# Hydrochemical Characterization And Water Quality Evaluation For Drinking And Irrigation Purposes Of Kosi River Water At Ramnagar, Uttarakhand

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***Abstract***.

*This study used geospatial, temporal, and statistical methods to evaluate the quality of water of Kosi River in the Ramnagar area, located in the Nainital district of Uttarakhand. Ramnagar city is located where the Kosi River enters the plain region after flowing through a hilly area. The river undergoes significant changes in terms of geography, environment, and urbanization. A total of fourteen water quality parameters including pH, electrical conductivity (EC), phosphate ($PO_4^-$), biological oxygen demand (BOD), chloride ($Cl^-$), sulfate ($SO_4^{2-}$), nitrate ($NO_3^-$), dissolved oxygen (DO), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), sodium ($Na^+$), TDS, turbidity and total hardness (TH) were measured in samples collected from eleven different sites to evaluate seasonal fluctuation during pre-monsoon (PRM) monsoon (MON), post-monsoon (POM) of the river in 2021. The concentration of parameters at each site is compared with their permissible limits recommended by the World Health Organization (WHO) and Bureau of Indian Standards (IS 10500: 2012) to assess their suitability for human drinking. Based on the physicochemical analysis, it can be observed that the majority of the water samples taken from the river are within the recommended permissible limits for drinking purposes. Moreover, the calculated average Water Quality Index (WQI) values for PRM (44.98), MON (38.79), and POM (33.80) fall under the excellent to good categories. Statistical analyses indicate positive correlation among most of the chemical parameters. Piper diagram illustrates that all the water samples fall in Calcium-Chloride type Hydrochemical facies, Irrigation water quality of the river water was found suitable during all the three seasons according to the result of sodium adsorption ratio and sodium percentage. Therefore, based on the WQI results, it can be inferred that the water of the Kosi River in the Ramnagar region is suitable for drinking and other domestic uses without any further treatment. Therefore, to restore the vitality and water quality of the rivers, proper water resource planning program should be developed.*

***Keywords:*** *Physio-chemical parameters, Water-Quality (WQI),seasonal fluctuations, Kosi River, and Ramnagar.*

## I. INTRODUCTION

Water pollution is a complex procedure including various environmental, geological and anthropogenic processes. It is a prominent current issue for the research community as it has resulted in numerous diseases and deaths across the world. India is a developing country causes a rapid increase in industries, fast growth in urbanization, and intense pollution collectively increases the discharge of effluents and pollutants into the environment [1–8] that changes in the physicochemical parameters of drinking water. Poor water quality can cause diseases and toxic effects once it is consumed by humans or animals. Moreover, a decline in water quality can also impact the survival conditions of aquatic ecosystems. To ensure that water is safe for a specific purpose, permissible limits are set for various physical, chemical, and biological characteristics. However, the ever-increasing human interventions have led to alarming levels of water pollution, as confirmed by multiple studies [2,9–20]. Regular use of polluted water for irrigation reduces soil fertility, rendering it unsuitable for farming and affecting human health (Zhang et al., 2020). Therefore, it is important to assess the water quality continuously to preserve and sustain the natural ecosystem [2,21–23].Rivers are an essential source of water for the growing life on earth. At the same time, rivers are the primary carriers and dumping sites for effluents, sewage, garbage, and other anthropogenic wastes. The quality of river water is adversely affected by waste discharged into the rivers, making it unsuitable for consumption through drinking, irrigation and other activities. As per the study, 70% of river water in India is unsuitable for human consumption [24].

The growing population and industrial activities have further led to increased consumption of fresh water and contamination of rivers and other reservoirs. This persistent demand for water has compelled the scientific community to research the water quality parameters of various freshwater sources to monitor and preserve these resources for future generation [2,21,22,25]. In general, water quality assessment includes monitoring its physical, chemical, and biological dimensions with different parameters [26]. Water quality indices (WQIs) have been used by researchers since the 1960s [27]. With increasing interest and understanding of water quality assessment, various WQI tools are being developed to effectively represent changes in water quality in a simple and comprehensible manner [28]. As per the literature, nearly 30 WQI tools are used worldwide to monitor water quality providing relevant information to the water authorities and can be used to formulate future recommendations [29,30].The Kosi River is a significant watercourse in Northern India, serving as a major tributary of the Ram Ganga. It originated from Rudradhari, District Almora, Uttarakhand, and covers a distance of 240 km through the hilly and flat terrain of Uttarakhand and Uttar Pradesh.

