance (Koshnood, 2016). These pollutants reduce dissolved oxygen levels, alter pH balance and damage aquatic habitats, leading to severe consequences such as population decline, developmental abnormalities and increased mortality in species like dragonflies, damselflies and fish (Kaur and Dua, 2015; Pinto et al., 2015).

This study focuses on the protection of freshwater ecosystems in Munnar with the objective of conserving threatened species. The freshwater habitat of Munnar landscape mainly comprised of streams (first order to third order); rivulets (fourth order); rivers (fifth order); reservoirs (of dams); and aquifers. The water quality of these resources has been explored in order to analyse their reasons, impacts on fauna, flora and human health and to suggest remedial measures. comprehensive water quality analysis

is being conducted to assess the physiochemical parameters and bacterial contamination of water-bodies in the region. This analysis serves as a critical tool for understanding the extent of pollution and its potential impacts on aquatic biodiversity. The findings aim to provide valuable insights into the current state of freshwater ecosystems in Munnar, enabling the formulation of targeted conservation strategies to safeguard these vital habitats and their unique biodiversity.

Figure 1 Water sample collection at Vattavada

2. Materials and Methods

2.1. Study Area and Sampling Strategy

The study was conducted in Munnar, a renowned hill station located in the Idukki district of Kerala, India. Positioned in the Western Ghats mountain range, Munnar lies at an elevation of approximately 1600 meters (5200 feet) above mean sea level. The name "Munnar", meaning "three rivers" in Malayalam, signifies the confluence of three major streams- Muthirapuzha, Nallathanni and Kundala- within the region. Geographically, Munnar is situated between the co-ordinates 10°05'19.43"N and 77°03'45.68"E. A total of 52 water samples were collected from 27 transects, including rivers, reservoirs and streams, across different sites in Munnar. Sampling was conducted during two distinct seasons:

- Season 1 (Summer): January to March
- Season 2 (Monsoon): August to October

The samples were systematically collected from both upstream and downstream locations to ensure comprehensive coverage of the water quality in the study area

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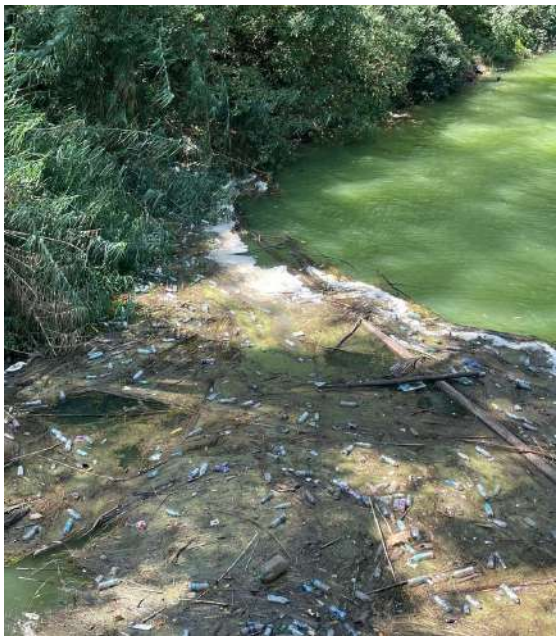
SL.No	Location Name	Start Co-ordinates	End Co-ordinates
1	PADIKAPPU STREAM	10°03'23"N 76°52'18"E	10°03'34"N 76°52'24"E
2	CHILLITHODU STREAM	10°02'14"N 76°52'44"E	10°02'09"N 76°52'47"E
3	AMBAZHACHAL RIVER	10°00'59"N 77°00'49"E	10°01'09"N 77°00'53"E
4	MUTTUKAD PADDY FIELD	10°00'42"N 77°08'48"E	10°00'42"N 77°08'40"E
5	KUWAIT CITY	10°08'19"N 76°55'28"E	10°08'27"N 76°55'22"E
6	MANKULAM RIVER	10.113549, 76.929851	10.115958, 76.928474
7	PEECHAD RIVER	10°02'32"N 76°57'57"E	10°02'29"N 76°58'14"E
8	POOPARA STREAM	9°58'51"N 77°12'30"E	9°58'39"N 77°12'23"E
9	KUNJITHANNY 1	10°00'47"N 77°03'58"E	10°00'40"N 77°03'58"E
10	KUNJITHANNY 2	10°01'12"N 77°03'35"E	10°00'59"N 77°03'30"E
11	ELLACKAL BRIDGE	10°00'00"N 77°04'02"E	9°59'51"N 77°03'57"E
12	MANKUZHI WATERFALLS	10°01'13"N 77°00'42"E	10°01'13"N 77°00'48"E
13	AANAKULAM	10°09'39"N 76°54'43"E	10°09'35"N 76°54'40"E
14	KALLARKUTTY RESERVOIR	9°58'22"N 77°01'01"E	9°58'41"N 77°00'23"E
15	PONMUDY RESERVOIR	9°57'33"N 77°03'27"E	9°57'33"N 77°03'28"E
16	AANAYIRANKAL RESERVOIR	10°00'47"N 77°12'07"E	10°00'50.0"N 77°12'13.1"E
17	SENGULAM RESERVOIR	10°00'04"N 77°02'28"E	10°00'41"N 77°01'57"E
18	MATTUPETTY RESERVOIR	10°07'33.7"N 77°09'38.8"E	10°07'30.6"N 77°09'30.7"E
19	SHANTHANPARA	9°58'07"N 77°13'03"E	9°58'07"N 77°13'08"E
20	VAGUVURRAI STREAM	10°10'49"N 77°06'24"E	10°10'41"N 77°06'27"E
21	NALLATHANNY RIVER	10°06'48"N 77°03'27"E	10°06'30"N 77°03'29"E
22	VATTAVADA KEEKARATHODU	10°10'51"N 77°15'23"E	10°10'50"N 77°15'18"E
23	VATTAVADA UMANKADAVU	10°10'31"N 77°15'25"E	10°10'46"N 77°15'23"E
24	CHILANTHIYAAR WATERFALLS, VATTAVADA	10°13'38"N 77°14'42"E	10°13'40"N 77°14'40"E
25	KAINAGIRI WATERFALLS, VIRIPPARA	10°04'42.5"N 76°57'42.8"E	10°04'43.7"N 76°57'45.2"E
26	KUNDALA RESERVOIR	10°08'36.7"N 77°11'55.4"E	10°08'43.2"N 77°12'04.6"E
27	NALLATHANNY ANTHONNIYAR	10.089974,77.054823	10.089003,77.056752

Table 1. Locations and GPS Co-ordinates of Transects in Munnar



Garbage dump at Vattavada chilanthiyar and Kundala ecopoint

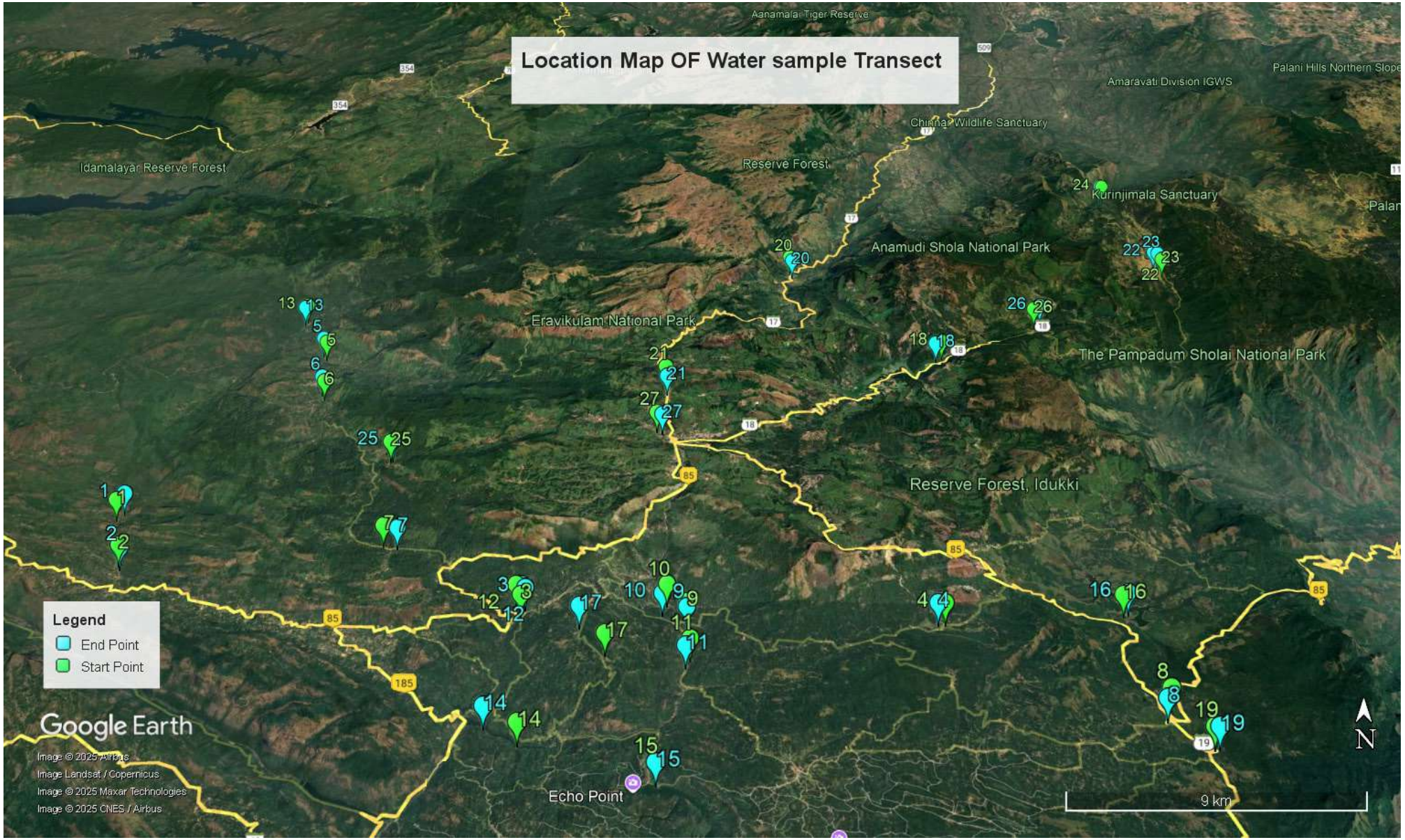


Figure 2. Map showing locations of water sample collections Munnar

2.2 Analysis of different water quality parameters

The collected water samples were analysed for different water quality parameters in the laboratory as per standard procedures used for water analysis. Turbidity of water samples were measured using Nephelometric Turbidity Meter 135. Temperature of water samples were measured at the sampling site using a digital thermometer. Digital pH Meter 335 was used to measure pH of water samples. Conductivity, TDS and Salinity of samples were measured using Microprocessor EC-TDS-SAL Meter (Model 1602). Chemical parameters like Acidity and Alkalinity of water samples were determined by indicator method using phenolphthalein and methyl orange as an indicator. Chloride was estimated by Mohr's method using AgNO3 solution and Potassium Chromate as an indicator. Total hardness, Calcium hardness and Magnesium hardness were determined by complexometric titration using Eriochrome Black-T as an indicator by EDTA method. Organic Carbon was determined through titration by Walkley-Black method. Oil content of water samples were determined by Gravimetric Method. UV-VIS Spectrophotometer 118 was used for measuring other chemical parameters like Iron, Fluoride, Sulphate, Nitrate and Phosphate. Bacteriological analysis was performed using Most Probable Number (MPN) Method. DO was determined by Winkler method. AR grade reagents and ultrapure de-ionized water were used for all the analyses wherever required.

2.3 Quality estimation using Water Quality Index (WQI)

In the present study, 16 different water quality parameters were
used for the indexing by using Weight Arithmetic Water Quality Index
(WAWQI) (Brown et al., 1970). Table 2. shows the standard value of different
water quality parameters recommended by World Health Organization
(WHO) and Bureau of Indian Standards (BIS) used in WAWQI.
WQI of the collected water samples were estimated by using the following
steps:

$$WQI = \sum Qn\, Wn / \sum Wn$$

Where, Qn = Quality rating of n^{th} water quality parameter.
Wn= Unit weight of n^{th} water quality parameter.

Quality rating (Qn)

The quality rating (Qn) is calculated using the expression:

$$Qn = [(Vn - V_0) / (Sn - V_0)] \times 100$$

Where,
Vn = Estimated value of n^{th} water quality parameter at a given sample location.
V_0 = Ideal value for n^{th} parameter in pure water.
Sn = Standard permissible value of n^{th} water quality parameter.

For all parameters, the ideal value (V_0) = 0, while for pH and DO parameters the (V_0) is equal to 7 and 14.6 respectively (Tyagi et al., 2013).

Unit weight
The unit weight (Wn) is calculated using the expression:

$$Wn = k / Sn$$

Where,
Sn = Standard permissible value of n^{th} water quality parameter.
k = Constant of proportionality and it is calculated by using the expression:

$$k = [1 / (\sum 1/ Sn)]$$

Figure 3. Sample collection at MankuzhytionsMunnar

Parameters	Standard Value	Reference
Turbidity (NTU)	1	BIS
pH	6.5-8.5	BIS
DO (mg/l)	5	WHO
Conductivity (µS/cm)	750	WHO
TDS (mg/l)	500	BIS
Alkalinity (as $CaCO_3$), mg/l	200	BIS
Total hardness (as $CaCO_3$), mg/l	200	BIS
Calcium hardness (mg/l)	75	WHO
Magnesium hardness (as Mg), mg/l	30	BIS
Chloride (as Cl), mg/l	250	BIS
Iron (as Fe), mg/l	0.3	BIS
Sulphate (as SO_4), mg/l)	200	BIS
Fluoride (as F), mg/l	1	BIS
Nitrate (as NO_3), mg/l	45	BIS
Phosphate (mg/l)	0.1	WHO
Oil content (mg/l)	0.5	BIS

Table 2. Different parameters tested

2.4. WQI AND STATUS

Water quality index is the simplest numerical expression of the quality of a water source for drinking purpose. The ranges of WQI and the corresponding status of water quality are summarized in Table 3.

Water Quality Value	Rating of Water Quality
0 - 25	Excellent water quality
26 - 50	Good water quality
51 - 75	Poor water quality
76 - 100	Very Poor water quality
Above 100	Unsuitable for drinking purpose

Table 3. Classification of water source based on water quality index values.

Figure 4. Sample collection at Mankuzhy Munnar

Figure 5. Field measurements at Padikappu

Figure 6. Water sample collection at Mankulam River

Figure 7. Water sample collection at Senkulam Dam

Figure 8. Water sample collection at Ambazhachal

Figure 9. Water sample collection at Peechadu

Figure 10. Field measurements at Ponmudi

Figure 11. Water sample collection at Santhanpara

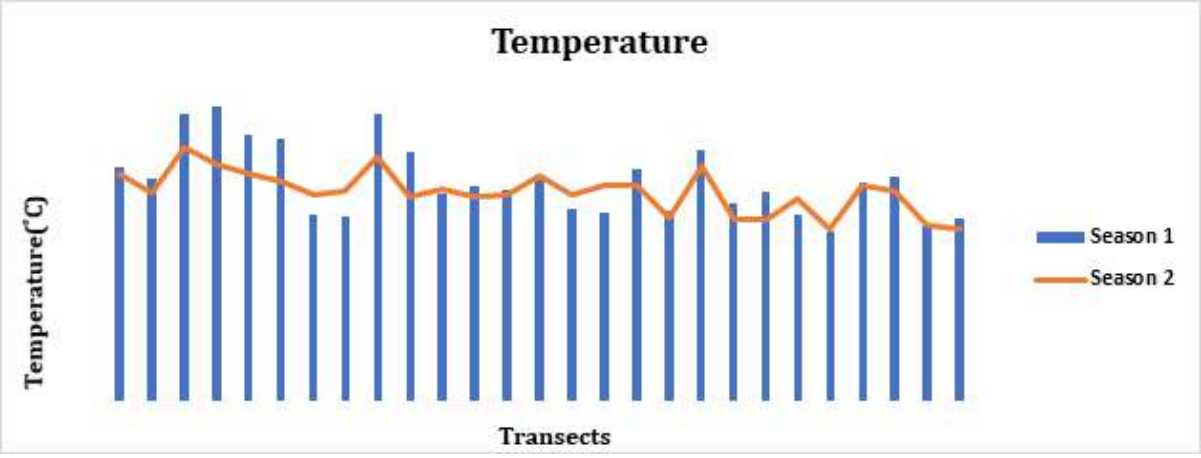
Figure 12. Water sample collection at Muttukadu

3. Result and Discussion

3.1 Temperature

River water temperature experiences noticeable changes throughout the year, with warmer temperatures in summer and cooler temperatures in winter. Temperature is a critical parameter for water quality, influencing biological activity and chemical processes in the water. Season 1 (summer) temperatures generally show higher values compared to Season 2 (Monsoon). For most locations, temperatures in Season 1 ranges from 18^0 C to 31^0 C, while in Season 2, values ranging from 18^0 C to 27^0 C. Lower MSL areas (e g: Padikappu at 600m and Kallarkutty at 473 m) exhibit higher temperatures due to warmer ambient conditions and increased exposure to sunlight. Higher MSL areas (e g: Vattavada Chilanthayar at 1552 m and Keekarathodu at 1629 m show lower temperatures due to cooler climates and reduced solar heating.

