J. Mountain Res. P-ISSN: 0974-3030, E-ISSN: 2582-5011 DOI: https://doi.org/10.51220/jmr.v19-i2.31
Vol. 19(2), (2024), 291-300

Comparative Analysis of Rainwater Chemistry in Urban and Semi-Urban Areas: A case study of Dehradun and Uttarkashi, Uttarakhand

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Received: 17.08.2024; Revised: 01.11.2024; Accepted: 25.11.2024

Abstract: This paper describes the rainwater (RW) quality taken at fully urban city and low altitude site Dehradun (30°19' N, 78°03' E, 640 AMSL: S_1) and semi urban hilly town Uttarkashi (30°43''56' N, 78°26''10' E, 1158 AMSL; S_2) of Garhwal region of Uttarakhnd state. A study was conducted to evaluate the quality of RW by analyzing the relationship with pH, electrical Conductivity (EC), Total dissolved solid (TDS), and meteorological parameters. September was the coldest month with temperatures of 21.3°C at S_1 and 17.37°C at S_2, while June was the hottest (26.6°C at S_1, 21.24°C, S_2). Relative humidity rose from 45% in June to 88% in September. Wind speeds varied from 1.9 m/s (September) to 3.1 m/s (S_1) and 2.8 m/s (S_2) in June, with peak precipitation in July (466.28 mm ; S1) and September (401.27 mm; S2). RW samples were collected during the monsoon period (June–September 2022) and were analyzed for pH, EC and TDS. This investigation seeks to understand how these parameters vary between the urban and semi-urban settings.

Keywords: Rainwater • Himalaya • pH • Electrical conductivity • TDS

Introduction

An intricate interaction between cloud dynamics and microphysical operations, as well as a number of atmospheric chemical reactions occurring both within and below the cloud, combine to produce precipitation chemistry. Rain serves as an effective mechanism of removing pollutants from the atmosphere (Mouli et al., 2005). In addition to offering a distinctive environment, the Himalayan region is an essential supply of water for many rivers in nations including China, India, Nepal, Bhutan, and Pakistan. For populations downstream, the meltwater from the Himalayan glaciers, sometimes called "water towers," is essential. But because of changes in precipitation patterns brought on by climate change, these glaciers are retreating. The Himalayan region is also seriously threatened by air pollution from dust, aerosols, and particulate matter, which changes the radiation budget. The recent increase in wealth and population has made air pollution worse (Kumar et al., 2022). A number of processes, including in-cloud scavenging, or rainout, and below-cloud scavenging, or the washout process, affect the concentration of particles in the atmosphere. While rainout integrates fine-mode particles, washout removes coarse-mode particles from the environment (Kajino & Aikawa, 2015). The chemistry of precipitation is measured at more than 1000 stations across the world. Global networks that gather precipitation samples from remote locations, like the Background Air Pollution Monitoring Network (BAPMON) and the Global Precipitation Chemistry Project (GPCP), provide baseline air pollution levels and information on the long-range transport of trace substances in the atmosphere (Datar et al., 1996). Located in northern India, the Himalayas are the youngest mountain ranges in the world and are regarded as having a pristine ecosystem within the Indian subcontinent. Data on precipitation chemistry are still rare, despite the fact that several recent research have looked at atmospheric aerosols, size distribution, aerosol composition, aerosol optical depth, trace gas levels, and the chemical compositions of snow and ice in the Himalayan areas (Bisht et al., 2016). This research study investigates the chemical composition of rainwater in two different locations during the 2022 monsoon season: Uttarkashi (1158 AMSL), a high-altitude semi-urban town in the central Himalaya, and Dehradun (640 AMSL), a low-altitude fully urban site. The main goals of this research are to: (i) analyze and comparision of the chemical properties of rainwater in S_1 and S_2; (ii) assess the influence of both natural and anthropogenic emission sources on rainwater composition; and (iii) identify the potential sources contributing to the rainwater chemistry through trajectory analysis and statistical methods.

Materials and Methods

sampling sites: The rooftops of residential buildings in Kargi Chowk Dehradun (S1) and Gyansu Uttarkashi (S2), Uttarakhand, India, have been chosen as the research location. One of the most important aspects of this study was determining the study location.