The catchment area of the Kosi River is 3420 $km^2$. The longitude and latitude coordinates of the river are 85°17" east and 27°47" north respectively. The Kosi River Basin comprises several important areas, including Tota-aam and Garjiya Temple in Ramnagar (District Nainital), Kashipur (District Udham Singh Nagar), Dadiyal, Swar, Lalpur, and City Rampur. The river merges with the Ramganga River near the village of Chamraul in the Rampur district of Uttar Pradesh. River Kosi serves as the primary source of water for the region and, along with its catchment area, forms a significant ecosystem for the hilly state of Uttarakhand. However, rapidly increasing anthropogenic activities and growing population in the city and towns along the course of river pose a challenge to the researchers assessing the water quality of the river. A wide range of parameters is used to give an accurate and up-to-date picture of the river's water quality. Unfortunately, an exhaustive literature review provides a grim picture on this front. Even after putting in sincere effort, we could not find any reliable, authentic research work done on the assessment of WQI of the river Kosi in the past decade. The literature on studying the physicochemical parameters and water quality monitoring of the river is more than a decade old and based on very few parameters [31] and references therein). We, therefore, decided to conduct one year of research dividing it into pre-, during, and post-monsoon seasons to determine the different physicochemical parameters and assess its water quality based on the latest and most widely used WQIs.

## II. STUDY AREA

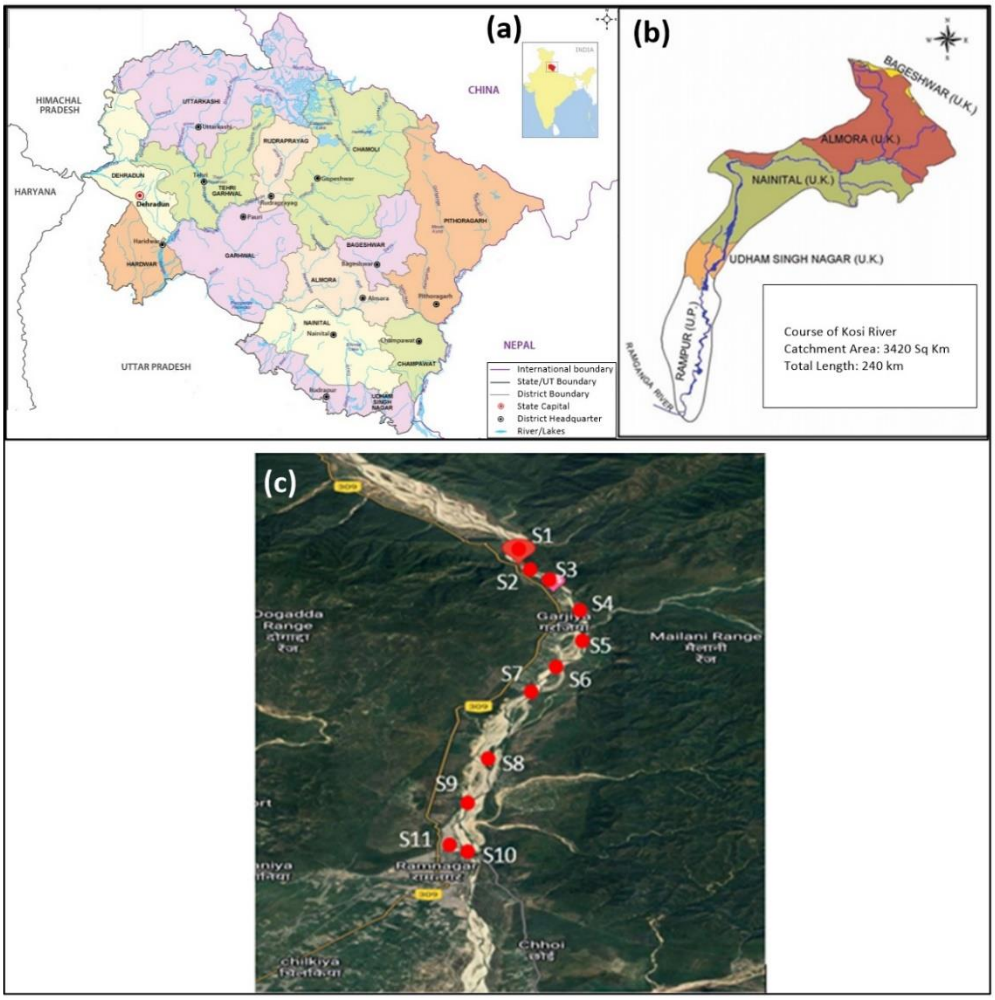
The study area Ramnagar of district Nainital, Uttarakhand, India, is located at the foothill of Himalaya (Fig. 1a, b) between 29°39′13″N and 29°24′42″N latitudes and 79°04′15″E to 79°08′22″E longitudes [32]. In the North, it is surrounded by the Shivalik hills and the Gangetic plains in the South. This area has coarse soil and rocks on the northern side which is dominated by the hilly slope. The southern side of the region has alluvium, clay-rich marshes. During the Southwest Monsoon (June-September), the area receives an average yearly rainfall of 1925 mm [33]. Measurement of Kosi River water quality in Ramnagar and around is crucial because the river leave the hills and enters into the plain and the population concentration increases suddenly along the course of the river.