Figure 13. Field level measurements with portable instruments



Graph 1. Seasonal variation in aquatic temperature across different transects in Munnar.

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	24.95 ± 0.63	24.25 ± 0.07
2	Kuwait City	368 m	23.85 ± 0.07	22.25 ± 0.07
3	Kallarkutty	473 m	30.7 ± 0.56	27.1 ± 0.7
4	Padikappu	600 m	31.4 ± 0.56	25.25 ± 0.6
5	Chillithodu	612 m	28.5 ± 0	24.35 ± 0.07
6	Mankulam	701 m	28.1 ± 0.28	23.4 ± 1.3
7	Ambazhachal	713 m	19.85 ± 0.21	22 ± 0.7
8	Mankuzhi W.F	720 m	19.775 ± 0.03	22.35 ± 1.2
9	Ponmudi	720 m	30.6 ± 0.42	26.15 ± 0.07
10	Ellackal Bridge	723 m	26.5 ± 1.41	21.75 ± 0.35
11	Kunjithanny 1	771 m	22.125 ± 0.53	22.7 ± 0.8
12	Kunjithanny 2	778 m	22.9 ± 0.42	21.9 ± 0.3
13	Sengulam Dam	847 m	22.55 ± 0.91	22.1 ± 0.56
14	Muttukad P.F	954 m	24.25 ± 0.21	24 ± 0.14
15	Peechadu stream	987 m	20.5 ± 0	22 ± 0.8
16	Shanthanpara	1052 m	20.2 ± 0	22.95 ± 0.07
17	Pooppara	1104 m	24.7 ± 0.98	23.15 ± 0.07
18	Kainagiri	1175 m	20.3 ± 0.42	19.6 ± 0.14
19	Anayirangal	1206 m	26.85 ± 0.21	25 ± 0.56
20	Vaguvarei Estate	1400 m	21.2 ± 0.42	19.35± 0.5
21	Nallathanny Anthonniyar	1480 m	22.25 ± 0.21	19.4 ± 0
22	Nallathanny	1520 m	20 ± 0.42	21.65 ± 0.2
23	Vattavada Chilanthiyar	1552 m	18.15 ± 0.07	18.45 ± 0.07
24	Kundala dam	1602 m	23.4 ± 1.27	22.95 ± 0.07
25	Mattupetty	1602 m	24 ± 0	22.5 ± 0.14
26	Vattavada Keekarathodu	1629 m	18.7 ± 0	18.8 ± 0.14
27	Vattavada Umankadavu	1632 m	19.45 ± 0.07	18.35 ± 0.5

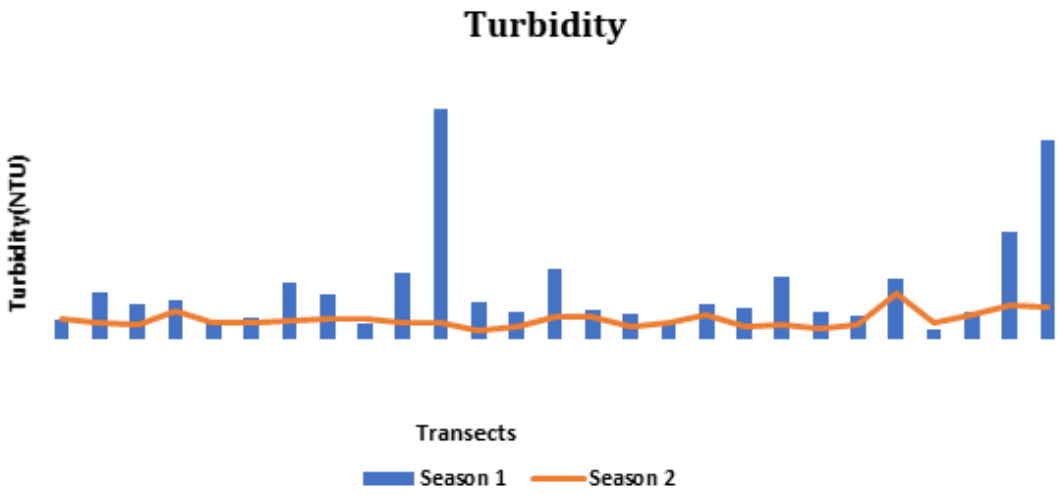
Values are Mean ± SD

Table 4. Seasonal variation in aquatic temperature of freshwater bodies in Munnar (transect -wise)

3.2 Turbidity

Turbidity is a measure of water clarity in streams, rivers, lakes, and the ocean. Turbidity describes the amount of light scattered or blocked by suspended particles in a water sample. Season 1 (Summer) generally shows lower turbidity values ranges from 0.95 NTU (Kundala Dam) to 23.9 NTU (Kunjithanny 1) compared to Season 2 (monsoon), ranges from 0.95(Kunjithanny 1) to 4.8 NTU (Vattavada Chilanthiyar). Permissible limit of turbidity in water sample is 5 NTU. In Season 2, all values are within the permissible limit. Higher turbidity in certain locations may indicate localized disturbances or human activities contributing to sediment load.

Figure 14. Turbidity analysis



Graph 2. Seasonal variation in turbidity across different transects in Munnar

Sl. No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	2.05 ± 0.35	2.1 ± 0
2	Kuwait City	368 m	4.85 ± 0.5	1.75 ± 0.07
3	Kallarkutty	473 m	3.6 ± 0.28	1.5 ± 0.14
4	Padikappu	600 m	4 ± 1.7	2.95 ± 1.7
5	Chillithodu	612 m	2.05 ± 0.35	1.7 ± 0
6	Mankulam	701 m	2.15 ± 1.2	1.7 ± 0.14
7	Ambazhachal	713 m	5.8 ± 2.97	1.95 ± 0.6
8	Mankuzhi W.F	720 m	4.65 ± 0.35	2.1 ± 0.8
9	Ponmudi	720 m	1.6 ± 0.14	2.15 ± 0.35
10	Ellackal Bridge	723 m	6.9 ± 5.37	1.7 ± 0
11	Kunjithanny 1	771 m	23.9 ± 25.03	1.8 ± 0.4

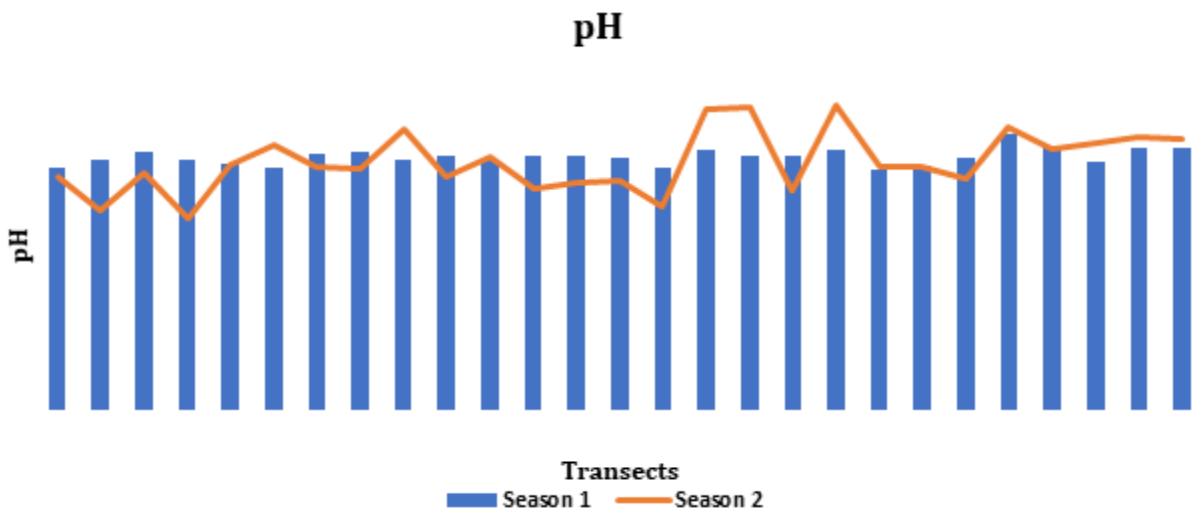
12	Kunjithanny 2	778 m	3.8 ± 0.7	0.95 ± 0.2
13	Sengulam Dam	847 m	2.9 ± 0.56	1.25 ± 0.2
14	Muttukad P.F	954 m	7.2 ± 1.83	2.3 ± 0.7
15	Peechadu stream	987 m	3.1 ± 0.42	2.35 ± 0.2
16	Shanthanpara	1052 m	2.6 ± 0	1.2 ± 0.28
17	Pooppara	1104 m	1.5 ± 0.42	1.65 ± 0.7
18	Kainagiri	1175 m	3.65 ± 0.77	2.6 ± 0.14
19	Anayirangal	1206 m	3.3 ± 0.7	1.35 ± 0.07
20	Vaguvarei Estate	1400 m	6.35 ± 6.01	1.5 ± 0.28
21	Nallathanny Anthonniyar	1480 m	2.75 ± 1.2	1.05 ± 0.07
22	Nallathanny	1520 m	2.5 ± 0.14	1.5 ± 0
23	Vattavada Chilanthiyar	1552 m	8.1 ± 0	4.8 ± 0.28
24	Kundala dam	1602 m	0.95 ± 0.07	1.6 ± 0.56
25	Mattupetty	1602 m	2.8 ± 2.12	2.45 ± 0.2
26	Vattavada Keekarathodu	1629 m	11.1 ± 0	3.55 ± 1.6
27	Vattavada Umankadavu	1632 m	7.1 ± 14.85	3.35 ± 0.6

Table 5. Seasonal variation in turbidity (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.3 pH

Figure 15. pH/mV testing in the fileld

Because pH influences the chemical and biological activities that take place in water bodies, it is a crucial metric for evaluating water quality. For instance, the availability and solubility of nutrients and minerals for aquatic organisms can be impacted by pH (Hossain et al., 2019). The pH values in season 1 (summer) varied from 6.56 ± 0.19 to 7.5 ± 0.007 and from 5.24 ± 0.2 to 8.3 ± 0.56 in season 2 (monsoon) (Graph.3, Table-6). The WHO recommends a maximum pH level of 6.5 to 8.5. In summer season all the values are within the desirable limit. Most transects show slightly lower pH values during monsoon compared to summer season. Aquatic life may suffer if hazardous metals are released from sediments due to low pH levels. Additionally, because dissolved oxygen is necessary for aquatic life, high pH values might harm aquatic life by decreasing its availability. Fish and other aquatic organisms are particularly sensitive to changes in pH because they rely on dissolved oxygen for respiration (Wang et al., 2019).



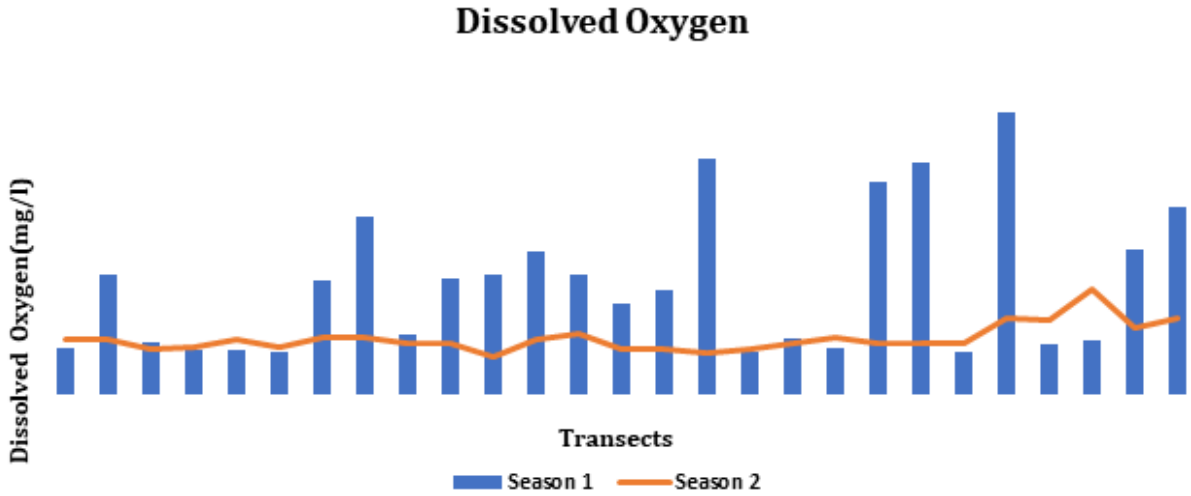
Graph 3. Seasonal variation in pH across different transects in Munnar.

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	6.6 ± 0.07	6.35 ± 0.2
2	Kuwait City	368 m	6.8 ± 0.04	5.45 ± 0.07
3	Kallarkutty	473 m	7.05 ± 0.27	6.45 ± 0.5
4	Padikappu	600 m	6.8 ± 0	5.24 ± 0.2
5	Chillithodu	612 m	6.7 ± 0.01	6.7 ± 0.14
6	Mankulam	701 m	6.6 ± 0.007	7.2 ± 0.14
7	Ambazhachal	713 m	6.97 ± 0.42	6.6 ± 0.14
8	Mankuzhi W.F	720 m	7.005 ± 0.007	6.55 ± 0.35
9	Ponmudi	720 m	6.8 ± 0.25	7.65 ± 0.07
10	Ellackal Bridge	723 m	6.9 ± 0	6.35 ± 0.07
11	Kunjithanny 1	771 m	6.8 ± 0.18	6.9 ± 0.14
12	Kunjithanny 2	778 m	6.9 ± 0.01	6.05 ± 0.07
13	Sengulam Dam	847 m	6.9 ± 0	6.2 ± 0.3
14	Muttukad P.F	954 m	6.87 ± 0.12	6.23 ± 0.24
15	Peechadu stream	987 m	6.6 ± 0.03	5.55 ± 0.07
16	Shanthanpara	1052 m	7.06 ± 0	8.2 ± 0.14
17	Pooppara	1104 m	6.9 ± 0.05	8.25 ± 0.07
18	Kainagiri	1175 m	6.9 ± 0.17	6 ± 0
19	Anayirangal	1206 m	7.08 ± 0.01	8.3 ± 0.56
20	Vaguvarei Estate	1400 m	6.56 ± 0.19	6.6 ± 0.14
21	Nallathanny Anthonniyar	1480 m	6.6 ± 0.04	6.65 ± 0.07
22	Nallathanny	1520 m	6.88 ± 0.20	6.3 ± 0.14
23	Vattavada Chilanthiyar	1552 m	7.5 ± 0.007	7.7 ± 0.3
24	Kundala dam	1602 m	7.1 ± 0.1	7.13± 0.1
25	Mattupetty	1602 m	6.77 ± 0.01	7.25 ± 0.07
26	Vattavada Keekarathodu	1629 m	7.16 ± 0	7.45 ± 0.2
27	Vattavada Umankadavu	1632 m	7.14 ± 0.03	7.4 ± 0.14

Table 6. Seasonal variation in pH (mean ± SD) of freshwater bodies in Munnar (transect-wise)

3.4 Dissolved Oxygen (D.O)

The values for both seasons vary significantly across different transects. Summer season generally exhibits higher DO concentrations compared to monsoon. Notable high values in summer include 36.6mg/l (Shanthanpara), Nallathanny Anthonniyar (36.1 mg/l), Vattavada Umankadavu (29.3 mg/l) and Mankuzhi (27.65mg/l). Monsoon values are lower than summer, showing a trend of decreased dissolved oxygen ranging from 6 mg/l to 16.5 mg/l due to increased water flow and potential dilution or organic matter decomposition. Due to delay of 2 days between sample collection and analysis, several DO values recorded in season 1 exceed the upper limit for river water (16 mg/l). These values are likely influenced by storage conditions or sample handling.