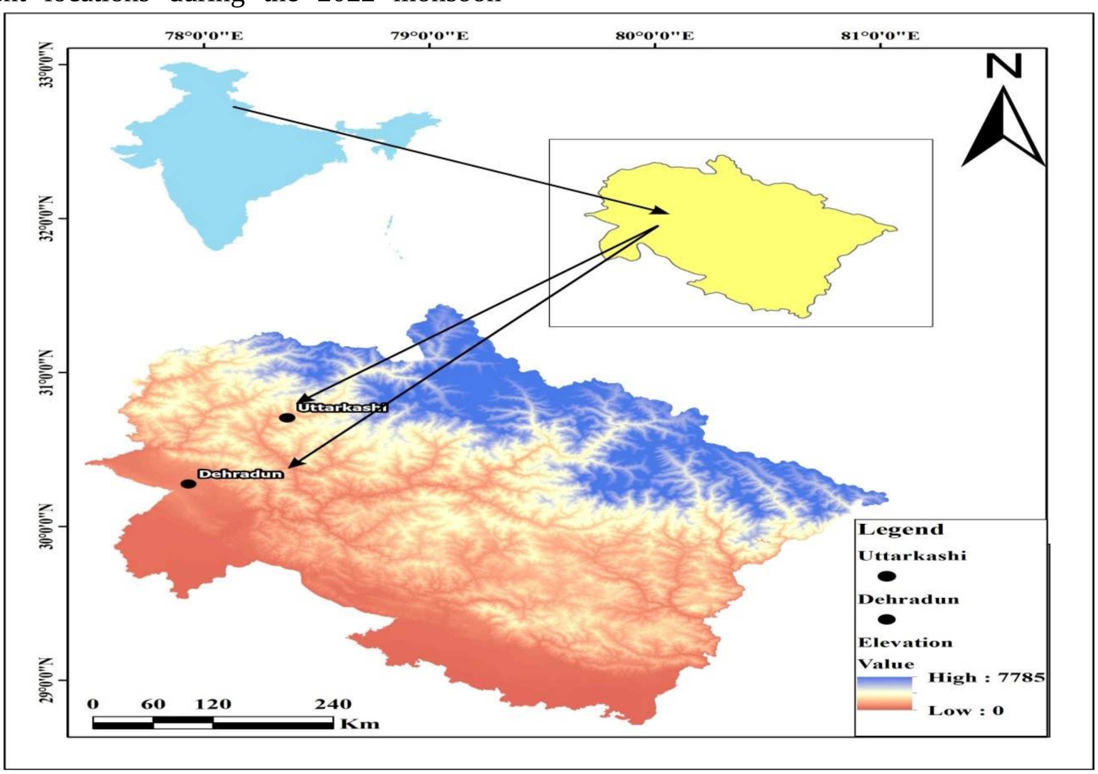

Fig.1. Sampling sites: Kargi chowk Dehradun and Gyansu Uttarkashi, Uttarakhand

Table 1: Study area specifics of the sampling sites

Sampling site	Study area	Coordinates	Description
S_1	Kargi Chowk, Dehradun (entire plains region encircled by hills)	30°19' N 78°03' E	urban setting adjacent highway with heavy traffic having industrial activities nearby
S_2	Gyansu, Uttarkashi, Uttarakhand (entirely hilly terrain)	30°43''56' N 78°26''10' E	A semi-urban setting free of industrial activities, with high traffic only during pilgrimage activities

Meteorological Parameters : Satellite data were used to measure meteorological parameters (MPs) like temperature, relative humidity, wind direction, wind speed and rainfall (POWER | DAVe (nasa.gov)). Monthly fluctuations in MPs throughout the monsoon season are depicted in Figure 2. With average temperatures of 21.3°C and 17.37°C at S1 and S2, respectively, September was the coldest month of the monsoon. As summer approaches, temperatures climb and reach their maximum in June (26.6°C and 21.24°C at S1 and S2, respectively). In comparison to S1, the temperature trend in S2 shows a decrease of 3.93°C at the lowest temperature and 5.36°C at the highest temperature. Throughout the study period, the RH varied from 45% (S1) and 52% (S2) in the month of June to 88% (S1 and S2) in the month of September. The majority of the rampant winds came from the south-west. The wind speed was varying from 1.9 m/s (September) to 3.1 (S1) and 2.8 (S2) m/s in the month of June. July at S_1 and September at S_2 saw the highest quantities of precipitation, while June saw the lowest amounts of precipitation at both sampling sites

Table 2: Monthly averaged meteorological parameter variation at the sampling sites.