## III. METHODS

### *1.1 Sampling*

Eleven different sites (S1- S11) were selected for sampling based on location, environment, and land use activities.The details of the location of sampling are shown on the map (Fig.1c) and compiled in Table 1.

**Fig 1. (a)** drainage map of Uttarakhand **(b)** showing the course of Kosi River **(c)** Google map of the study area showing the location of the collected water samples (Ramnagar, Nainital districts, Uttarakhand, India)




The water samples were collected and stored in 500 mL sterilized bottles as per the standard method American Public Health Association (APHA) 2017 [34], from March 2020 to February 2021 in order to observe seasonal variations in river water quality. The temperature of the water was also noted at the time of sampling. The time from March to May was designated as pre-monsoon season (PRM), June to September was taken as during monsoon (MON), and October to January as post-monsoon (POM) season based on the percentage of rainfall the region receives during these months. The analyses were performed based on twelve physicochemical parameters; pH, Turbidity, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), nitrate, chloride, sulfate, sodium, potassium, magnesium, and calcium in the laboratory per the standard guidelines (APHA American Public Health Association, 2017).

**Table 1.** Compiled the geographical position and locality of sample collection sites.

| No | Latitude | Longitude | Locality name |
|---|---|---|---|
| **1.** | 29.48703 | 79.14205 | Garjiya Bridge (Near Garjiya Temple) |
| **2.** | 29.48219 | 79.14725 | Kosi river (Near Garjiya Village) |
| **3.** | 29.472767 | 79.13054 | Kosi Canal (Near Post Office Dhikuli) |
| **4.** | 29.41156 | 79.149589 | Dhikuli Resort |
| **5.** | 29.463968 | 79.149589 | River Point (Garjiya road) |
| **6.** | 29.410131 | 79.130890 | Corbett Park |
| **7.** | 29.40524 | 79.13024 | Near Pampapuri |
| **8.** | 29.40122 | 79.13152 | Bharatpuri |
| **9.** | 29.39888 | 79.13201 | Behind GPG College Ramnagar |
| **10.** | 29.395581 | 79.1320890 | Kosi Barrage |
| **11.** | 29.391403 | 79.1306561 | Kosi Canal (Barrage Road) |

### 1.2 Analytical Measurements

All water samples are analyzed using standard protocol for various physiochemical parameters i.e., pH, Electrical Conductivity (EC), total dissolved solids (TDS), total hardness (TH) as $CaCO_3$, major cations such as Calcium ($Ca^{2+}$), Magnesium ($Mg^{2+}$), Sodium ($Na^+$), major anions such as Nitrate ($NO_3^-$), Sulfate ($SO_4^{2-}$), and Chloride ($Cl^-$) in the laboratory. pH, TDS and EC of the water samples were measured on-site by multi-parameter PC Tester 35. This was done to evade the unusual changes in the quality according to the regular protocol (WHO 2011; APHA 2017). Test techniques adopted are the basic protocols proposed by APHA, 2017. Water quality parameters for analysis and investigative techniques are shown in Table 2. The study samples were performed in triplicate and the average values were utilized in the water quality indices.

**Table 2.** Methods used for the analysis of water quality parameters

| Parameters | Methods | References |
|---|---|---|
| pH | pH/EC/TDS meter (multi-parameter PC Tester 35) | APHA(2017) |
| EC | pH/EC/TDS meter (multi-parameter PC Tester 35) | APHA(2017) |
| TDS | pH/EC/TDS meter (multi-parameter PC Tester 35) | APHA(2017) |
| TH | EDTA titrimetric method | APHA(2017) |
| Turbidity | ORLAB Field Water Test Kit | APHA(2017) |
| $Ca^{2+}$ | EDTA titrimetric method | APHA(2017) |
| $Mg^{2+}$ | EDTA titrimetric method | APHA(2017) |
| $Na^+$ | Flame photometric method | APHA(2017) |
| $SO_4^{2-}$ | Turbidimetric method (UV spectrophotometer) | APHA(2017) |
| $NO_3^-$ | UV spectrophotometer | APHA(2017) |
| $Cl^-$ | Argentometric titration method | APHA(2017) |
| DO | Titrimetric method | APHA(2017) |
| BOD | 5-days Incubation method | APHA(2017) |