Graph 4. Seasonal variation in DO across different transects in Munnar

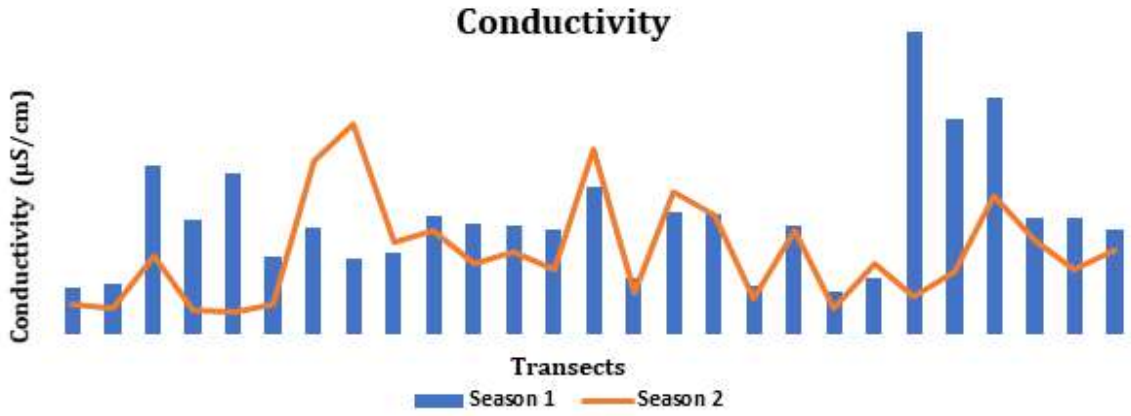
Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	7.3 ± 0	8.5 ± 0.7
2	Kuwait City	368 m	18.65 ± 3.74	8.5 ± 0.7
3	Kallarkutty	473 m	8.3 ± 0.42	7 ± 0
4	Padikappu	600 m	6.95 ± 4.17	7.5 ± 0.7
5	Chillithodu	612 m	6.95 ± 0.5	8.5 ± 2.1
6	Mankulam	701 m	6.65 ± 0.92	7.5 ± 0.7
7	Ambazhachal	713 m	17.65 ± 0.5	9 ± 0
8	Mankuzhi W.F	720 m	27.65 ± 3.32	9 ± 0
9	Ponmudi	720 m	9.25 ± 0.92	8 ± 0
10	Ellackal Bridge	723 m	18 ± 2.83	8 ± 0
11	Kunjithanny 1	771 m	18.6 ± 0	6 ± 1.4
12	Kunjithanny 2	778 m	22.3 ± 5.23	8.5 ± 0.7
13	Sengulam Dam	847 m	18.6 ± 0	9.5 ± 0.7
14	Muttukad P.F	954 m	14.3 ± 1.4	7 ± 1.4
15	Peechadu stream	987 m	16.3 ± 0.42	7 ± 0
16	Shanthanpara	1052 m	36.6 ± 0	6.5 ± 0.7
17	Pooppara	1104 m	6.6 ± 2.82	7 ± 0

18	Kainagiri	1175 m	8.65 ± 0.92	8 ± 1.4
19	Anayirangal	1206 m	7.3 ± 0	9 ± 0
20	Vaguvarei Estate	1400 m	33 ± 1.41	8 ± 0
21	Nallathanny Anthonniyar	1480 m	36.1 ± 2.12	8 ± 0
22	Nallathanny	1520 m	6.6 ± 0	8 ± 0
23	Vattavada Chilanthiyar	1552 m	44 ± 8.5	12 ± 0
24	Kundala dam	1602 m	7.95 ± 1.9	11.5 ± 0.7
25	Mattupetty	1602 m	8.6 ± 0	16.5 ± 0.7
26	Vattavada Keekarathodu	1629 m	22.65 ± 0.92	10.5 ± 2.1
27	Vattavada Umankadavu	1632 m	29.3 ± 10.32	12 ± 0

Table 7. Seasonal variation in DO (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.5 Conductivity

The ability of water to carry electrical current is measured by its conductivity. This capability is directly correlated with the water's ion concentration. Conductivity are generally higher in summer season compared to monsoon. General acceptable range for a healthy river water is 50 to 1500 µS/cm. The current investigation indicated that the mean ranges of EC value showed variations ranged from 26.135 ± 15.36 to 183.75 ± 8.13 in summer and from 14.55 ± 0.77 to 128.5 ± 51.62 during monsoon (Graph. 5, Table 8). Higher conductivity in summer may indicate increased mineral concentrations, potentially due to lower water levels and higher evaporation rates. The monsoon significantly reduces conductivity across most locations due to dilution caused by increased rainfall and water flow. Normal conductivity levels support diverse aquatic life. Extreme deviations (too low or too high) can harm ecosystems by affecting species that rely on stable water chemistry.



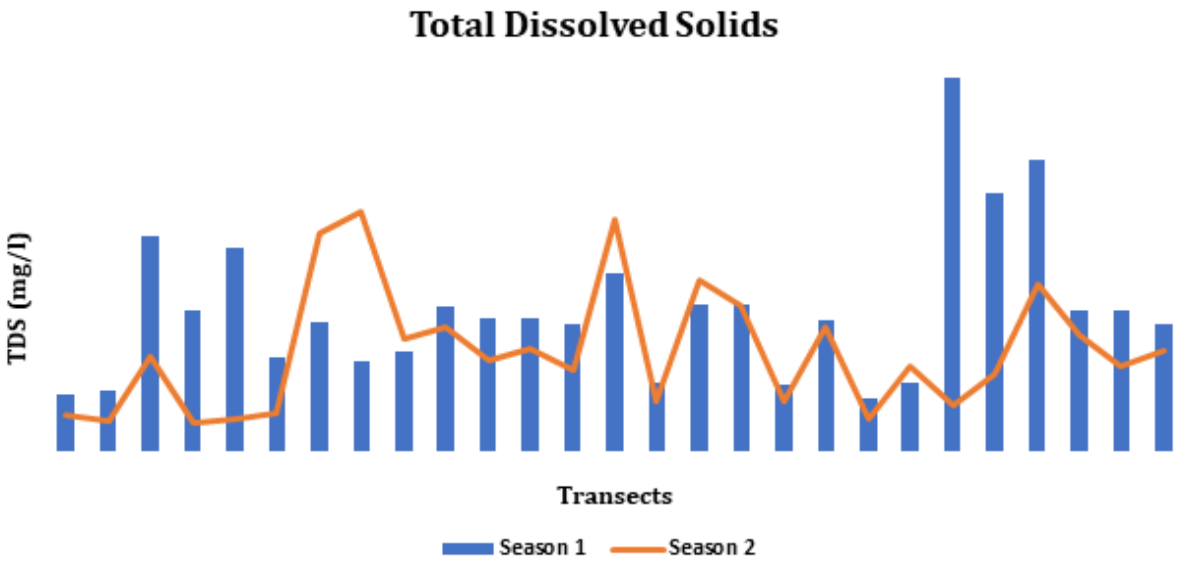
Graph 5. Seasonal variation in Conductivity across different transects in Munnar

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	28.5 ± 6.36	18.7 ± 0.14
2	Kuwait City	368 m	31.05 ± 0.77	16.35 ± 1.9
3	Kallarkutty	473 m	103 ± 39.6	48 ± 14.1
4	Padikappu	600 m	70 ± 31.1	14.72± 0.96
5	Chillithodu	612 m	97.5 ± 20.5	14.55 ± 0.77
6	Mankulam	701 m	47.5 ± 26.16	18.9 ± 1.41
7	Ambazhachal	713 m	64.75 ± 22.41	105.5 ± 37.47
8	Mankuzhi W.F	720 m	45.925 ± 0.81	128.5 ± 51.62
9	Ponmudi	720 m	49.75 ± 1.06	56.5 ± 2.1
10	Ellackal Bridge	723 m	72.425 ± 2.3	63.5 ± 7.7
11	Kunjithanny 1	771 m	67.45 ± 0.28	44 ± 19.8
12	Kunjithanny 2	778 m	66.75 ± 3.6	51 ± 9.9
13	Sengulam Dam	847 m	63.725 ± 5.26	40 ± 0
14	Muttukad P.F	954 m	90.2 ± 2.83	112.5± 10.6
15	Peechadu stream	987 m	34.625 ± 2.3	25.4 ± 2.4
16	Shanthanpara	1052 m	74.35 ± 0	87 ± 0
17	Pooppara	1104 m	73 ± 57.98	73 ± 4.2
18	Kainagiri	1175 m	30.25 ± 0.35	22.55± 2.47
19	Anayirangal	1206 m	66.2 ± 1.5	63 ± 9.9
20	Vaguvarei Estate	1400 m	26.135 ± 15.36	16.4 ± 6.6
21	Nallathanny Anthonniyar	1480 m	35.1 ± 0.7	43.3 ± 0.14
22	Nallathanny	1520 m	183.75 ± 8.13	22.9 ± 3.4
23	Vattavada Chilanthiyar	1552 m	130.7 ± 13.57	39.2 ± 41.3
24	Kundala dam	1602 m	144 ± 51.61	84.85 ± 1.06
25	Mattupetty	1602 m	71.35 ± 0.63	57.725 ± 1.87
26	Vattavada Keekarathodu	1629 m	71.1 ± 0	39.5 ± 0.7
27	Vattavada Umankadavu	1632 m	64.475 ± 4.35	51.35 ± 1.9

Table 8. Seasonal variation in Conductivity (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.6 Total Dissolved Solids (TDS)

When water comes into contact with soluble material, particles of the material are absorbed into the water, resulting in total dissolved solids. TDS is the amount of organic and inorganic materials, such as metals, minerals, salts, and ions, dissolved in a specific volume of water. The amount of TDS ranges from 100 – 500 mg/l in rivers. Lakes and streams may have a TDS reading of 50-250 mg/l. The highest value of TDS among all collected samples in summer season was measured as 122.75 mg/l and the lowest value was 17.19 mg/l. During monsoon, mean values ranges from 9.59 mg/l to 78.5 mg/l (Graph.6, Table 9). Most locations experience a decline in TDS during the rainy season, confirming the dilution effect due to monsoon rains. Aquatic life requires a steady concentration of minerals in the water. Since the density of total dissolved solids controls the flow of water into and out of an organism's cells, variations in the quantities of dissolved solids can be detrimental. Excessive or insufficient concentrations of total dissolved solids can hinder the growth and even kill a lot of aquatic life.



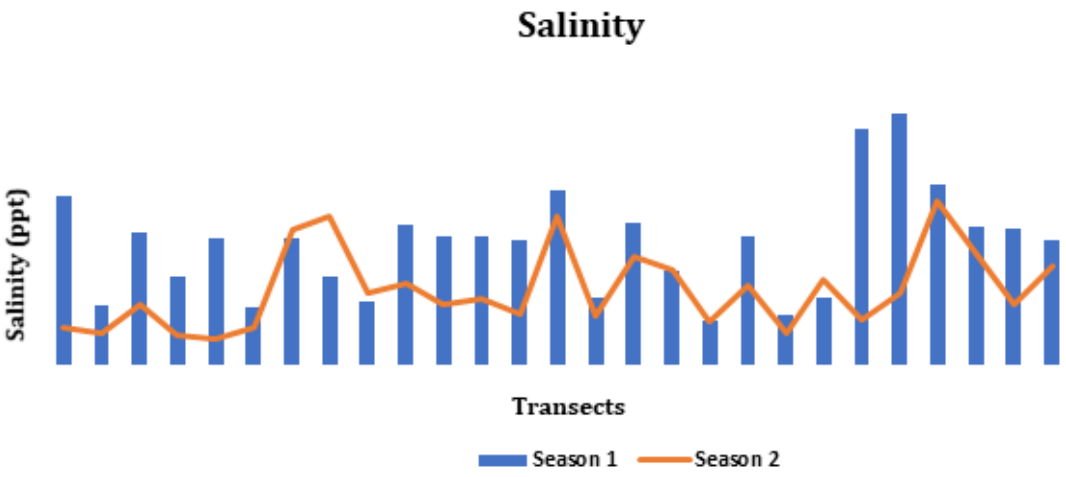
Graph 6. Seasonal variation in TDS across different transects in Munnar.

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	18.5 ± 4.24	12.195 ± 0.14
2	Kuwait City	368 m	20.27 ± 0.46	10.35 ± 0.9
3	Kallarkutty	473 m	70.5 ± 28.9	31 ± 7.07
4	Padikappu	600 m	46 ± 21.2	9.59 ± 0.7
5	Chillithodu	612 m	66.75 ± 14.5	10.4 ± 0.84
6	Mankulam	701 m	31 ± 18.4	12.31 ± 1
7	Ambazhachal	713 m	42.55 ± 15.06	71.5 ± 24.7
8	Mankuzhi W.F	720 m	29.82 ± 0.46	78.5 ± 24.7
9	Ponmudi	720 m	32.5 ± 0.7	37 ± 1.4
10	Ellackal Bridge	723 m	47.5 ± 1.13	41 ± 4.24
11	Kunjithanny 1	771 m	43.9 ± 0.07	30 ± 14.14
12	Kunjithanny 2	778 m	43.4 ± 2.3	33.5 ± 6.36
13	Sengulam Dam	847 m	41.62 ± 3.005	27 ± 1.4
14	Muttukad P.F	954 m	58.6 ± 1.7	76 ± 5.65
15	Peechadu stream	987 m	22.27 ± 1.6	16.5 ± 1.55
16	Shanthanpara	1052 m	48.4 ± 0	56.5 ± 3.53
17	Pooppara	1104 m	48.25 ± 38.5	48 ± 2.8
18	Kainagiri	1175 m	21.75 ± 2.47	16.15 ± 3.7
19	Anayirangal	1206 m	43.2 ± 0.85	41 ± 7.07
20	Vaguvarei Estate	1400 m	17.19 ± 10.3	10.65± 4.3
21	Nallathanny Anthonniyar	1480 m	22.8 ± 0.42	28.3 ± 0
22	Nallathanny	1520 m	122.75 ± 4.6	14.95 ± 2.2
23	Vattavada Chilanthiyar	1552 m	85 ± 8.98	25.25 ± 27.2
24	Kundala dam	1602 m	95.5 ± 34.6	55.2 ± 0.7
25	Mattupetty	1602 m	46.45 ± 0.35	37.95 ± 1.76
26	Vattavada Keekarathodu	1629 m	46.3 ± 0	28 ± 2.8
27	Vattavada Umankadavu	1632 m	41.9 ± 2.83	33.35± 1.34

Table 9. Seasonal variation in TDS (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.7 Salinity

Salinity is the measure of the amount of dissolved salts in water. Measuring the salinity or the dissolved salt content of water is important as aquatic organisms, livestock, and crops thrive at different salinity levels. Freshwater from rivers has a salinity value of 0.5ppt or less. Graph Shows salinity values ranging from 0.017 ± 0.003 to 0.097 ± 0.01 during summer and from 0.009 ± 0.002 to 0.064 ± 0.0007 during monsoon. Salinity levels are generally higher in summer season due to lower water flow, evaporation and concentration of salts and lower in monsoon due to increased water volume and dilution caused by rainfall. Increasing salinity in rivers can lead to: the slow elimination of freshwater biodiversity, the death of trees and wetland plants, the elimination of fish, and stimulation of toxic cyanobacterial blooms.



Graph 7. Seasonal variation in Salinity across different transects in Munnar.