Meteorological Parameters	Unit	Site1				Site2			
		June	July	August	September	June	July	August	September
Temperature	°C	26.6	23.44	22.83	21.3	21.24	19.58	19.09	17.37
Relative Humidity	%	44.88	84.69	87.31	87.5	52.19	86.88	87.56	87.62
Wind speed	m/s	3.13	2.22	2.28	1.95	2.83	2.22	2.18	1.91
Wind direction	°(deg.)	257.9	257.9	212.31	217.81	243.75	222.38	221.25	224.56
Rainfall	mm	115.8	466.28	269.74	370.92	88.36	346.85	233.41	401.27

Data collection and Analysis : During the monsoon season (June–September) of 2022, a total of 50 samples were collected from both sampling sites in a pre-washed polyethylene sampler and preserved in a Refrigerator at 4˚C. Samples were analyzed for pH, EC and TDS. The pH analysis of samples was done by using a portable pH meter (LABWAN Model: LW-PH-22), while the total dissolved solid (TDS) was also measured by a portable TDS meter having range 0-9,990 ppm and accuracy ±2%. The Electrical Conductivity of all RW samples was measured by Systronics conductivity meter- 304 and the conductivity meter was calibrated with 0.1M KCl solution. The analysis's findings were then contrasted with the World Health

DOI: https://doi.org/10.51220/jmr.v19-i2.31

Organization's (WHO) suggested raw water standards. This study not only evaluated the quality of the water but also looked into how rainfall amount and rainwater quality relate to each other. By making this comparison, it will be possible to decide whether or not gathered rainwater is suitable for use as raw water.

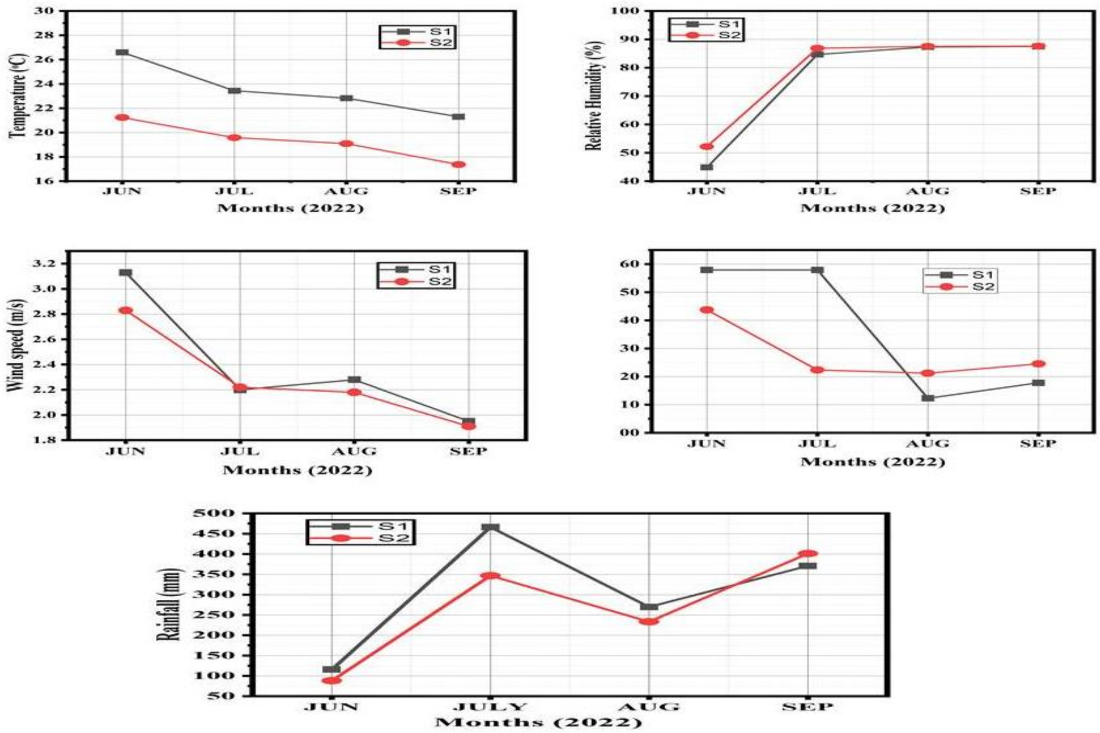

Fig.2. Variations in Meteorological parameters at sampling sites $S_1$and S_2

Results and Discussion

Following laboratory analysis of the rainwater samples, Figure 3, 4 and 5 displays the findings of the field measurements (pH, EC, and TDS). The obtained outcomes show that the physical criteria (taste, odor, color, and appearance) are colorless and acceptable.