### 1.3 Water Quality Index

Assessing the quality of water is done using the Water Quality Index (WQI). In present study, to measure water quality, we used the Weighted Arithmetic Water Quality Index (WAWQI). Below, we summarised the methods/steps employed to evaluate the WAWQI:

*3.3.1 Weighted Arithmetic Water Quality Index (WAWQI)*

The WAWQI was measured by following the steps as mentioned [27]:

***Step 1:** Calculation of unit weight (Wi) for different parameters:*

Unit weight (Wi) was calculated using the following formula [36]:

$$W_i = K \sum \frac{1}{S_{Standard}} \quad (1)$$

Where K is a proportionality constant that can be calculated by using the following equation:

$$K = \frac{1}{\sum_1^n \frac{1}{S_n}} \quad (2)$$

According to the formula, unit weight has an inverse relationship to the recommended standard value (Standard) of the corresponding parameter (Table 3).

**Table 3:** Standards values of physiochemical parameters given by BIS and WHO

| S. No. | Physico-chemical Parameters | BIS 10500: (2012) | | WHO (2011) | |
|---|---|---|---|---|---|
| | | Acceptable Limit | Permissible Limit | Acceptable Limit | Permissible Limit |
| 1. | pH | 6.5-8.5 | No relaxation | 6.5-8.5 | No relaxation |
| 2. | EC (µS/cm) | 770 | 1500 | 770 | 1500 |
| 3. | TDS (ppm) | 500 | 2000 | 500 | No relaxation |
| 4. | Alkalinity as $CaCO_3$ (mg/l) | 200 | 600 | 200 | No relaxation |
| 5. | Chloride (mg/l) | 250 | 1000 | 250 | No relaxation |
| 6. | Hardness as $CaCO_3$ (mg/l) | 200 | 600 | 100 | 300 |
| 7. | Potassium (mg/l) | 12 | No relaxation | 12 | No relaxation |
| 8. | Sodium (mg/l) | 200 | No relaxation | 200 | No relaxation |
| 9. | RFC (mg/l) | 0.2 | 1 | 5 | No relaxation |
| 10. | Turbidity (NTU) | 1 | 5 | 1 | 4 |
| 11. | Fluoride (mg/l) | 1 | 1.5 | 0.5 | 1 |
| 12. | Iron(mg/l) | 0.3 | No relaxation | 0.5 | No relaxation |
| 13. | Nitrate(mg/l) | 45 | No relaxation | 50 | No relaxation |
| 14. | Calcium (mg/l) | 75 | 200 | 75 | No relaxation |
| 15. | Magnesium(mg/l) | 30 | 100 | 30 | No relaxation |

***Step 2:*** *Calculation of quality rating scale ($Q_i$) for each parameter:*

To calculate Qi for each parameter, we employed the formula written below:

$$Q_i = \frac{(Q_{act} - Q_{ideal})}{(Q_{standard} - Q_{ideal})} \times 100 \qquad (3)$$

Where, $Q_{act}$ = estimated concentration of $i^{th}$ parameter in the analyzed water; $Q_{ideal}$ = the ideal value of $i^{th}$ parameter in pure water. It has a value 'zero' (except pH = 7.0 and DO = 14.6 mg $L^{-1}$) $S_{standard}$= Recommended standard value of $i^{th}$ parameter

***Step 3:*** *Calculation of overall WQI:*

The WQI was calculated by adding the product of the quality rating of each parameter with the corresponding unit weight and taking the average.

$$WAWQI = \frac{\sum_{i=1}^{i=n} Q_i W_i}{\sum W_i} \qquad (4)$$

The weighted Arithmetic Water Quality Index (WAWQI) method takes the maximum WQI as 100 and grades the water sample on a scale of 0-100 as per its WQI as shown in the table 4.

**Table 4.** Standard rating of water quality as per WQI

| **WQI** | **Water quality rating** |
|---|---|
| > 100 | Unsuitable for drinking |
| 51–100 | Acceptable |
| 26–50 | Good |
| ≤ 25 | Excellent |

## IV. RESULT AND DISCUSSION

### 1.4 physicochemical characteristics

The investigated results of water quality parameters during the PRM, MON and POM seasons of 2020-21 from the Kosi River in Ramnagar City, Nainital, Uttarakhand are presented in Table 5.