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	0.065 ± 0.07	0.014 ± 0.0001
2	Kuwait City	368 m	0.023 ± 0	0.012 ± 0.001
3	Kallarkutty	473 m	0.051 ± 0.02	0.023 ± 0.004
4	Padikappu	600 m	0.034 ± 0.015	0.011 ± 0.0007
5	Chillithodu	612 m	0.049 ± 0.009	0.009 ± 0.002
6	Mankulam	701 m	0.022 ± 0.013	0.014 ± 0.001
7	Ambazhachal	713 m	0.049 ± 0.02	0.052 ± 0.02
8	Mankuzhi W.F	720 m	0.034 ± 0	0.058 ± 0.017
9	Ponmudi	720 m	0.024 ± 0.0007	0.028 ± 0.001
10	Ellackal Bridge	723 m	0.054 ± 0.0007	0.031 ± 0.003
11	Kunjithanny 1	771 m	0.05 ± 0	0.023 ± 0.01
12	Kunjithanny 2	778 m	0.05 ± 0.003	0.025 ± 0.005
13	Sengulam Dam	847 m	0.048 ± 0.003	0.019 ± 0.0007
14	Muttukad P.F	954 m	0.067 ± 0.002	0.058 ± 0.004
15	Peechadu stream	987 m	0.026 ± 0.0014	0.019 ± 0.002
16	Shanthanpara	1052 m	0.055 ± 0	0.042 ± 0.001
17	Pooppara	1104 m	0.036 ± 0.027	0.036 ± 0.002
18	Kainagiri	1175 m	0.017 ± 0.003	0.017 ± 0.002

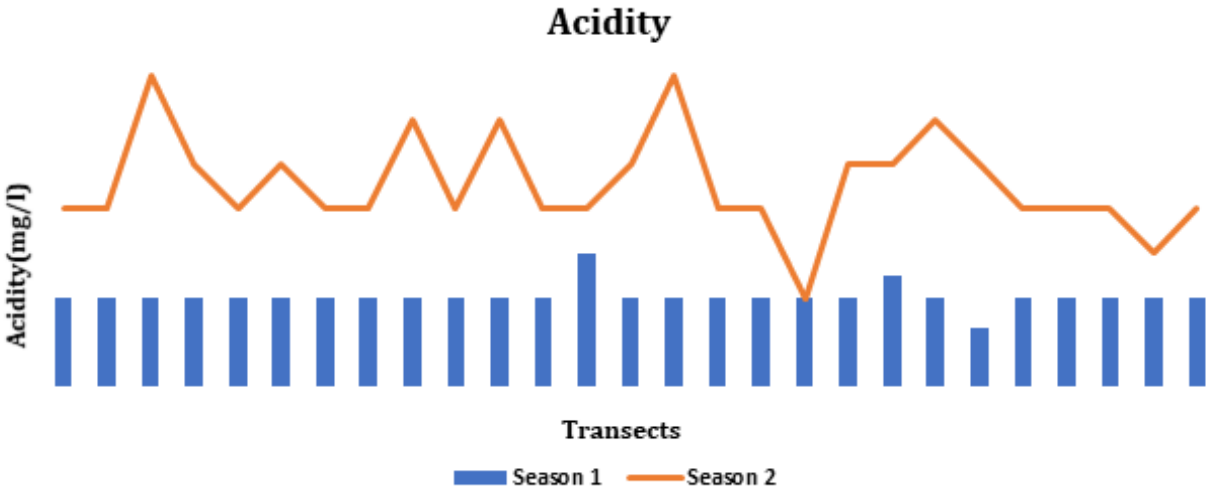
19	Anayirangal	1206 m	0.049 ± 0.0007	0.030 ± 0.005
20	Vaguvarei Estate	1400 m	0.019 ± 0.01	0.012 ± 0.005
21	Nallathanny Anthonniyar	1480 m	0.026 ± 0	0.032 ± 0.00007
22	Nallathanny	1520 m	0.091 ± 0.003	0.017 ± 0.002
23	Vattavada Chilanthiyar	1552 m	0.097 ± 0.01	0.027 ± 0.03
24	Kundala dam	1602 m	0.07 ± 0.025	0.064 ± 0.0007
25	Mattupetty	1602 m	0.053 ± 0.0007	0.044 ± 0.002
26	Vattavada Keekarathodu	1629 m	0.053 ± 0	0.023 ± 0.003
27	Vattavada Umankadavu	1632 m	0.048 ± 0.003	0.038 ± 0.001

Table 10. Seasonal variation in Salinity (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.8 Acidity

Acidity is the quantitative capacity of a water or solution to neutralize an alkali.
Carbon dioxide, mineral acids, and hydrolysed salts like aluminium and ferric sulphates are typically the causes of acidity in water. The acceptable limit of acidity in water is 200mg/l (IS:3025 (part 22)-1986). Table 11. shows that acidity levels for all locations in both seasons (summer and monsoon) are within the acceptable limit.

Figure 16. Waste dumped at Ponmudi Dam area, a tourist destination. During rain, waste reaches nearby river



Graph 8. Seasonal variation in Acidity across different transects in Munnar.

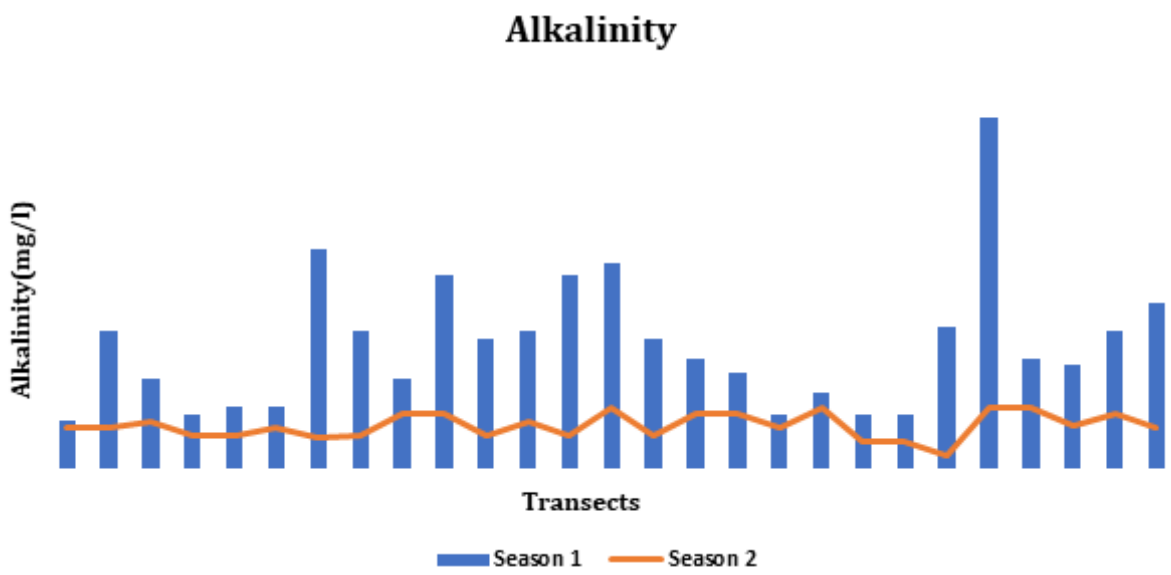
Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	5 ± 0	10 ± 0
2	Kuwait City	368 m	5 ± 0	10 ± 0
3	Kallarkutty	473 m	5 ± 0	17.5 ± 3.53
4	Padikappu	600 m	5 ± 0	12.5 ± 3.53
5	Chillithodu	612 m	5 ± 0	10 ± 0
6	Mankulam	701 m	5 ± 0	12.5 ± 3.53
7	Ambazhachal	713 m	5 ± 0	10 ± 0
8	Mankuzhi W.F	720 m	5 ± 0	10 ± 0
9	Ponmudi	720 m	5 ± 0	15 ± 0
10	Ellackal Bridge	723 m	5 ± 0	10 ± 0
11	Kunjithanny 1	771 m	5 ± 0	15 ± 0
12	Kunjithanny 2	778 m	5 ± 0	10 ± 0
13	Sengulam Dam	847 m	7.5 ± 3.53	10 ± 0
14	Muttukad P.F	954 m	5 ± 0	12.5 ± 3.53
15	Peechadu stream	987 m	5 ± 0	17.5 ± 3.53
16	Shanthanpara	1052 m	5 ± 0	10 ± 0
17	Pooppara	1104 m	5 ± 0	10 ± 0
18	Kainagiri	1175 m	5 ± 0	5 ± 0
19	Anayirangal	1206 m	5 ± 0	12.5± 3.53
20	Vaguvarei Estate	1400 m	6.25 ± 1.76	12.5 ± 3.53
21	Nallathanny Anthonniyar	1480 m	5 ± 0	15 ± 0
22	Nallathanny	1520 m	3.3 ± 0	12.5 ± 3.53
23	Vattavada Chilanthiyar	1552 m	5 ± 0	10 ± 0
24	Kundala dam	1602 m	5 ± 0	10 ± 7.07
25	Mattupetty	1602 m	5 ± 0	10 ± 0
26	Vattavada Keekarathodu	1629 m	5 ± 0	7.5 ± 3.53
27	Vattavada Umankadavu	1632 m	5 ± 0	10 ± 0

Table 11. Seasonal variation in Acidity (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.9 Alkalinity

Alkalinity is a measure of its capacity to neutralize acids, mainly due to the presence of bicarbonates, carbonates and hydroxides. The acceptable limit of alkalinity in water is 200mg/l as per BIS guidelines.

Alkalinity of the samples ranges from 17.5 ± 3.53 to 127.5 ± 24.7 during summer and from 5 ± 0 to 22.5 ± 3.53 during monsoon. In the present study, levels of alkalinity in all the samples were between the WHO prescribed guidelines (Graph 9, Table-12).



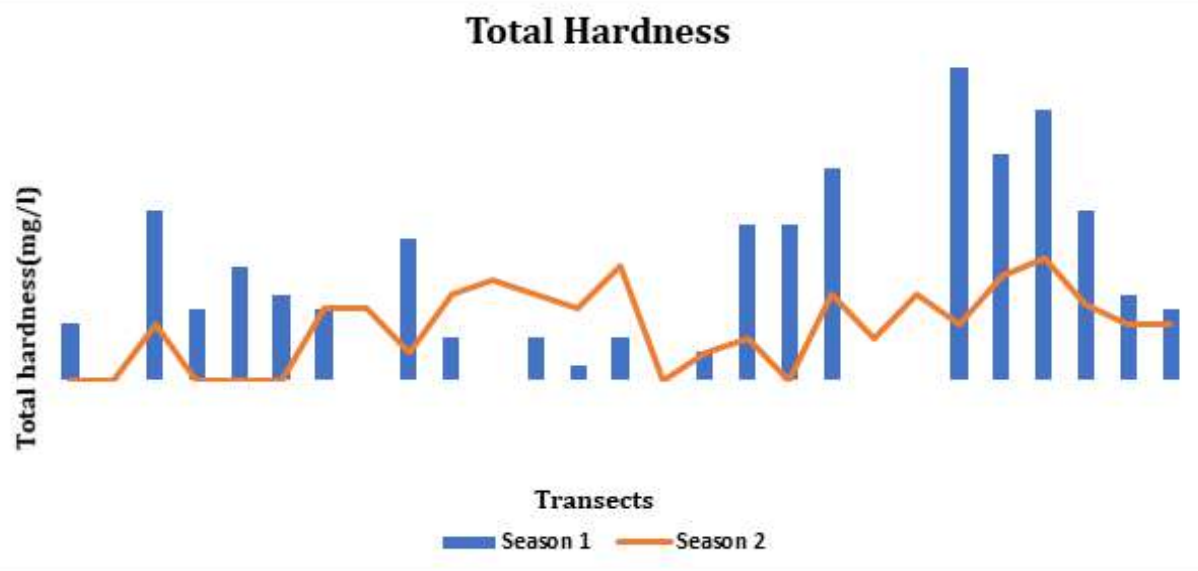
Graph 9. Seasonal variation in Alkalinity across different transects in Munnar.

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	17.5 ± 3.53	15 ± 0
2	Kuwait City	368 m	50 ± 0	15 ± 0
3	Kallarkutty	473 m	32.5 ± 3.53	17.5 ± 3.53
4	Padikappu	600 m	20 ± 0	12.5 ± 3.53
5	Chillithodu	612 m	22.5 ± 3.53	12.5 ± 3.53
6	Mankulam	701 m	22.5 ± 3.53	15 ± 0
7	Ambazhachal	713 m	80 ± 28.3	11.65 ± 2.3
8	Mankuzhi W.F	720 m	50 ± 0	12.5 ± 3.53
9	Ponmudi	720 m	32.5 ± 3.53	20 ± 0
10	Ellackal Bridge	723 m	70 ± 0	20 ± 0
11	Kunjithanny 1	771 m	47.5 ± 3.53	12.5 ± 3.53
12	Kunjithanny 2	778 m	50 ± 7.07	17.5 ± 10.6
13	Sengulam Dam	847 m	70 ± 7.07	12.5 ± 3.53
14	Muttukad P.F	954 m	75 ± 0	22.5 ± 3.53
15	Peechadu stream	987 m	47.5 ± 3.53	12.5 ± 3.53
16	Shanthanpara	1052 m	40 ± 0	20 ± 0
17	Pooppara	1104 m	35 ± 0	20 ± 0
18	Kainagiri	1175 m	20 ± 0	15 ± 0
19	Anayirangal	1206 m	27.5 ± 3.53	22.5 ± 3.53
20	Vaguvarei Estate	1400 m	20 ± 0	10 ± 0
21	Nallathanny Anthonniyar	1480 m	20 ± 0	10 ± 0
22	Nallathanny	1520 m	51.65 ± 2.33	5 ± 0
23	Vattavada Chilanthiyar	1552 m	127.5 ± 24.7	22.5± 3.53
24	Kundala dam	1602 m	40 ± 7.07	22.5 ± 3.53
25	Mattupetty	1602 m	37.5 ± 3.53	15.8 ± 1.13
26	Vattavada Keekarathodu	1629 m	50 ± 0	20 ± 0
27	Vattavada Umankadavu	1632 m	60 ± 7.07	15 ± 0

Table 12. Seasonal variation in Alkalinity (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.10 Total Hardness

Total hardness in water is the sum of the concentrations of calcium and magnesium, expressed in equivalent amounts of calcium carbonate. Total hardness is usually reported in terms of calcium carbonate concentration (mg/L as CaCO3). Desirable limit of total hardness as per BIS is 200 mg/l, which is obeyed by all water samples in Munnar (Graph.10, Table-13).



Graph 10. Seasonal variation in Total hardness across different transects in Munnar.

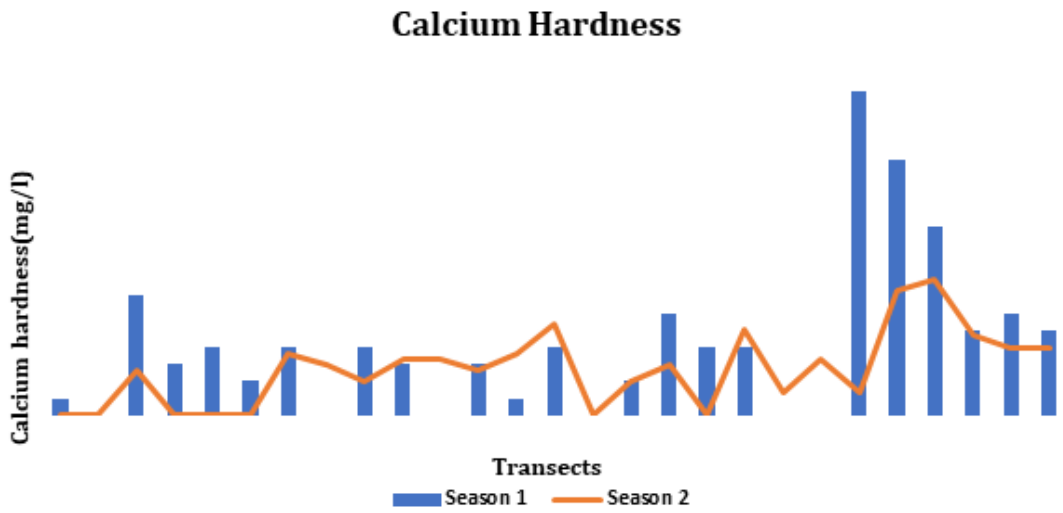
Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	10 ± 0	0 ± 0
2	Kuwait City	368 m	0 ± 0	0 ± 0
3	Kallarkutty	473 m	30 ± 0	10 ± 14.14
4	Padikappu	600 m	12.5 ± 3.53	0 ± 0
5	Chillithodu	612 m	20 ± 0	0 ± 0
6	Mankulam	701 m	15 ± 0	0 ± 0
7	Ambazhachal	713 m	12.5 ± 17.67	12.5± 3.53
8	Mankuzhi W.F	720 m	0 ± 0	12.5 ± 3.53
9	Ponmudi	720 m	25 ± 0	5 ± 7.07
10	Ellackal Bridge	723 m	7.5 ± 3.53	15 ± 7.07
11	Kunjithanny 1	771 m	0 ± 0	17.5 ± 3.53
12	Kunjithanny 2	778 m	7.5 ± 3.53	15 ± 0
13	Sengulam Dam	847 m	2.5 ± 3.53	12.5 ± 10.6
14	Muttukad P.F	954 m	7.5 ± 3.53	20 ± 0
15	Peechadu stream	987 m	0 ± 0	0 ± 0
16	Shanthanpara	1052 m	5 ± 0	5 ± 0
17	Pooppara	1104 m	27.5 ± 3.53	7.5 ± 3.53
18	Kainagiri	1175 m	27.5 ± 10.6	0 ± 0
19	Anayirangal	1206 m	37.5 ± 17.67	15 ± 0
20	Vaguvarei Estate	1400 m	0 ± 0	7.5 ± 3.53
21	Nallathanny Anthonniyar	1480 m	0 ± 0	15 ± 0

22	Nallathanny	1520 m	55 ± 0	10 ± 0
23	Vattavada Chilanthiyar	1552 m	40 ± 7.07	18.3 ± 2.4
24	Kundala dam	1602 m	47.5 ± 3.53	21.65 ± 2.3
25	Mattupetty	1602 m	30 ± 7.07	13.3 ± 4.6
26	Vattavada Keekarathodu	1629 m	15 ± 0	9.95 ± 4.7
27	Vattavada Umankadavu	1632 m	12.5 ± 3.53	9.95 ± 4.7

Table 13. Seasonal variation in Total hardness (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.11 Calcium Hardness

Calcium hardness is a measure of the level of calcium ions (Ca2+) in water. High levels of calcium hardness can lead to scaling, which can clog pipes and equipment, while low levels can lead to corrosion. According to WHO, the desirable limit for calcium hardness in water is 75 mg/l. The collected water samples showed calcium hardness values within the permissible limit, ranging from 0 - 47.5 mg/l during summer and 0-20mg/l during the monsoon (Table-14). Water from areas with low mineral deposits have very low or undetectable levels of calcium.