pH

The RW pH is a tool used to identify various ionic species, which are influenced by the neutralization of cations such as Ca^{2+}, NH_4^+, and Mg^{2+}, as well as atmospheric scavenging processes. When RW pH is greater than 5.6, it indicates the influence of crustal species or mineral dust, categorizing it as alkaline. Conversely, if RW pH is less than 5.6, it suggests that SO_4^{2-} and NO_3^- are predominant, indicating an acidic nature (Bisht et al., 2022b). Fig. 4 and 5 show that The controlled water samples' average pH was found to be 6.59±0.43 (S1) and 6.52±0.24 (S2) which is consistent with findings from Bisht et al., 2022 study conducted in the hilly region of Uttarakhand's semi-urban city of Srinagar Garhwal. The pH measurements across the sites of Dehradun and Uttarkashi revealed notable variations over the months of the study. At Dehradun, the pH levels ranged from a low of 6.11 on September 26, 2022, to a high of 7.01 on June 16, 2022. Similarly, at Uttarkashi, the lowest pH value recorded was 6.15 on August 29, 2022, while the highest was 7.11 on June 28, 2022. The average monthly analysis further elucidated these trends.

Both sites exhibited their highest pH values in June, with Dehradun reaching 6.9 and Uttarkashi 7.07. Conversely, the lowest pH values for both sites were recorded in August, measuring 6.35 at Dehradun and 6.37 at Uttarkashi. These observations underscore a consistent seasonal pattern, with peak pH levels occurring in June and the lowest in August across both locations. This suggests that the overall RW samples are alkaline in nature and the concentration of SO_4^{2-} and NO_3^- are predominated over the receptor sites

Table 3: Rainwater quality analysis

Parameters	Unit	Site$_1$				Site$_2$			
		June	July	August	September	June	July	August	September
Colour	-	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
Odour	-	Odourless	Odourles	Odourles	Odourles	Odourles	Odourles	Odourles	Odourles
Taste	-	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable
pH	-	6.9	6.68	6.35	6.46	7.07	6.52	6.37	6.69
EC	µS/cm	51.75	38.82	16.7	20.36	39.6	11.16	8.87	13.86
TDS	mg/l	28	52.6	6.0	7.33	20.5	3.26	1.90	3.33

Table 4: Suitability of collected water for raw water

Parameter	Unit	Min (S$_1$)	Max (S$_1$)	Average	Min (S$_2$)	Max (S$_2$)	Average	Recommended raw water criteria (WHO, 2011)
pH	-	6.11	7.01	6.59	6.15	7.11	6.52	6.5 – 8.5
EC	µS/cm	6.1	111	31.17	2.8	64.7	12.37	700 µS/cm
TDS	mg/L	1	232	26.35	0	37	3.9	1000 mg/L

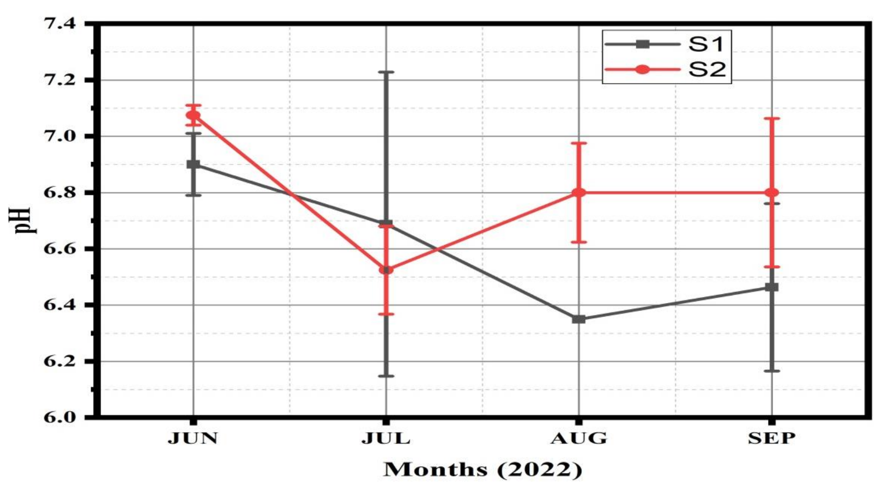

Fig. 3: Averaged monthly variation and comparative analysis of pH levels at S$_1$ and S$_2$.