**Table 5.** Seasonal variation in water quality of Kosi River near Ramnagar during PRM, MON and POM seasons

| **PARAMETERS** | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **avg** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-monsoon | pH | 7.85 | 7.98 | 7.9 | 7.95 | 8.03 | 8 | 8.05 | 7.93 | 8.01 | 8.21 | 8.23 | 8.04 |
| | Turbidity | 0.85 | 0.76 | 0.68 | 0.74 | 0.84 | 0.88 | 1 | 0.69 | 0.76 | 0.84 | 0.51 | 0.75 |
| | EC | 160.5 | 191.13 | 202.3 | 199.45 | 228.58 | 202.58 | 183.55 | 176.73 | 230.83 | 167.3 | 172.55 | 195.66 |
| | TDS | 207 | 208.75 | 247.5 | 220.75 | 220 | 220 | 232.25 | 200.25 | 237.5 | 236.25 | 232 | 223.88 |
| | TH | 128.5 | 126.5 | 118 | 116 | 117 | 120.25 | 129 | 129.75 | 124.5 | 119.5 | 143.75 | 129.88 |
| | Ca | 88.25 | 84.25 | 81 | 80.25 | 81.5 | 80.75 | 94.75 | 90.25 | 85.5 | 89 | 92.75 | 87.5 |
| | Mg | 32.7 | 34.93 | 33.8 | 36.25 | 33.73 | 37.3 | 44.95 | 47.6 | 44 | 44.88 | 44.08 | 40.15 |
| | Na | 7.1 | 7 | 7.2 | 7 | 7.34 | 7.28 | 7.88 | 7.85 | 7.43 | 7.43 | 7.63 | 7.44 |
| | Cl | 5.3 | 4.33 | 4.68 | 4.23 | 4.98 | 4.4 | 5.3 | 5.5 | 5.2 | 5.28 | 5.85 | 5.04 |
| | $NO_3^-$ | 0.57 | 0.5 | 0.84 | 0.94 | 0.85 | 0.75 | 0.94 | 1.13 | 1.05 | 1.06 | 2.83 | 1.67 |
| | $SO_4$ | 34.98 | 35.76 | 35.13 | 35.75 | 35.1 | 36.55 | 36.08 | 36.95 | 35.48 | 36.65 | 36 | 35.96 |
| | DO | 6.95 | 6.88 | 7.15 | 7.48 | 7.6 | 7.45 | 7.5 | 7.18 | 7.3 | 7.25 | 7.48 | 7.24 |
| | BOD | 3.98 | 4.4 | 4.2 | 3.43 | 3.6 | 3.6 | 3.68 | 4.63 | 3.88 | 4.3 | 4.2 | 4.03 |
| | Phosphate | 0.0058 | 0.0033 | 0 | 0 | 0 | 0.023 | 0.022 | 0.0125 | 0 | 0.0023 | 0.012 | 0.0115 |
| PARAMETERS | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | avg |
| Monsoon | pH | 7.43 | 7.65 | 7.58 | 7.79 | 7.82 | 7.58 | 7.67 | 7.76 | 7.45 | 7.58 | 7.6 | 7.62 |
| | Turbidity | 0.96 | 0.95 | 0.82 | 0.35 | 0.34 | 0.69 | 1.11 | 0.59 | 0.52 | 0.89 | 0.79 | 0.72 |
| | EC | 164.58 | 155.28 | 160.88 | 158.88 | 171.65 | 205.95 | 221.95 | 208.23 | 234.4 | 240.28 | 226.43 | 197.78 |
| | TDS | 245 | 270.25 | 246.25 | 251 | 264.5 | 267.5 | 271 | 289.25 | 273.75 | 292.5 | 294.75 | 269.88 |
| | TH | 133.25 | 128.75 | 123.75 | 127.25 | 128 | 122.75 | 133.5 | 140.75 | 144 | 144.75 | 140.25 | 133.75 |
| | Ca | 99.33 | 98.03 | 99.85 | 98.53 | 100.48 | 113.53 | 110.25 | 116.2 | 120.95 | 130.23 | 134 | 116.01 |