Graph 11. Seasonal variation in Calcium hardness across different transects in Munnar.

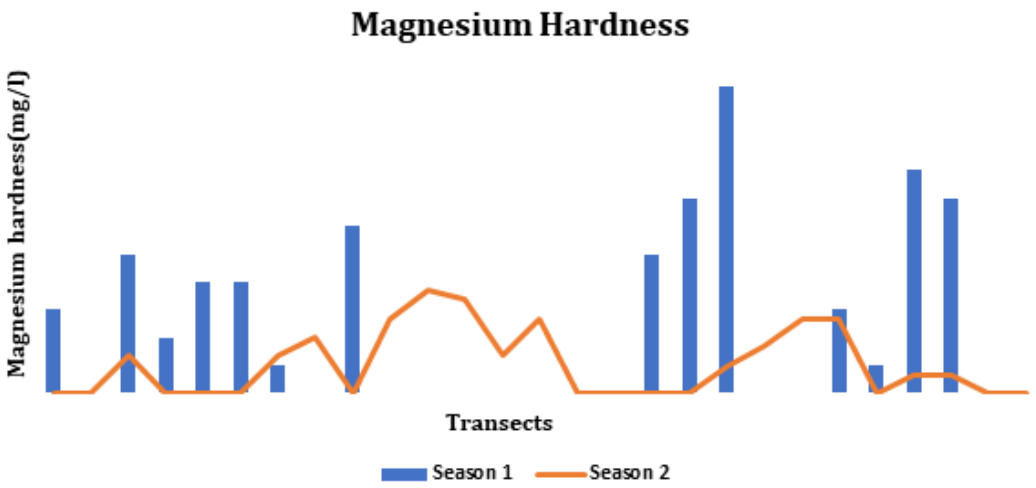
Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	2.5 ± 3.53	0 ± 0
2	Kuwait City	368 m	0 ± 0	0 ± 0
3	Kallarkutty	473 m	17.5 ± 3.53	6.65 ± 9.4
4	Padikappu	600 m	7.5 ± 3.53	0 ± 0
5	Chillithodu	612 m	10 ± 0	0 ± 0
6	Mankulam	701 m	5 ± 0	0 ± 0
7	Ambazhachal	713 m	10 ± 14.14	9.15 ± 5.9
8	Mankuzhi W.F	720 m	0 ± 0	7.5 ± 3.53
9	Ponmudi	720 m	10 ± 0	5 ± 7.07
10	Ellackal Bridge	723 m	7.5 ± 3.53	8.3 ± 2.4
11	Kunjithanny 1	771 m	0 ± 0	8.3 ± 2.4

12	Kunjithanny 2	778 m	7.5 ± 3.53	6.6 ± 0
13	Sengulam Dam	847 m	2.5 ± 3.53	9.15 ± 5.9
14	Muttukad P.F	954 m	10 ± 0	13.3 ± 0
15	Peechadu stream	987 m	0 ± 0	0 ± 0
16	Shanthanpara	1052 m	5 ± 0	5 ± 0
17	Pooppara	1104 m	15 ± 0	7.5 ± 3.53
18	Kainagiri	1175 m	10 ± 0	0 ± 0
19	Anayirangal	1206 m	10 ± 0	12.5 ± 3.53
20	Vaguvarei Estate	1400 m	0 ± 0	3.3 ± 0
21	Nallathanny Anthonniyar	1480 m	0 ± 0	8.3 ± 2.4
22	Nallathanny	1520 m	47.5 ± 3.53	3.3 ± 0
23	Vattavada Chilanthiyar	1552 m	37.5 ± 10.6	18.3 ± 2.4
24	Kundala dam	1602 m	27.5 ± 3.53	20 ± 0
25	Mattupetty	1602 m	12.5 ± 3.53	11.65 ± 2.3
26	Vattavada Keekarathodu	1629 m	15 ± 0	9.95 ± 4.7
27	Vattavada Umankadavu	1632 m	12.5 ± 3.53	9.95 ± 4.7

Table 14. Seasonal variation in Calcium hardness (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.12 Magnesium Hardness

Hard water contains a lot of minerals. It is created when water seeps through the deposits of chalk and limestone, which are made up of magnesium and calcium carbonates. Hardness caused by magnesium is called magnesium hardness. The acceptable limit of Mg in water is 30mg/l (APHA 3500 B). In the table 15 (Graph.12) we can see that all the values of Mg falls under the desirable limit.



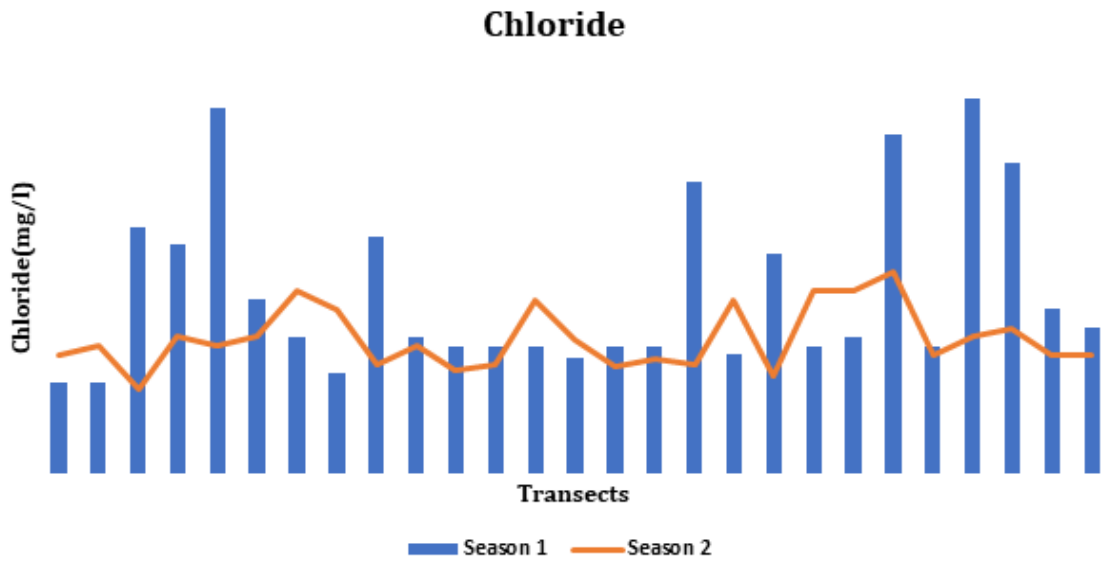
Graph 12. Seasonal variation in Magnesium hardness across different transects in Munnar.

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	7.5 ± 3.53	0 ± 0
2	Kuwait City	368 m	0 ± 0	0 ± 0
3	Kallarkutty	473 m	12.5 ± 3.53	3.35 ± 4.7
4	Padikappu	600 m	5 ± 7.07	0 ± 0
5	Chillithodu	612 m	10 ± 0	0 ± 0
6	Mankulam	701 m	10 ± 0	0 ± 0
7	Ambazhachal	713 m	2.5 ± 3.53	3.35 ± 2.3
8	Mankuzhi W.F	720 m	0 ± 0	5 ± 0
9	Ponmudi	720 m	15 ± 0	0 ± 0
10	Ellackal Bridge	723 m	0 ± 0	6.7 ± 4.6
11	Kunjithanny 1	771 m	0 ± 0	9.2 ± 5.9
12	Kunjithanny 2	778 m	0 ± 0	8.4 ± 0
13	Sengulam Dam	847 m	0 ± 0	3.35 ± 4.7
14	Muttukad P.F	954 m	0 ± 0	6.7 ± 0
15	Peechadu stream	987 m	0 ± 0	0 ± 0
16	Shanthanpara	1052 m	0 ± 0	0 ± 0
17	Pooppara	1104 m	12.5 ± 3.53	0 ± 0
18	Kainagiri	1175 m	17.5 ± 10.6	0 ± 0
19	Anayirangal	1206 m	27.5 ± 17.67	2.5 ± 3.53
20	Vaguvarei Estate	1400 m	0 ± 0	4.2 ± 3.53
21	Nallathanny Anthonniyar	1480 m	0 ± 0	6.7 ± 2.4
22	Nallathanny	1520 m	7.5 ± 3.53	6.7 ± 0
23	Vattavada Chilanthiyar	1552 m	2.5 ± 3.53	0 ± 0
24	Kundala dam	1602 m	20 ± 7.07	1.65 ± 2.3
25	Mattupetty	1602 m	17.5 ± 10.6	1.65 ± 2.3
26	Vattavada Keekarathodu	1629 m	0 ± 0	0 ± 0
27	Vattavada Umankadavu	1632 m	0 ± 0	0 ± 0

Table 15. Seasonal variation in Magnesium hardness (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.13 Chloride

A naturally occurring ion that dissolves in water is chloride. Atoms or molecules with a positive or negative charge are called ions. A common metric for determining salinity, or how salty water is, is chloride. But other ions including calcium, magnesium, sodium, potassium, carbonate, and bicarbonate also have an impact on salinity. Both natural and man-made sources contribute to chloride presence in water. Natural sources include the weathering of rocks and soils. Man-made sources, such as road salts, industrial and municipal wastewater and agricultural inputs also add chloride levels in water. The upper limit of chloride (as Cl^-) concentrations in freshwater is considered to be 250 mg/L. According to table 12, chloride levels range between 17.66 ± 1.61 - 72.75 ± 2.47 during summer and 16.6 ± 0 - 39.05 ± 5.02 during the monsoon season (Graph.13, Table-16). Excessive levels of chloride in freshwater can be harmful to both plants and animals. Chloride does not breakdown. Therefore, it will be more difficult for plants, insects and fish that are adapted to freshwater conditions to survive if there is a constant flow of chloride into a river or lake and not enough water to dilute it.



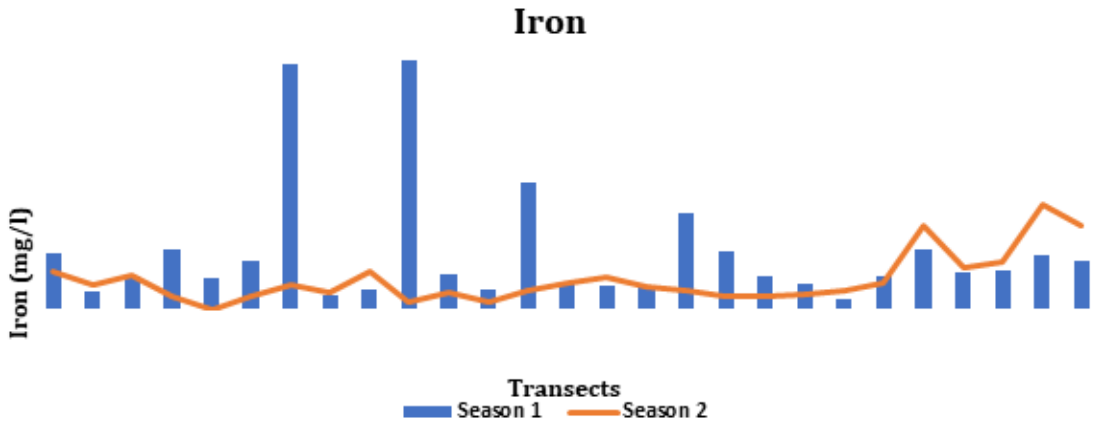
Graph 13. Seasonal variation in Chloride across different transects in Munnar.

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	17.75 ± 5.02	23.05 ± 7.56
2	Kuwait City	368 m	17.66 ± 1.61	24.8 ± 0
3	Kallarkutty	473 m	47.925 ± 7.53	16.6 ± 0
4	Padikappu	600 m	44.375 ± 27.61	26.6 ± 7.5
5	Chillithodu	612 m	71 ± 10.04	24.8 ± 0
6	Mankulam	701 m	33.725 ± 2.51	26.6 ± 2.54
7	Ambazhachal	713 m	26.625 ± 2.51	35.52 ± 4.98
8	Mankuzhi W.F	720 m	19.525 ± 2.51	32 ± 0
9	Ponmudi	720 m	46.15 ± 5.02	21.3 ± 0
10	Ellackal Bridge	723 m	26.625 ± 2.51	24.8 ± 1.7
11	Kunjithanny 1	771 m	24.78 ± 1.67	20.1 ± 1.7
12	Kunjithanny 2	778 m	24.85 ± 0	21.3 ± 0
13	Sengulam Dam	847 m	24.85 ± 5.02	33.75 ± 2.5
14	Muttukad P.F	954 m	22.42 ± 1.67	26.03 ± 0
15	Peechadu stream	987 m	24.8 ± 0	20.7 ± 5.8
16	Shanthanpara	1052 m	24.85 ± 0	22.46 ± 5.04
17	Pooppara	1104 m	56.61 ± 25.3	21.3 ± 0
18	Kainagiri	1175 m	23.075 ± 2.51	33.7 ± 2.54
19	Anayirangal	1206 m	42.6 ± 5.02	18.9 ± 0
20	Vaguvarei Estate	1400 m	24.85 ± 5.02	35.5 ± 0
21	Nallathanny Anthonniyar	1480 m	26.625 ± 2.51	35.5 ± 20.08
22	Nallathanny	1520 m	65.675 ± 2.51	39.05 ± 5.02
23	Vattavada Chilanthiyar	1552 m	24.85 ± 0	23.05 ± 2.5
24	Kundala dam	1602 m	72.75 ± 2.47	26.6 ± 2.5
25	Mattupetty	1602 m	60.35 ± 5.02	28.35 ± 5.02
26	Vattavada Keekarathodu	1629 m	31.95 ± 0	23.05 ± 2.5
27	Vattavada Umankadavu	1632 m	28.4 ± 5.02	23.05 ± 2.5

Table 16. Seasonal variation in Chloride (mean ± SD) of freshwater bodies in Munnar

3.14 Iron

Iron is an essential trace element for both plants and animals, required by most organisms for essential growth and development, and iron deficiency could cause adverse biological effects. However, acute toxicity to aquatic insects has been reported at iron concentrations ranging from 320 to 16,000 µg/L (Warnick & Bell 1969). Season 1 consistently shows higher iron concentrations compared to Season 2 for most transects. The recommended level of iron in water is less than 0.3 mg/l. For season 1(summer), the iron concentration ranges between 0.024 ± 0.034 and 0.595 ± 0.007, while for season 2 (monsoon), it ranges between 0 ± 0 and 0.25 ± 0.07(Graph.14, Table 17). This suggests seasonal factors such as lower water levels and higher sediment deposition in summer, contribute to poorer water quality. In contrast, the improvement in water quality during the monsoon season is due to the dilution effect from rainfall. As a limiting nutrient for phytoplankton growth, especially in iron-deficient environments, iron is essential to freshwater ecosystems. However, high concentrations of iron can be toxic to aquatic life, and its availability is greatly influenced by redox potential, pH, and the presence of organic matter.



Graph 14. Seasonal variation in Iron concentration across different transects in Munnar.(transect-wise).