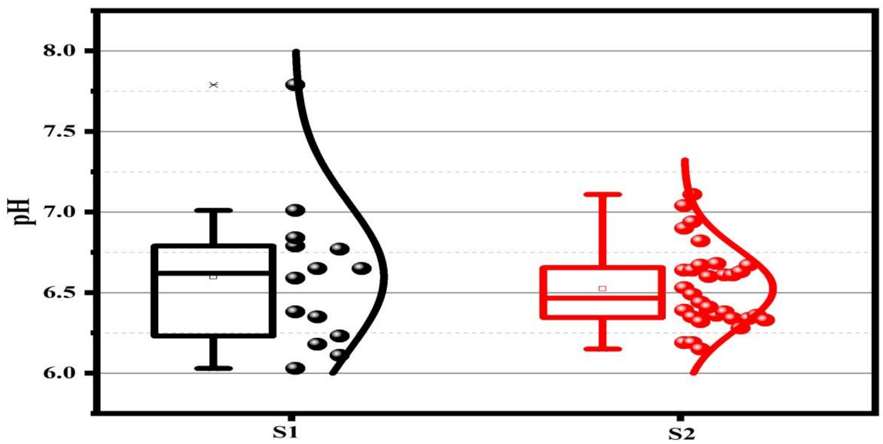

Fig. 4: Seasonal averages during monsoon and comparative analysis of pH levels at S_1 and S_2.

Electrical conductivity:

EC is a crucial factor in assessing the purity of water, as it depends on the nature and concentration of ionized substances such as Cl^-, NO_3^-, SO_4^-, and PO_4^{3-}, as well as Na^+, Mg^{2+}, Ca^{2+}, Fe^{2+}, and Al^{3+} cations at a given water temperature (Chughtai et al., 2014). In Dehradun and Uttarkashi, rainwater samples have shown conductivity values ranging from 6.1-111 µS/cm with an average of 31.17±26.58 and 2.8-64.7 µS/cm with an average of 12.37±12.95 respectively (Fig. 6). These conductivity values indicate that the Dehradun and uttarkashi's rainwater is largely free from significant contamination by atmospheric cations and anion, suggesting it is relatively pure. The greater value of EC recorded at both sites in the month of June (51.75 and 39.6 for S1 and S2 respectively) indicates the presence of more ions than all other sampling months (Fig 5). Pure water, despite undergoing dissociation into H_3O^+ and OH^- ions, exhibits minimal conductivity (WHO 2006). The measured conductivity levels from the rainwater analysis comply with the WHO guidelines for safe drinking water, reinforcing the assessment of the rainwater's purity.

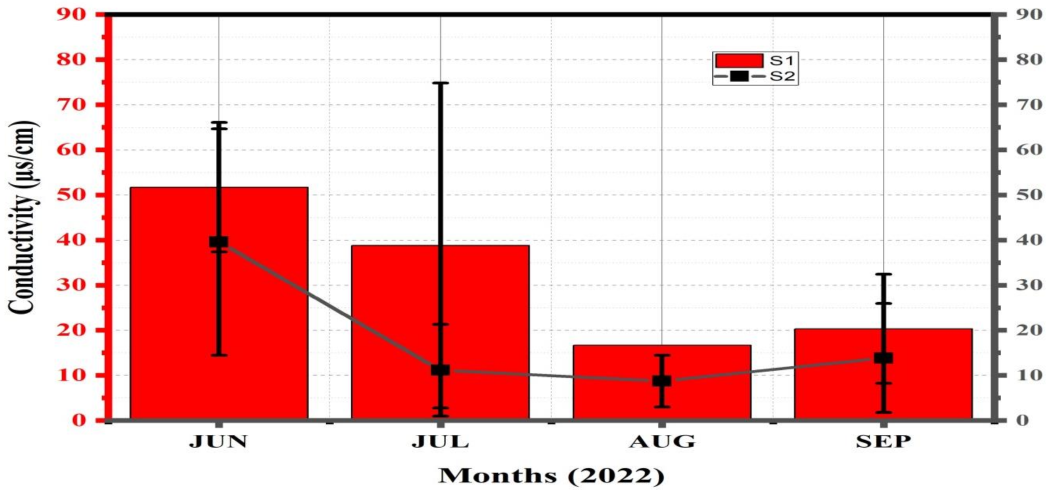

Fig. 5: Averaged monthly variation and comparative analysis of coductivities at S_1 and S_2.