| | Mg | 19.7 | 21.85 | 18.23 | 15.78 | 17.18 | 16.63 | 24.73 | 28.45 | 26.73 | 32.45 | 32.95 | 24.36 |
| | Na | 7.48 | 7.5 | 7.2 | 7.23 | 7.2 | 7.08 | 7.43 | 7.63 | 7.3 | 7.55 | 8.1 | 7.59 |
| | Cl | 5.41 | 5 | 4.78 | 4.83 | 4.6 | 4.1 | 4.53 | 4.96 | 4.56 | 5.02 | 5.3 | 4.76 |
| | $NO_3^-$ | 0.65 | 0.65 | 0.73 | 0.62 | 0.73 | 0.97 | 0.95 | 1.05 | 1.04 | 1.46 | 1.49 | 1.05 |
| | $SO_4$ | 35.95 | 35.5 | 33.9 | 33.88 | 34.8 | 34.65 | 36.1 | 35.93 | 34.58 | 35.4 | 34.5 | 34.99 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DO | 6.15 | 6.15 | 6.65 | 6.88 | 6.6 | 6.15 | 6.13 | 5.93 | 6.03 | 6.05 | 6 | 6.4 |
| | BOD | 4.98 | 5.15 | 4.8 | 4.43 | 4.55 | 5.13 | 5.25 | 5.43 | 5.05 | 5.93 | 5.83 | 5.18 |
| | Phosphate | 0.0013 | 0.0023 | 0 | 0.003 | 0.001 | 0.0125 | 0.0038 | 0.0038 | 0.0035 | 0.01 | 0.0005 | 0.0063 |
| PARAMETRS | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | avg |
| Post-monsoon | pH | 8.18 | 8.15 | 8.05 | 7.95 | 8 | 7.95 | 8.43 | 8.58 | 8.38 | 8.58 | 8.45 | 8.26 |
| | Turbidity | 0.14 | 0.14 | 0.27 | 0.28 | 0.28 | 0.26 | 0.35 | 0.39 | 0.39 | 0.39 | 0.38 | 0.26 |
| | EC | 164.28 | 165.63 | 165.75 | 159.1 | 159.38 | 160.5 | 177.2 | 194.53 | 184.49 | 211.23 | 190.13 | 185.16 |
| | TDS | 234 | 234.75 | 234.25 | 235.25 | 232.75 | 235.75 | 230.75 | 228 | 233.75 | 226.5 | 230.75 | 231.13 |
| | TH | 137.25 | 140 | 138.25 | 139.75 | 143 | 143.75 | 156 | 160.25 | 140 | 157.5 | 164.25 | 150.75 |
| | Ca | 101.6 | 105.2 | 100.15 | 101.35 | 99.05 | 104.78 | 104 | 110.1 | 107.95 | 123.33 | 129.13 | 114.09 |
| | Mg | 15.5 | 16.45 | 16.13 | 17.3 | 18.4 | 18.1 | 25.43 | 30.2 | 28.28 | 31.45 | 33.3 | 24.4 |
| | Na | 6.8 | 6.6 | 6.58 | 6.15 | 6 | 6.15 | 6.65 | 7.05 | 6.75 | 7.35 | 7.8 | 6.9 |
| | Cl | 4.63 | 4.73 | 4.23 | 4 | 4.05 | 4.05 | 4.8 | 4.8 | 4.45 | 4.73 | 4.75 | 4.4 |
| | $NO_3^-$ | 0.54 | 0.49 | 0.79 | 0.65 | 0.79 | 0.7 | 1.16 | 1.19 | 1.08 | 1.15 | 1.12 | 0.84 |
| | $SO_4$ | 32.06 | 32.78 | 33.95 | 32.45 | 31.88 | 30.5 | 32.98 | 34.21 | 31.94 | 32.15 | 32.93 | 32.35 |
| | DO | 7.9 | 7.93 | 8.43 | 8.2 | 9.18 | 8.88 | 8.15 | 7.95 | 8.8 | 7.48 | 7.6 | 8.33 |
| | BOD | 2.08 | 2.18 | 2.05 | 1.9 | 1.15 | 1.15 | 1.68 | 2.15 | 1.35 | 2.53 | 2.48 | 1.84 |
| | Phosphate | 0.0028 | 0.005 | 0.001 | 0.0085 | 0.001 | 0 | 0.0148 | 0.0223 | 0.0078 | 0.0315 | 0.0373 | 0.0186 |