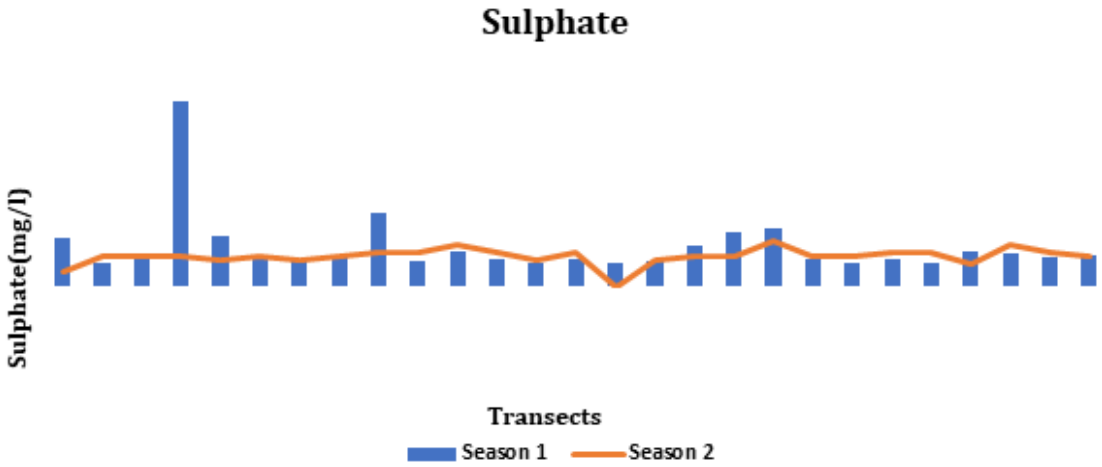
Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	0.1315 ± 0.007	0.09 ± 0
2	Kuwait City	368 m	0.04 ± 0.014	0.06 ± 0.04
3	Kallarkutty	473 m	0.0785 ± 0.012	0.08 ± 0.03
4	Padikappu	600 m	0.145 ± 0.035	0.03 ± 0
5	Chillithodu	612 m	0.075 ± 0.007	0 ± 0
6	Mankulam	701 m	0.115 ± 0.015	0.03 ± 0
7	Ambazhachal	713 m	0.585 ± 0.007	0.06 ± 0.014
8	Mankuzhi W.F	720 m	0.035 ± 0.007	0.04 ± 0.014
9	Ponmudi	720 m	0.0455 ± 0.003	0.09 ± 0.014
10	Ellackal Bridge	723 m	0.595 ± 0.007	0.015 ± 0.02
11	Kunjithanny 1	771 m	0.085 ± 0.064	0.04 ± 0.014
12	Kunjithanny 2	778 m	0.045 ± 0.007	0.015 ± 0.02
13	Sengulam Dam	847 m	0.305 ± 0.375	0.045 ± 0.02
14	Muttukad P.F	954 m	0.06 ± 0.014	0.065 ± 0.007
15	Peechadu stream	987 m	0.055 ± 0.007	0.075 ± 0.007
16	Shanthanpara	1052 m	0.05 ± 0	0.055 ± 0.02
17	Pooppara	1104 m	0.2285 ± 0.027	0.045 ± 0.007
18	Kainagiri	1175 m	0.137 ± 0.015	0.03 ± 0

19	Anayirangal	1206 m	0.081 ± 0	0.03 ± 0
20	Vaguvarei Estate	1400 m	0.0585 ± 0.03	0.035 ± 0.007
21	Nallathanny Anthonniyar	1480 m	0.024 ± 0.034	0.045 ± 0.007
22	Nallathanny	1520 m	0.0785 ± 0.012	0.065 ± 0.02
23	Vattavada Chilanthiyar	1552 m	0.1445 ± 0.02	0.2 ± 0
24	Kundala dam	1602 m	0.0895 ± 0.012	0.1 ± 0
25	Mattupetty	1602 m	0.093 ± 0	0.115 ± 0.02
26	Vattavada Keekarathodu	1629 m	0.13 ± 0	0.25 ± 0.07
27	Vattavada Umankadavu	1632 m	0.115 ± 0.007	0.2 ± 0

Table 17. Seasonal variation in Iron concentration (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.15 Sulphate

Particularly in soft waters with low calcium and magnesium concentrations, high sulphate levels can harm aquatic life by causing osmotic stress, affecting the availability of vital metals for plants, and possibly resulting in the death of invertebrates and other organisms. This can upset the ecosystem's equilibrium by changing the carbon, nitrogen, and phosphorus biogeochemical cycles. When sulphate content in water surpasses 250 mg/l, it imparts a medicinal or bitter flavour. SO4 was recorded at a range between 0.3045 ± 0.006 - 2.421 ± 1.23 during the summer and 0 ± 0 - 0.55 ± 0.21 during the monsoon as shown in the table-18 (Graph.15).



Graph 15. Seasonal variation in Sulphate across different transects in Munnar.

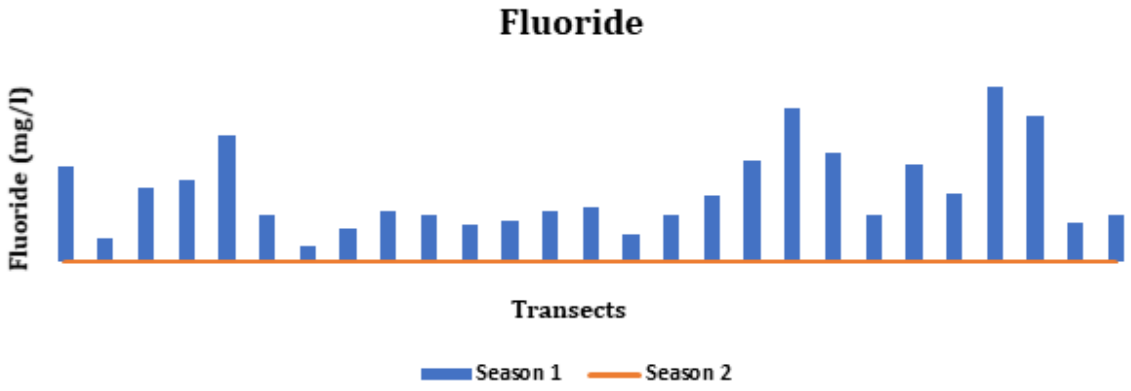
Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	0.6355 ± 0.08	0.2 ± 0.3
2	Kuwait City	368 m	0.307 ± 0.02	0.4 ± 0.14
3	Kallarkutty	473 m	0.383 ± 0.03	0.4 ± 0.14
4	Padikappu	600 m	2.421 ± 1.23	0.4 ± 0.14
5	Chillithodu	612 m	0.6505 ± 0.03	0.35 ± 0.07
6	Mankulam	701 m	0.3685 ± 0.12	0.4 ± 0
7	Ambazhachal	713 m	0.325 ± 0.05	0.35 ± 0.07
8	Mankuzhi W.F	720 m	0.375 ± 0.02	0.4 ± 0
9	Ponmudi	720 m	0.9595 ± 0.85	0.45 ± 0.07
10	Ellackal Bridge	723 m	0.3425 ± 0.08	0.45 ± 0.07
11	Kunjithanny 1	771 m	0.4645 ± 0.22	0.55 ± 0.21

12	Kunjithanny 2	778 m	0.365 ± 0.03	0.45 ± 0.21
13	Sengulam Dam	847 m	0.309 ± 0	0.35 ± 0.07
14	Muttukad P.F	954 m	0.36 ± 0.01	0.45 ± 0.21
15	Peechadu stream	987 m	0.3195 ± 0.01	0 ± 0
16	Shanthanpara	1052 m	0.33 ± 0	0.35 ± 0.07
17	Pooppara	1104 m	0.5245 ± 0.05	0.4 ± 0
18	Kainagiri	1175 m	0.706 ± 0.09	0.4 ± 0
19	Anayirangal	1206 m	0.762 ± 0.58	0.6 ± 0
20	Vaguvarei Estate	1400 m	0.35 ± 0.01	0.4 ± 0
21	Nallathanny Anthonniyar	1480 m	0.3045 ± 0.006	0.4 ± 0.14
22	Nallathanny	1520 m	0.35 ± 0.04	0.45 ± 0.07
23	Vattavada Chilanthiyar	1552 m	0.32 ± 0.03	0.45 ± 0.07
24	Kundala dam	1602 m	0.4725 ± 0.01	0.3 ± 0
25	Mattupetty	1602 m	0.428 ± 0	0.55 ± 0.21
26	Vattavada Keekarathodu	1629 m	0.38 ± 0	0.45 ± 0.07
27	Vattavada Umankadavu	1632 m	0.405 ± 0.03	0.4 ± 0

Table 18. Seasonal variation in Sulphate (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.16 Fluoride

Fluoride is one of the parameters which is non-degradable and naturally occurring inorganic anion found in many natural streams, lakes, and groundwater. There are several natural sources of fluoride, but it mostly comes from rocks, minerals, and volcanic activity. Fluoride is found in high concentrations in minerals like apatite ($Ca_5(PO_4)_3F$) and fluorite (CaF_2). These minerals contribute to the fluoride found in soil, water, and sediments by releasing it into the environment through weathering and erosion processes. As per BIS, the Permissible Limit of Fluoride in the absence of alternate sources is 1 mg/l. During the summer season, fluoride concentrations were within the range of 0.1395 ± 0.18 mg/l to 1.599 ± 0.039mg/l, with some locations nearing or exceeding the permissible limit of 1 mg/l. In the monsoon season, fluoride concentrations dropped below the detection limit, represented as 0 mg/l for graphical and comparative purposes (Graph.16, Table 19). Fluoride levels during monsoon season dropped significantly due to dilution from increased rainfall, making the concentrations negligible or undetectable. The ecosystem may be negatively impacted by environmental fluoride contamination. Higher fluoride concentrations in water bodies are especially harmful to aquatic life. According to a study by Wang et al. (2018), fish species' growth and survival were impacted by high fluoride levels, which resulted in population decreases and disturbed aquatic ecosystems.



Graph 16. Seasonal variation in Fluoride across different transects in Munnar.

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	0.8775 ± 0.379	0 ± 0
2	Kuwait City	368 m	0.207 ± 0.025	0 ± 0
3	Kallarkutty	473 m	0.667 ± 0.201	0 ± 0
4	Padikappu	600 m	0.753 ± 0.694	0 ± 0
5	Chillithodu	612 m	1.148 ± 0.005	0 ± 0
6	Mankulam	701 m	0.434 ± 0.247	0 ± 0
7	Ambazhachal	713 m	0.1395 ± 0.18	0 ± 0
8	Mankuzhi W.F	720 m	0.31 ± 0.056	0 ± 0
9	Ponmudi	720 m	0.458 ± 0.011	0 ± 0
10	Ellackal Bridge	723 m	0.418 ± 0.017	0 ± 0
11	Kunjithanny 1	771 m	0.33 ± 0.226	0 ± 0
12	Kunjithanny 2	778 m	0.3655 ± 0.147	0 ± 0
13	Sengulam Dam	847 m	0.4565 ± 0.344	0 ± 0
14	Muttukad P.F	954 m	0.505 ± 0.106	0 ± 0
15	Peechadu stream	987 m	0.2575 ± 0.046	0 ± 0
16	Shanthanpara	1052 m	0.418 ± 0	0 ± 0
17	Pooppara	1104 m	0.6125 ± 0.76	0 ± 0
18	Kainagiri	1175 m	0.923 ± 0.424	0 ± 0
19	Anayirangal	1206 m	1.403 ± 0.322	0 ± 0
20	Vaguvarei Estate	1400 m	0.985 ± 0.092	0 ± 0
21	Nallathanny Anthonniyar	1480 m	0.42 ± 0.07	0 ± 0
22	Nallathanny	1520 m	0.8935 ± 0.698	0 ± 0
23	Vattavada Chilanthiyar	1552 m	0.619 ± 0.03	0 ± 0
24	Kundala dam	1602 m	1.599 ± 0.039	0 ± 0
25	Mattupetty	1602 m	1.326 ± 0.092	0 ± 0
26	Vattavada Keekarathodu	1629 m	0.35 ± 0	0 ± 0
27	Vattavada Umankadavu	1632 m	0.429 ± 0.015	0 ± 0

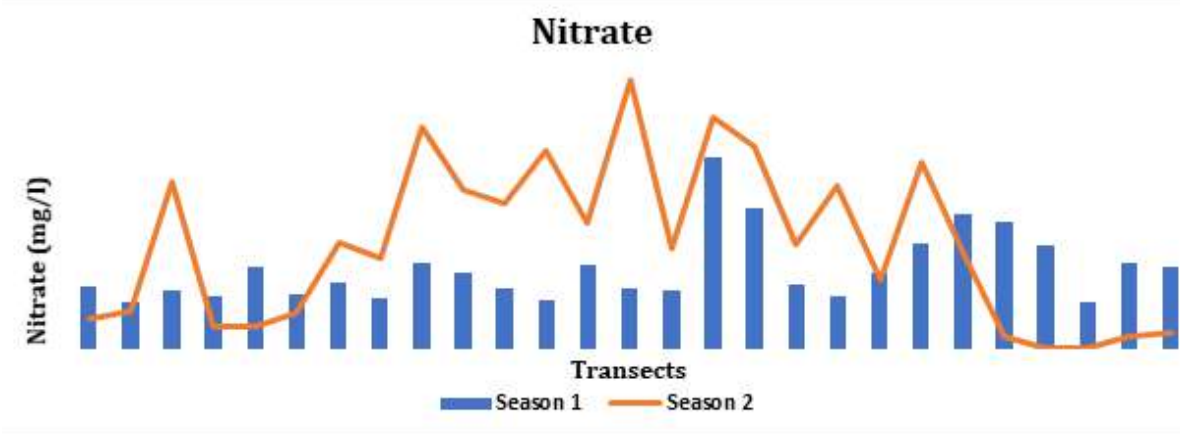
Table 19. : Seasonal variation in Fluoride (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.17 Nitrate

In a water environment, nitrate exhibits stable features, high solubility, and ease of migration. The impact of human activities (such as excessive use of agricultural chemical fertilizer, inadequate sewage discharge, landfill leakage, chemical fuel leakage, and so forth) on the river and groundwater environment has increased in recent years due to the acceleration of urbanization, industrialization, and population growth. As a result, the nitrate concentration in freshwater has been rising annually (Jin et al., 2015), (Meghdadi and Javar, 2018), (Onodera et al., 2020).

According to BIS guidelines, the acceptable limit for nitrate in river water is 45 mg/l. The nitrate levels remain under control across both seasons, suggesting that seasonal variations such as rainfall and temperature have not significantly influenced nitrate pollution (Graph.17, Table 20).

Figure 17. Cardamom plantation



Graph 17. Seasonal variation in Nitrate across different transects in Munnar.

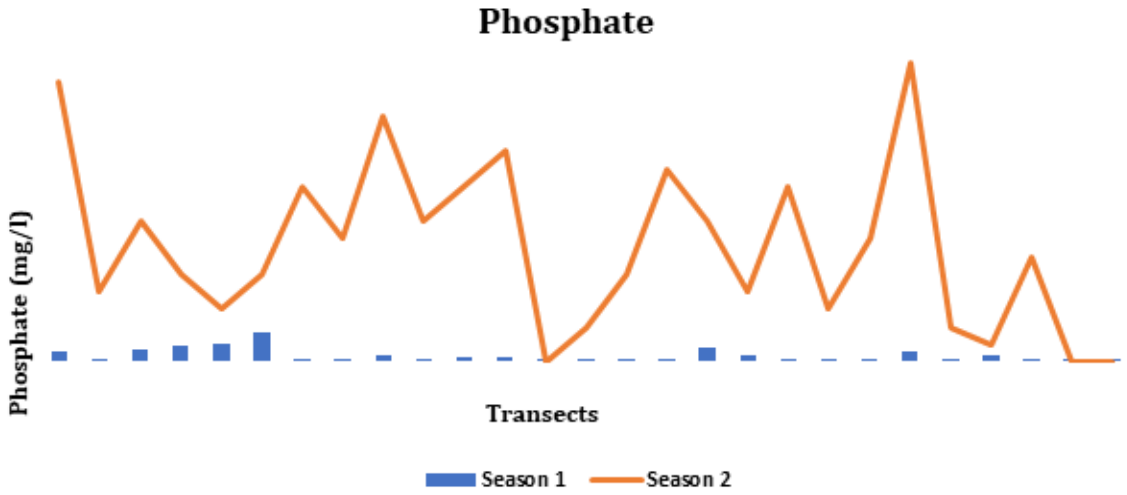
Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	1.663 ± 0.745	0.8 ± 0.14
2	Kuwait City	368 m	1.25 ± 0.014	1 ± 0.3
3	Kallarkutty	473 m	1.545 ± 0.162	4.45 ± 0.2
4	Padikappu	600 m	1.415 ± 0.176	0.6 ± 0.3
5	Chillithodu	612 m	2.19 ± 0	0.6 ± 0.3
6	Mankulam	701 m	1.435 ± 0.304	0.95 ± 0.5
7	Ambazhachal	713 m	1.76 ± 0.551	2.85 ± 0.7
8	Mankuzhi W.F	720 m	1.35 ± 0	2.4 ± 0.4
9	Ponmudi	720 m	2.26 ± 0.24	5.95 ± 0.2
10	Ellackal Bridge	723 m	2 ± 0.085	4.25 ± 0.07
11	Kunjithanny 1	771 m	1.6 ± 0.254	3.9 ± 0.8
12	Kunjithanny 2	778 m	1.305 ± 0.007	5.3 ± 0.3
13	Sengulam Dam	847 m	2.21 ± 0.042	3.35 ± 1.34
14	Muttukad P.F	954 m	1.58 ± 0.113	7.2 ± 0
15	Peechadu stream	987 m	1.565 ± 0.12	2.7 ± 0
16	Shanthanpara	1052 m	5.13 ± 0	6.2 ± 0.3
17	Pooppara	1104 m	3.78 ± 0.085	5.4 ± 0.14
18	Kainagiri	1175 m	1.69 ± 0.268	2.81 ± 0.3
19	Anayirangal	1206 m	1.395 ± 0.15	4.35 ± 0.07
20	Vaguvarei Estate	1400 m	2.05 ± 2.33	1.85 ± 1.9
21	Nallathanny Anthonniyar	1480 m	2.81 ± 0.014	5 ± 0
22	Nallathanny	1520 m	3.5935 ± 2.024	2.55 ± 1.2
23	Vattavada Chilanthiyar	1552 m	3.38 ± 0.17	0.3 ± 0.2
24	Kundala dam	1602 m	2.74 ± 0.18	0 ± 0
25	Mattupetty	1602 m	1.22 ± 0.27	0 ± 0
26	Vattavada Keekarathodu	1629 m	2.29 ± 0	0.32 ± 0.03
27	Vattavada Umankadavu	1632 m	2.18 ± 0.212	0.425 ± 0.03