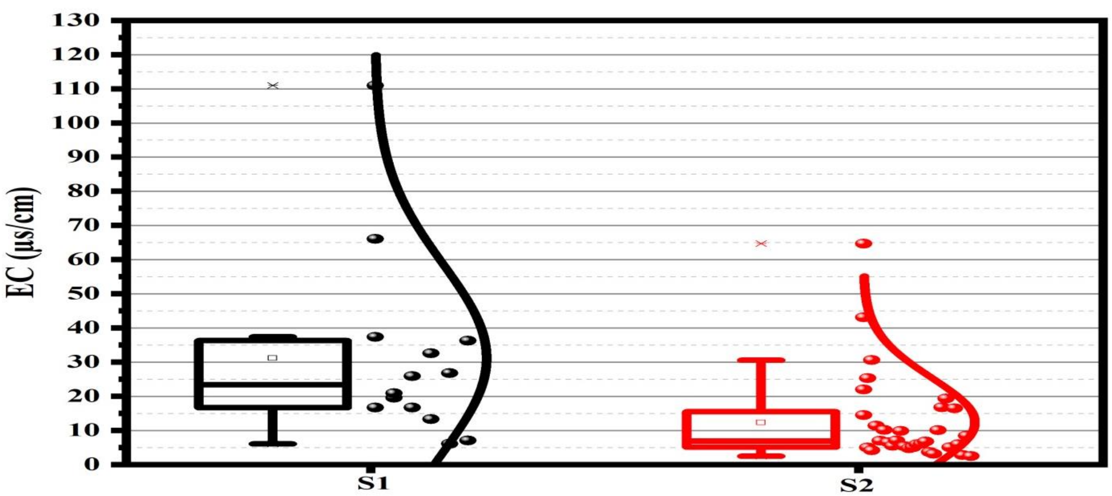

Fig. 6: Seasonal averages during monsoon and comparative analysis of conductivities at S_1 and S_2.

TDS:

The materials dissolved in water are referred to as TDS. TDS is a crucial metric that characterizes the chemical makeup of water and can reveal the edaphic elements that influence a body of water's productivity (Goher et al., 2022). Rainwater contains both carbonic and sulfurous acids, but their presence has little effect on hardness. Increased TDS levels in precipitation indicate a higher concentration of dust and suspended particulates. Rainfall totals also affect the total dissolved solids (TDS) in rainwater. The values also show that rainwater meets the criteria for being considered fresh (Chughtai et al., 2014). The total averaged TDS during the monsoon season observed in S1 was 26.35±57.7 and in S2 was 3.90±6.9 which is satisfactory or even very good but the value of TDS is unexpected on July 20, 2022 at S1 is which is probably due to the high concentration of particulate matter in the atmospheric air

(Cobbina et al., 2013) . In S1, July shows the highest value of TDS 52.6±89.7, followed by June (28±9), September (20±12) and August (6 mg/L). In S2 June shows the highest average value of TDS (20.5±16.5) followed by September (3.3±2.8), July (3.2±4.3) and August (1.9±1.72) (Fig. 7).