**pH-Value:** The pH value indicates a change in the source's quality. Water that is extremely acidic or alkaline has a sour or alkaline flavour. Furthermore, higher pH values limit chlorine's germicidal potential. The variation in pH in Kosi River during pre-monsoon, monsoon and post-monsoon seasons is shown in the figure 2a.

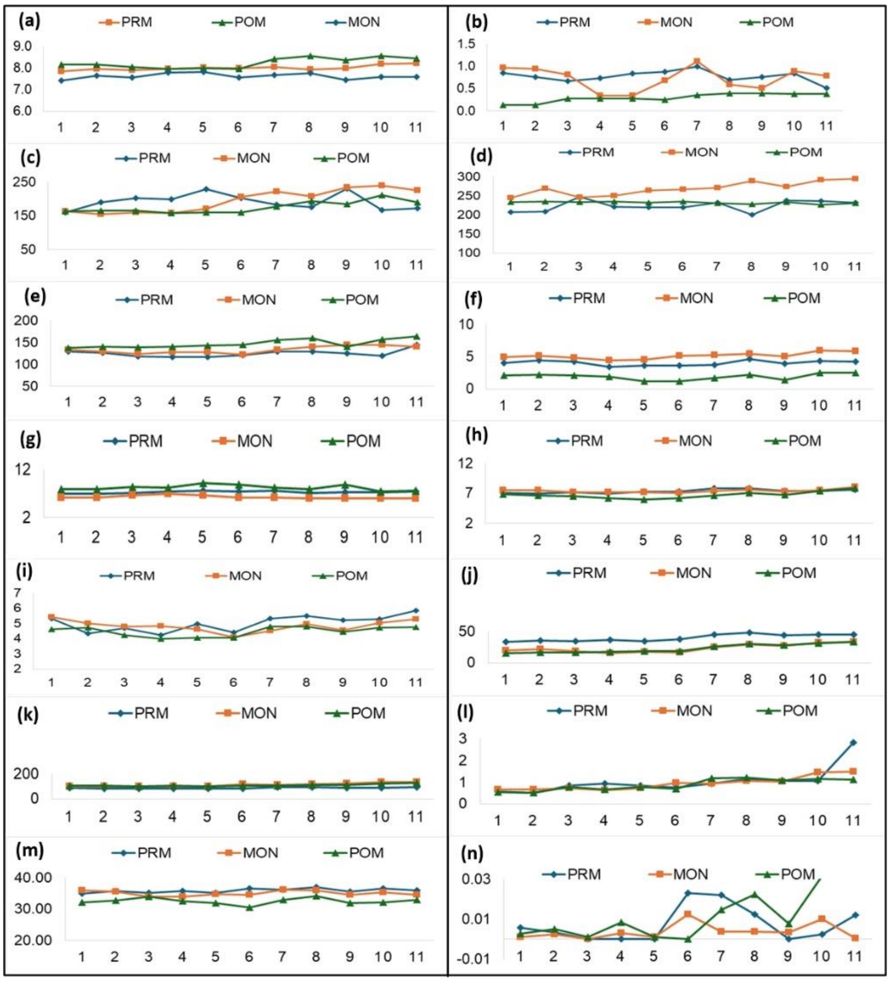



**Fig 2.** Spiderdiagram showing seasonal variations in various physicochemical parameters. **a:** pH values, **b:**turbidity, **c:** Electrical Conductivity (EC), **d:** Total Dissolved Solid (TDS), **e:** Total Hardness (TH), **f:** Biochemical Oxygen Demand (BOD), **g:** Dissolved Oxygen (DO), **h:** Sodium ($Na^+$), **i:** Chloride ($Cl^-$),**j:** Magnesium ($Mg^+$), **k:** Calcium ($Ca^+$), l: Nitrate ($NO_3^-$), **m:** Sulphate ($SO_4^-$), **n:** Phosphate ($PO_4^-$)

The average pH of these sites ranges between 7.85-8.23 with an average of 8.04 during the pre-monsoon season (PRM) whereas, the average pH during monsoon (DM) varied in the range of 7.43-7.82 (Avg. = 7.62) and 7.95-8.58 (Avg. = 8.26) during post-monsoon (POM) season. A geological formation composed of $CaCO_3$ is a major cause of shifting in pH value towards the alkaline or acidic side of neutrality [37,38]. The above findings suggest that the pH level of the river water is slightly higher during the post-monsoon season as compared to the pre- and during-monsoon periods. However, all the pH values fall within the acceptable limit recommended by the World Health Organization (pH = 6.5-8.5). Therefore, it can be concluded that seasonal variations in the river water have a negligible impact on its pH level. The pH range of the river water is safe for human consumption.