Table 20. Seasonal variation in Nitrate (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.18 Phosphate

Phosphates, chemical compounds containing the phosphate ion (PO_4^{3}), are essential for a variety of biological processes and are frequently found in fertilizers for plants. But the introduction of phosphates into aquatic environments, mostly via sewage discharge, industrial effluents, and agricultural runoff, has grown to be a serious environmental issue (Bhateria and Jain, 2016), (Nieder et al.,2018). Since phosphate is one of the main nutrients for aquatic plants, its concentration in natural water has been utilized as a water quality indicator. Desirable limit of phosphate as per WHO is 0.1 mg/l. In summer season, lower runoff, reduced erosion and higher evaporation generally result in lower phosphate concentration ranging from 0.001 ± 0 to 0.0855 ± 0.005. However, in season 2, values ranging from 0 ± 0 to 0.85 ± 0.77 reflect increased variability due to factors such as runoff, soil erosion, decaying organic matter, wastewater inflow and leaching. Lack of phosphorus frequently restricts the growth of life in aquatic systems. On the other hand, too much phosphorus is typically seen as a contaminant.

Figure 18. A paddy field at Muttukad



Graph 18. Seasonal variation in Phosphate across different transects in Munnar.

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	0.0299 ± 0.041	0.8 ± 0
2	Kuwait City	368 m	0.0095 ± 0.0007	0.2 ± 0
3	Kallarkutty	473 m	0.0335 ± 0.047	0.4 ± 0.14
4	Padikappu	600 m	0.0475 ± 0.02	0.25 ± 0.07
5	Chillithodu	612 m	0.052 ± 0.041	0.15 ± 0.07
6	Mankulam	701 m	0.0855 ± 0.005	0.25 ± 0.07
7	Ambazhachal	713 m	0.004 ± 0.001	0.5 ± 0.14

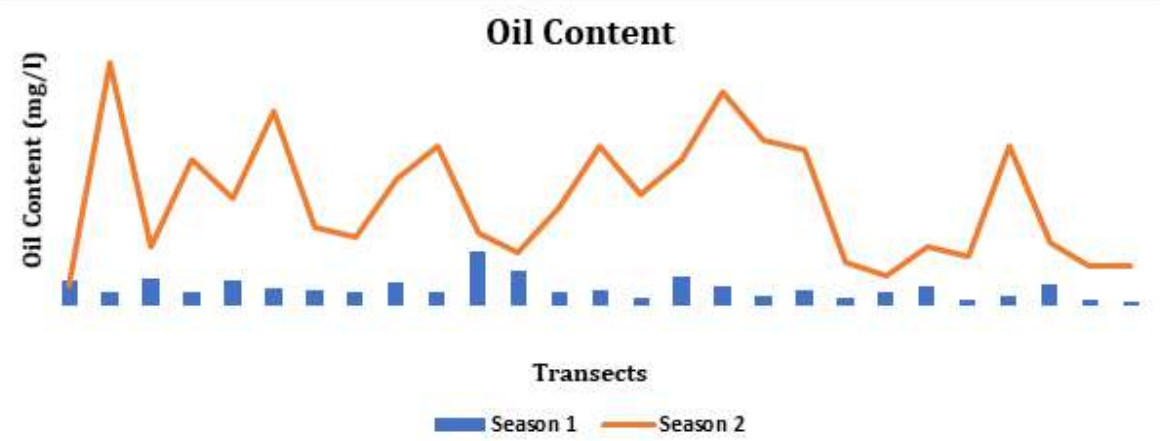
8	Mankuzhi W.F	720 m	0.0085 ± 0.006	0.35 ± 0.07
9	Ponmudi	720 m	0.021 ± 0.013	0.7 ± 0.14
10	Ellackal Bridge	723 m	0.0065 ± 0.003	0.4 ± 0
11	Kunjithanny 1	771 m	0.016 ± 0.017	0.5 ± 0.3
12	Kunjithanny 2	778 m	0.0125 ± 0.003	0.6 ± 0
13	Sengulam Dam	847 m	0.006 ± 0.005	0 ± 0
14	Muttukad P.F	954 m	0.01 ± 0.003	0.1 ± 0.14
15	Peechadu stream	987 m	0.001 ± 0	0.25 ± 0.07
16	Shanthanpara	1052 m	0.006 ± 0	0.55 ± 0.35
17	Pooppara	1104 m	0.042 ± 0.04	0.4 ± 0.14
18	Kainagiri	1175 m	0.018 ± 0.025	0.2 ± 0
19	Anayirangal	1206 m	0.009 ± 0.007	0.5 ± 0
20	Vaguvarei Estate	1400 m	0.0075 ± 0.002	0.15 ± 0.2
21	Nallathanny Anthonniyar	1480 m	0.007 ± 0.001	0.35 ± 0.5
22	Nallathanny	1520 m	0.0315 ± 0.013	0.85 ± 0.77
23	Vattavada Chilanthiyar	1552 m	0.003 ± 0.003	0.1 ± 0.14
24	Kundala dam	1602 m	0.021 ± 0.027	0.05 ± 0.07
25	Mattupetty	1602 m	0.0032 ± 0.004	0.3 ± 0
26	Vattavada Keekarathodu	1629 m	0.002 ± 0	0 ± 0
27	Vattavada Umankadavu	1632 m	0.001 ± 0	0 ± 0

Table 21. Seasonal variation in Phosphate (mean ± SD) of freshwater bodies in Munnar (transect-wise

3.19 Oil Content

Even minute amounts of oil can have a negative impact on freshwater organisms like fish, amphibians, insects, and plants. Oil contamination in freshwater ecosystems, usually from spills, is regarded as a serious contaminant that can seriously damage aquatic life by coating the water surface, affecting organisms directly through contact, upsetting the food chain, and harming sensitive habitats like marshes and shoreline vegetation, ultimately affecting the entire ecosystem balance. To ensure sustainable water management and preserve ecological balance, it is essential to analyse the oil content of water. According to the Indian drinking water standards (IS 10500:2012-2nd revision), the permissible limit of mineral oil in drinking water is 0.5mg/L. According to most environmental standards, the permissible limit of oil and grease in river water is typically considered to be <10 mg/L. The water samples showed oil content within the permissible limits, ranging from 0.0025 ± 0.003 - 0.055 ± 0.021mg/l and from 0.02 ± 0.014 - 0.25 ± 0.07mg/l in both summer and monsoon seasons (Graph.19, Table-22).

Figure 19. A rivulet in Munnar town



Graph 19. Seasonal variation in Oil content across different transects in Munnar.

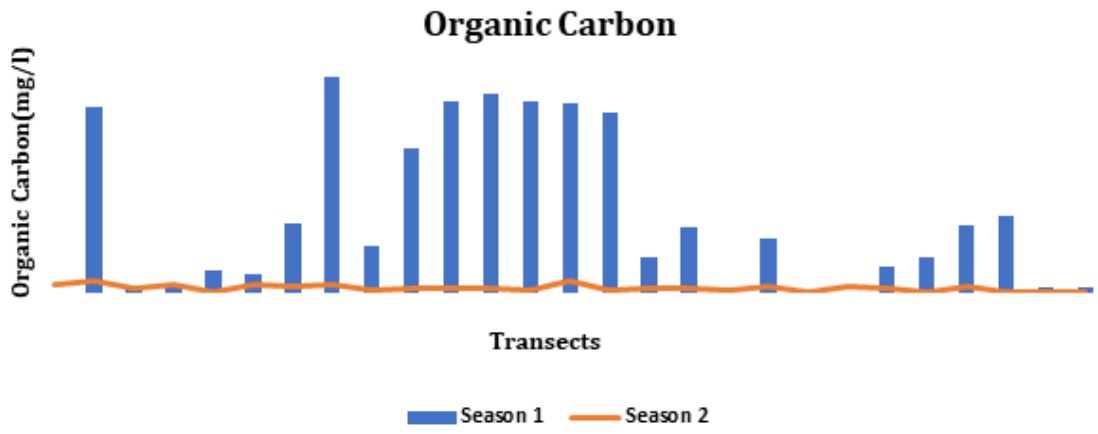
Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	0.026 ± 0.009	0.02 ± 0.014
2	Kuwait City	368 m	0.0125 ± 0.01	0.25 ± 0.07
3	Kallarkutty	473 m	0.027 ± 0.008	0.06 ± 0.03
4	Padikappu	600 m	0.0125 ± 0.003	0.15 ± 0.07
5	Chillithodu	612 m	0.026 ± 0.009	0.11 ± 0.13
6	Mankulam	701 m	0.0175 ± 0.003	0.2 ± 0
7	Ambazhachal	713 m	0.015 ± 0.007	0.08 ± 0.01
8	Mankuzhi W.F	720 m	0.0125 ± 0.01	0.07 ± 0.01
9	Ponmudi	720 m	0.023 ± 0.003	0.13 ± 0.04
10	Ellackal Bridge	723 m	0.0125 ± 0.01	0.165 ± 0.2
11	Kunjithanny 1	771 m	0.055 ± 0.021	0.075 ± 0.03
12	Kunjithanny 2	778 m	0.035 ± 0.035	0.055 ± 0.007
13	Sengulam Dam	847 m	0.0125 ± 0.003	0.1 ± 0
14	Muttukad P.F	954 m	0.015 ± 0.007	0.165 ± 0.12
15	Peechadu stream	987 m	0.0075 ± 0.003	0.115 ± 0.12
16	Shanthanpara	1052 m	0.03 ± 0	0.15 ± 0.07
17	Pooppara	1104 m	0.019 ± 0.003	0.22 ± 0.11
18	Kainagiri	1175 m	0.01 ± 0.004	0.17 ± 0.2
19	Anayirangal	1206 m	0.015 ± 0	0.16 ± 0.05
20	Vaguvarei Estate	1400 m	0.0075 ± 0.003	0.045 ± 0.007
21	Nallathanny Anthonniyar	1480 m	0.0125 ± 0.003	0.03 ± 0
22	Nallathanny	1520 m	0.02 ± 0.007	0.06 ± 0.05
23	Vattavada Chilanthiyar	1552 m	0.005 ± 0.007	0.05 ± 0.014
24	Kundala dam	1602 m	0.0095 ± 0.006	0.165 ± 0.05
25	Mattupetty	1602 m	0.022 ± 0.004	0.065 ± 0.02
26	Vattavada Keekarathodu	1629 m	0.005 ± 0	0.04 ± 0
27	Vattavada Umankadavu	1632 m	0.0025 ± 0.003	0.04 ± 0

Table 22. Seasonal variation in Oil content (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.20 Organic Carbon

Total Organic Carbon is a measure of the total amount of carbon in organic compounds in pure water and aqueous systems. All of the visible and invisible organic molecules dissolved in water, including wastewater, municipal water, and water used to make semiconductors, food and beverage goods, and medications, can be identified by measuring TOC. The world Health Organization (WHO) and the Bureau of Indian Standards (BIS) do not specify an exact limit for TOC. Natural water bodies usually have TOC levels ranging from 1 to 10 mg/l depending on organic matter and pollution levels. The organic carbon levels remain within the permissible limits for both seasons. However, the data indicates (Graph.20, Table 23) higher organic carbon during season 1 (summer), which might be due to reduced water flow and increased organic matter decomposition. The lower levels during season 2 (monsoon) suggest dilution from rainfall. Organic carbon plays a central role in lake and stream chemistry because it complexes metals and minerals, influences pH and alkalinity, and serves as a substrate for microbial activity (Dillon and Molot 1997).

Figure 20. Plastic waste dumped in a Tea Plantation at Munnar



Graph 20. Seasonal variation in Organic carbon across different transects in Munnar.

Sl.No	Transects	MSL	Mean ± SD	
			Season 1	Season 2
1	Anakulam	345 m	0 ± 0	0.002 ± 0
2	Kuwait City	368 m	0.0415 ± 0.0007	0.0025 ± 0.0007
3	Kallarkutty	473 m	0.0006 ± 0.0008	0.00085 ± 0.0002
4	Padikappu	600 m	0.0018 ± 0.002	0.002 ± 0
5	Chillithodu	612 m	0.0048 ± 0.002	0.00035 ± 0.0005
6	Mankulam	701 m	0.0042 ± 0.0008	0.00185 ± 0.0016

7	Ambazhachal	713 m	0.0155 ± 0.002	0.0015 ± 0.0021
8	Mankuzhi W.F	720 m	0.0485 ± 0.0035	0.00185 ± 0.0016
9	Ponmudi	720 m	0.0104 ± 0.008	0.0007 ± 0
10	Ellackal Bridge	723 m	0.0325 ± 0.01	0.001 ± 0
11	Kunjithanny 1	771 m	0.043 ± 0	0.001 ± 0
12	Kunjithanny 2	778 m	0.0445 ± 0.0035	0.001 ± 0
13	Sengulam Dam	847 m	0.043 ± 0	0.0007 ± 0
14	Muttukad P.F	954 m	0.0425 ± 0.0007	0.0025 ± 0.0021
15	Peechadu stream	987 m	0.0405 ± 0.002	0.0005 ± 0.0007
16	Shanthanpara	1052 m	0.008 ± 0	0.001 ± 0
17	Pooppara	1104 m	0.0145 ± 0.0007	0.001 ± 0
18	Kainagiri	1175 m	0 ± 0	0.0005 ± 0.0007
19	Anayirangal	1206 m	0.012 ± 0.005	0.00135 ± 0.0009
20	Vaguvarei Estate	1400 m	0 ± 0	0 ± 0
21	Nallathanny Anthonniyar	1480 m	0 ± 0	0.00135 ± 0.0009
22	Nallathanny	1520 m	0.006 ± 0.001	0.001 ± 0.0014
23	Vattavada Chilanthiyar	1552 m	0.008 ± 0	0 ± 0
24	Kundala dam	1602 m	0.015 ± 0	0.0015 ± 0.0007
25	Mattupetty	1602 m	0.017 ± 0.004	0 ± 0
26	Vattavada Keekarathodu	1629 m	0.001 ± 0	0 ± 0
27	Vattavada Umankadavu	1632 m	0.001 ± 0	0 ± 0

Table 23. Seasonal variation in Organic carbon (mean ± SD) of freshwater bodies in Munnar (transect-wise).

3.21 Total Coliforms

All warm-blooded animals and humans have coliform bacteria in their feces and in the environment. Their existence in drinking water, however, suggests that the water system may contain pathogens, which are organisms that cause disease. The majority of diseases that might contaminate water sources originate from human or animal excrement. Total coliform bacteria are commonly found in the environment (e.g., soil or vegetation) and are generally harmless. If only total coliform bacteria are detected in drinking water, the source is probably environmental. There is little chance of fecal contamination. However, if environmental contamination can enter the system, there may also be a way for pathogens to enter the system. Therefore, it is crucial to identify the cause and fix the issue. The analysis of bacterial contamination for summer and monsoon seasons can be seen in the data provided in Table 24 and Table 25. Season 1 (summer) and season 2 (monsoon) recorded high levels of total coliform ranging from 150 -2400 MPN/100 mL and 23-2400 MPN/100 mL (including upstream and downstream), with all sites exceeding the WHO guideline of 0 MPN/100 mL.