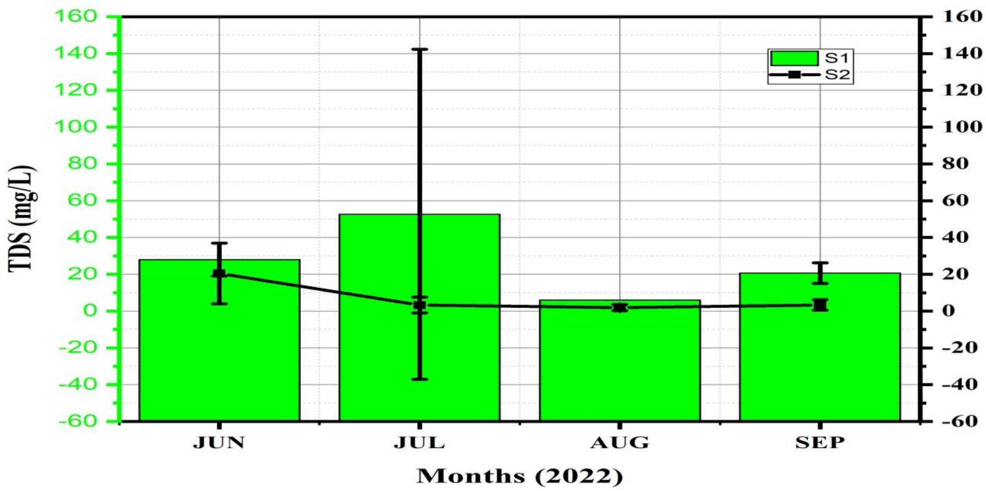

Fig. 7: Averaged monthly variation and comparative analysis of TDS at S_1 and S_2.

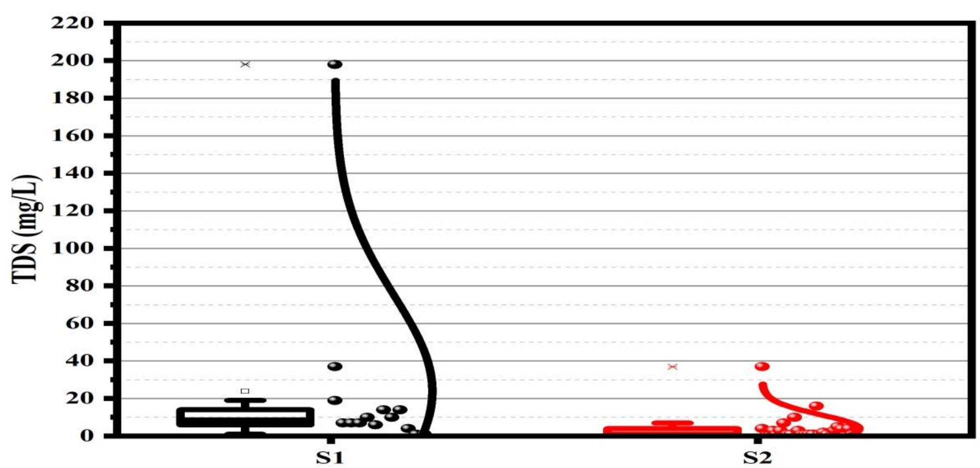

Fig. 8: Seasonal averages during monsoon and comparative analysis of TDS at S_1 and S_2.

Conclusion:

In regard of pH, TDS, and Conductivity all sample comply with recommended raw water criteria set by WHO. The analysis of RW Chemistry reveals a predominantly alkaline nature, indicative of the influence of crustal species or mineral dust, rather than acidic ions such as SO_4^{2-} and NO_3^-. Both Dehradun and Uttarkashi display this alkalinity, with average pH levels exceeding 5.6, underscoring the impact of mineral dust and crustal components. In June, elevated electrical EC values suggest a heightened presence of ions, yet the rainwater remains relatively pristine, devoid of significant contamination by atmospheric cations and anions. A comparative analysis between Dehradun and Uttarkashi reveals that Dehradun's rainwater exhibits substantially higher EC values (31.17±26.58) than Uttarkashi (12.37±12.95), a clear indication of increased ion concentration attributable to urbanization, encompassing increased industrial activities, vehicular emissions, construction, and higher population density. Dehradun's rainwater samples consistently show higher TDS levels (26.35±57.7) compared to those from Uttarkashi (3.90±6.9), further illustrating the impact of urbanization on Dehradun's rainwater composition. Overall, Dehradun demonstrates greater variability and elevated average values for pH, EC, and TDS compared to Uttarkashi. The observed trends suggest that both sites experience seasonal fluctuations, with peak values typically occurring in June and declining in August. This pattern highlights the dynamic nature of rainwater chemistry in these regions, influenced by both natural and anthropogenic factors.

Acknowledgment
The authors extend their heartfelt gratitude to the Himalayan Atmospheric and space Physics Research Laboratory, Department of Physics, Hemvati Nandan Bahuguna Garhwal University Srinagar Garhwal Uttarakhand, for their invaluable assistance in Chemical characterization of Rainwater samples. Special appreciation goes to Mr. Pushpendra Semwal for his support in sampling of Rainwater. Furthermore, the authors convey their heartfelt gratitude to the Department of Chemistry SRT Campus H.N.B. Garhwal University, for generously providing essential facilities. Their contributions were instrumental in the successful completion of this research endeavour.

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