Figure 21. Waste dumped rivulet at Chillithodu

3.22 Fecal Coliforms

Fecal coliform bacteria are a sub-group of total coliform bacteria. They appear in great quantities in the intestines and feces of people and animals. The presence of fecal coliform in a drinking water sample often indicates recent fecal contamination, meaning that there is a greater risk that pathogens are present than if only total coliform bacteria is detected. Confirmation of fecal coliform bacteria or E. coli in a water system indicates recent fecal contamination, which may pose an immediate health risk to anyone consuming the water. Fecal contamination can arise from sources such as combined sewer overflows, leaking septic tanks, sewer malfunctions, contaminated storm drains, animal feedlots, and other sources. During rainfalls, snow melts, or other types of precipitation, E. coli may be washed into creeks, rivers, streams, lakes, or ground water (Minor, 2007)). The study assesses fecal coliform concentrations in water samples collected during two seasons- Season 1 (summer) and Season 2 (monsoon). The values are compared to WHO

Figure 22. Waste water flowing to rivulter at Chattupara

Figure 23. Nallathanni River at Munnar town; sewage and septage directly flows to the river

guideline of 0 MPN/100 mL. The fecal coliform levels in both upstream and downstream locations during both seasons are well above the WHO safety standard, rendering the water unsuitable for direct human consumption without treatment (Table 24 and Table 25). One of the most damaging environmental effects of fecal coliform bacteria stems from contamination of aquatic systems, which can either be from the direct introduction of human or animal waste into waterways, or from wastewater treatment plants, septic systems, or agricultural runoff.

3.23 E. coli

Since the last century, Escherichia coli has been utilized as a Fecal Indicator Bacteria (FIB) all over the world (USEPA, 1986). Its widespread use has led to a great deal of research on its aquatic survivability. Both biotic and abiotic variables influence E. coli's ability to survive in aquatic environments (Jang et al., 2017). Biofilm development and the presence of other microbes are examples of biotic factors (Korajkic et al., 2014; Stocker et al., 2019), while temperature, pH, salinity, sunshine, and nutrient availability are examples of abiotic factors (Petersen & Hubbart, 2020; Moon et al., 2023). Consequently, seasonal fluctuations in temperature, precipitation, and human activity may also have an impact on the survival and abundance of E. coli. The study examines the presence of E. coli during summer and monsoon seasons. According to WHO guidelines, E. coli should be absent in water for safe consumption. E. coli is present in a majority of both upstream and downstream sites, indicating widespread fecal contamination. Locations such as Kallarkutty, Anayirangal, Padikappu, Chillithodu and Ponmudi showed an increase in E. coli presence in downstream locations during season 2 compared to season 1. Season 2 shows a worsening trend in E. coli contamination compared to season 1 (Table 24 and Table 25). The increase in contamination during the monsoon highlights the impact of runoff, poor sanitation practices and sewage leaks.

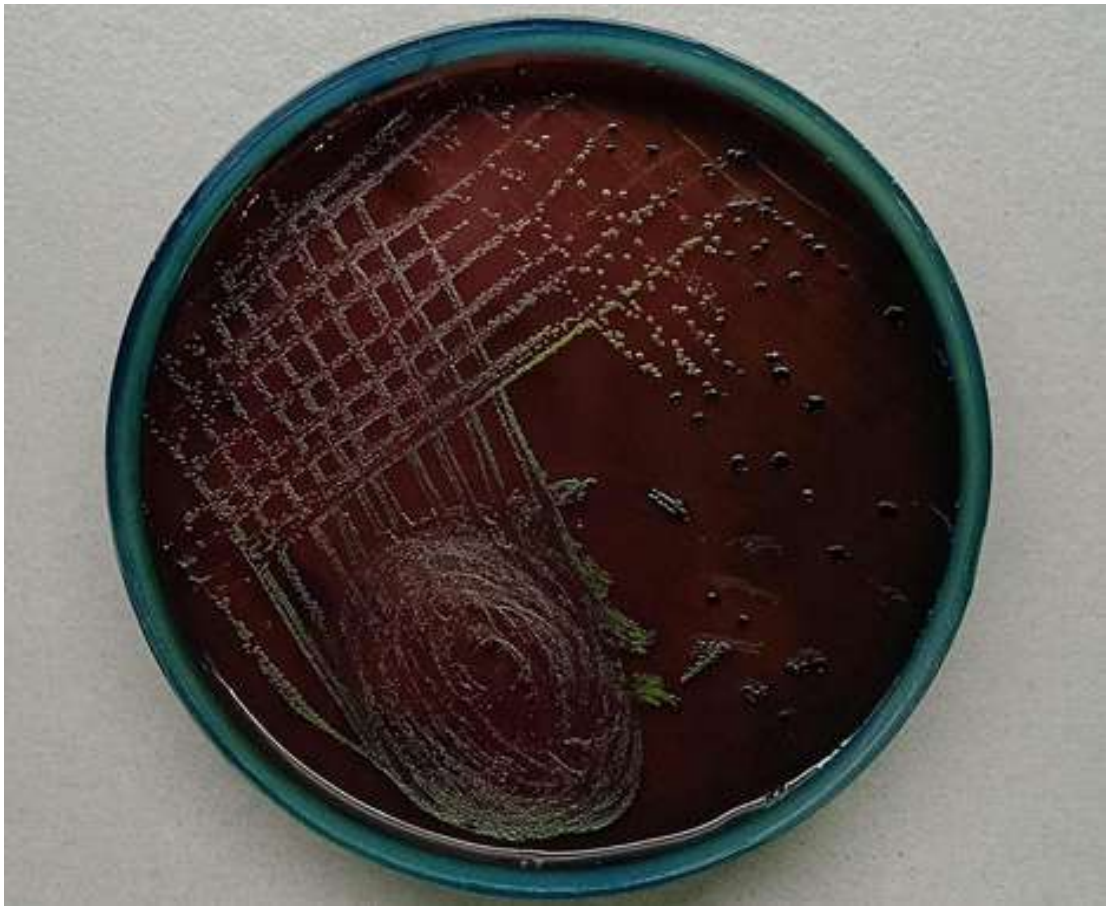


Figure 24. Plate showing E. coli

Sl.No	Transects (Season 1)	MPN Index Value				E. coli	
		Total Coliforms		Fecal Coliforms			
		Up	Down	Up	Down	Up	Down
1	Anakulam	2400	2400	2400	23	Present	Present
2	Kuwait City	2400	2400	1100	240	Present	Present
3	Kallarkutty	2400	2400	43	23	Absent	Absent
4	Padikappu	460	1100	240	1100	Present	Absent
5	Chillithodu	2400	2400	93	460	Present	Absent

6	Mankulam	2400	2400	43	43	Present	Present
7	Ambazhachal	2400	2400	1100	2400	Present	Present
8	Mankuzhi W.F	2400	2400	240	460	Present	Present
9	Ponmudi	1100	2400	23	75	Present	Absent
10	Ellackal Bridge	2400	2400	1100	460	Present	Present
11	Kunjithanny 1	2400	2400	2400	460	Present	Present
12	Kunjithanny 2	2400	2400	240	93	Present	Present
13	Sengulam Dam	2400	2400	460	93	Present	Present
14	Muttukad P.F	2400	2400	1100	93	Present	Present
15	Peechadu stream	2400	2400	1100	2400	Present	Present
16	Shanthanpara	2400	-	460	-	Present	Present
17	Pooppara	2400	2400	28	43	Present	Present
18	Kainagiri	2400	1100	210	1100	Present	Present
19	Anayirangal	2400	2400	23	4	Absent	Absent
20	Vaguvarei Estate	1100	2400	43	2400	Present	Present
21	Nallathanny Anthonniyar	1100	460	150	43	Present	Present
22	Nallathanny	2400	2400	2400	2400	Present	Present
23	Vattavada Chilanthiyar	2400	2400	1100	1100	Present	Present
24	Kundala dam	2400	460	23	150	Absent	Present
25	Mattupetty	2400	150	23	23	Present	Present
26	Vattavada Keekarathodu	-	2400	-	2400	Present	Present
27	Vattavada Umankadavu	2400	2400	150	2400	Present	Present

Table 24. Water Quality Data for Season 1 (Summer) Transects, including Total and Fecal Coliform MPN Index Values and E. coli Presence.

Sl.No	Transects (Season 2)	MPN Index Value				E. coli	
		Total Coliforms		Fecal Coliforms			
		Up	Down	Up	Down	Up	Down
1	Anakulam	2400	2400	2400	2400	Present	Present
2	Kuwait City	2400	2400	2400	2400	Present	Present
3	Kallarkutty	2400	2400	2400	1100	Present	Present
4	Padikappu	2400	2400	1100	2400	Present	Present
5	Chillithodu	2400	2400	460	2400	Present	Present
6	Mankulam	2400	2400	2400	2400	Present	Present
7	Ambazhachal	1100	2400	240	460	Present	Present
8	Mankuzhi W.F	460	2400	2400	2400	Present	Present
9	Ponmudi	2400	2400	120	1100	Present	Present
10	Ellackal Bridge	2400	2400	2400	1100	Present	Present
11	Kunjithanny 1	2400	2400	1100	2400	Present	Present
12	Kunjithanny 2	2400	2400	2400	1100	Present	Present
13	Sengulam Dam	2400	2400	1100	210	Present	Present
14	Muttukad P.F	2400	2400	2400	1100	Present	Present

15	Peechadu stream	2400	2400	2400	2400	Present	Present
16	Shanthanpara	2400	2400	2400	2400	Present	Present
17	Pooppara	2400	2400	2400	2400	Present	Present
18	Kainagiri	2400	2400	2400	2400	Present	Present
19	Anayirangal	1100	2400	1100	2400	Present	Present
20	Vaguvarei Estate	1100	2400	75	1100	Present	Present
21	Nallathanny Anthonniyar	2400	240	1100	240	Present	Present
22	Nallathanny	2400	2400	2400	1100	Present	Present
23	Vattavada Chilanthiyar	93	460	43	93	Present	Present
24	Kundala dam	460	2400	93	43	Present	Absent
25	Mattupetty	210	460	9	23	Present	Present
26	Vattavada Keekarathodu	2400	23	39	20	Present	Present
27	Vattavada Umankadavu	460	150	9	150	Present	Present

Table 25. Water Quality Data for Season 2 (Monsoon) Transects, including Total and Fecal Coliform MPN Index Values and E. coli Presence

3.24 Water Quality Index

Sl.No	Transects	WQI	Rating of Water Quality
1	Anakulam	43.1	Good
2	Kuwait City	36.65	Good
3	Kallarkutty	49.3	Good
4	Padikappu	63.87	Poor
5	Chillithodu	53.6	Poor
6	Mankulam	71.4	Poor
7	Ambazhachal	72.75	Poor
8	Mankuzhi W.F	35.24	Good
9	Ponmudi	27.5	Good
10	Ellackal Bridge	82.5	Very Poor
11	Kunjithanny 1	152.2	Unsuitable for drinking purpose
12	Kunjithanny 2	34.15	Good
13	Sengulam Dam	41.7	Good
14	Muttukad P.F	53.2	Poor
15	Peechadu stream	23.1	Excellent
16	Shanthanpara	24.25	Excellent
17	Pooppara	51.4	Poor
18	Kainagiri	45.5	Good
19	Anayirangal	38.1	Good
20	Vaguvarei Estate	49.4	Good
21	Nallathanny Anthonniyar	23.6	Excellent

22	Nallathanny	43.3	Good
23	Vattavada Chilanthiyar	60.3	Poor
24	Kundala dam	33.04	Good
25	Mattupetty	32.2	Good
26	Vattavada Keekarathodu	74.02	Poor
27	Vattavada Umankadavu	50.35	Good

Table 26. Water Quality Index of Transects in Munnar during Summer season (Season 1) based on Physio-Chemical Parameters

Figure 25. Waste dump at Mattupetty boating site (Tourism Zone)

Sl.No	Transects	WQI	Rating of Water Quality
1	Anakulam	469.5	Unsuitable for drinking purpose
2	Kuwait City	132.7	Unsuitable for drinking purpose
3	Kallarkutty	241.2	Unsuitable for drinking purpose
4	Padikappu	163.6	Unsuitable for drinking purpose
5	Chillithodu	97.3	Very poor
6	Mankulam	157.8	Unsuitable for drinking purpose
7	Ambazhachal	299.07	Unsuitable for drinking purpose
8	Mankuzhi W.F	213.9	Unsuitable for drinking purpose
9	Ponmudi	416.3	Unsuitable for drinking purpose
10	Ellackal Bridge	240.5	Unsuitable for drinking purpose
11	Kunjithanny 1	297.2	Unsuitable for drinking purpose
12	Kunjithanny 2	346.5	Unsuitable for drinking purpose
13	Sengulam Dam	12.76	Excellent
14	Muttukad P.F	78.09	Very poor
15	Peechadu stream	162.3	Unsuitable for drinking purpose
16	Shanthanpara	325.1	Unsuitable for drinking purpose
17	Pooppara	244	Unsuitable for drinking purpose
18	Kainagiri	133.8	Unsuitable for drinking purpose

19	Anayirangal	296.2	Unsuitable for drinking purpose
20	Vaguvarei Estate	97.02	Very poor
21	Nallathanny Anthonniyar	207.5	Unsuitable for drinking purpose
22	Nallathanny	493.5	Unsuitable for drinking purpose
23	Vattavada Chilanthiyar	97.7	Very poor
24	Kundala dam	47.6	Good
25	Mattupetty	191.7	Unsuitable for drinking purpose
26	Vattavada Keekarathodu	37.3	Good
27	Vattavada Umankadavu	32.8	Good

Figure 25. Waste disposal at Mattupetty boating site (Tourism Zone)

4. Conclusion

The water quality analysis, based on 52 samples collected across 27 transects (both upstream and downstream), highlights significant seasonal variations in both physiochemical and biological parameters. Cooler temperatures during the monsoon season indicates seasonal climate influence on water conditions. Higher turbidity in summer suggests increased sedimentation and runoff during the drier months. While pH values remain within permissible limits, slight variability is observed, potentially due to seasonal rainfall and runoff. Higher DO values in summer indicate increased aeration or biological activity during the warmer months. Lower conductivity and TDS during the monsoon suggest dilution effects from increased rainfall. Seasonal variations in salinity align with TDS and conductivity trends. Chloride levels are higher in summer, likely due to reduced dilution. Elevated iron concentrations during summer may result from oxidation processes, while, higher fluoride levels may be attributed to geological leaching. Increased phosphate levels in summer indicate nutrient runoff from agricultural areas. Acidity, alkalinity, total hardness, calcium hardness, magnesium hardness, sulphate nitrate, oil content and organic carbon remain within prescribed limits across seasons. However, total coliforms exceed permissible limits in both seasons, with higher levels in summer, suggesting anthropogenic contamination. The presence of fecal coliforms, including E. coli, exceeds the WHO guideline of 0 MPN/100 ml in most samples, indicating potential health risks. However, in summer season, E. coli is absent in the upstream of 3 locations (Kallarkutty, Anayirangal and Kundala Dam) and the downstream of 5 locations (Kallarkutty, Padikappu, Chillithodu, Ponmudi and Anayirangal). In monsoon, E. coli is absent only in the downstream of Kundala Dam. Dams and reservoirs typically hold large volume of water, which can dilute microbial contaminants, making the concentration of E. coli below detectable levels. Seasonal differences are evident in turbidity, pH, DO, conductivity, TDS and nutrient levels. Summer exhibits higher mineral concentrations and turbidity, while the monsoon shows dilution effects due to rainfall. Elevated levels of total and fecal coliforms signify contamination likely resulting from untreated sewage, agricultural runoff or other anthropogenic activities.

Untreated or partially treated sewage from residential and commercial areas directly enters water bodies, contributing to high coliform levels. Inappropriate disposal of plastics and non-biodegradable waste clogs water channels, affecting turbidity and ecosystem health. Runoff during monsoon carries fertilizers and pesticides from agricultural lands into water sources, increasing nutrient loads (e.g: phosphates) and affecting pH. Improperly maintained sewage drains contribute significantly to microbial contamination and poor water quality. Unregulated dumping of organic and chemical waste directly into streams aggravates contamination, especially in downstream areas. Tourist waste, including plastics, food wrappers and other non-biodegradable materials, poses a severe threat to the pristine environment of Munnar. Unregulated sand mining disturbs sedimentation patterns, increases turbidity and affects aquatic habitats. Inadequate sanitation facilities in some areas lead to open defecation, significantly contributing to microbial contamination.

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