**Turbidity:** Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. The more concentration of total suspended solids in the water, the cloudier it seems corroborate to the higher turbidity. The turbidity of drinking water should never exceed 5 NTU. The turbidity of water during PRM at different sampling sites was in the range of 0.51-1.00 NTU with an average of 0.75 NTU (table: 5). The turbidity shows a large variation of 0.34 -1.11 NTU (Avg. = 0.72 NTU) in the DM season (Fig. 2b). On the other hand, the turbidity varies from 0.14 to 0.39 NTU (Avg. = 0.26) in the POM season. The average turbidity of Kosi River water of all seasons collected from different sites is below the acceptable limit (i.e., < 1NTU). As a result, it can be stated that the water of the river is ready for direct use without treating for turbidity. A closer examination shows that there is a negative relationship between the pH and turbidity values of the river. This indicates that a higher pH value reduces the turbidity of water [39].

**Electrical Conductivity:** To measure the concentration of soluble salts in water, electrical conductivity (EC) is used. The higher concentration of charged ions in the water corresponding to more EC of the water. Drinking water with a high concentration of dissolved solids has an unpleasant flavour. The variation in electrical conductivity in Kosi River during pre-monsoon, monsoon and post-monsoon seasons is shown in Figure 2c. In the PRM season, the electrical conductivity of river Kosi water of different sites at Ramnagar ranged between 160.50-230.83 S/cm (Avg. =195.66 S/cm) in the pre-monsoon season. It was found to be 155.28 - 240.28 S/cm (Avg. = 197.78 S/cm) during monsoon and from 159.10 to 211.23 S/cm (Avg. = 185.16 S/cm) in post-monsoon season. All of the values are within the acceptable range.

**Total Dissolved Solid (TDS):** Total Dissolved Solid (TDS) is a term that refers to dissolved solids and colloids in the form of chemical compounds and other substances. High TDS levels in the water can make the water salty and/or bitter. It may not drastically impact our health but the high level of lead or copper can make us sick. The comparison in TDS of Kosi River during PRM, monsoon and POM seasons is shown in Figure 2d. TDS levels in Kosi River in PRM water ranged from 200.25 mg/L to 247.50 mg/L (Avg. = 223.88 mg/L), between 245.0mg/L to 294.75 mg/L (Avg. = 269.88 mg/L) during monsoon and POM water ranged from 226.50 mg/L to 235.75 mg/L (Avg. = 231.13 mg/L). The level of TDS in stream water is influenced by the natural weathering of sedimentary rocks, which increases the presence of a large number of ions or minerals in the stream, which leads to a higher salinity level. TDS in drinking water has an upper limit of 500 mg/L, and all of the values for water samples fall below 500 mg/L.

**Total hardness (TH):** Total hardness is the measurement of the mineral content in a water sample that is irreversible by boiling. More specifically, total hardness is determined by the concentration of multivalent cations ($Mg^{2+}$, $Ca^{2+}$) in water. In PRM season TH of water collected from the river Kosi was in the range of 116.00-143.75 mg/L (Avg. = 129.88 mg/L) whereas during monsoon it had a range of 122.75 - 144.75 mg/L (Avg. = 133.75 mg/L) and POM season the TH values vary between 137.25-164.25 mg/L (Avg. = 150.75 mg/L). A closer look at the data reveals that total hardness increases as the sample site moves away from the hills (refer to Figure 2e).

**Biochemical Oxygen Demand (BOD):** Biochemical oxygen demand is usually defined as the amount of oxygen required by bacteria in stabilizing the decomposable organic matter. BOD can be used to measure the degree of pollution. High BOD levels indicate that the water is highly polluted with organic matter. The BOD level in the research area ranged from 3.43 to 4.63 mg/L (Avg. = 4.03 mg/L), 4.43-5.93 mg/L (Avg. = 5.18 mg/L) and 1.15 to 2.53 mg/L (Avg. = 1.84 mg/L) during PRM, MON and POM season, respectively. There is no any random fluctuation the BOD values (Fig. 2f). high BOD during MON indicates more biodiversity during monsoon.

**Dissolved Oxygen (DO):** Dissolved oxygen plays a significant role in biological processes, both directly (organism physiology and survival), and indirectly (the effect on nitrogen and carbon cycles in water). The dissolved oxygen in the water could be useful up a certain limit. If DO levels are too high, water cannot hold onto other dissolved substances. If DO levels are too low, minerals from riverbeds and runoff will start to dissolve into the water, which affects water quality. The DO levels in the research area ranged from 6.88 to 7.60 mg/L (Avg. = 7.24 mg/L), 5.93-6.88 mg/L (Avg. = 6.40 mg/L) and 7.48 to 9.18 mg/L (Avg. = 8.33 mg/L) during PRM, MON and POM season, respectively. Relatively high DO, measured during POM (fig. 2g) corroborate less microbiological activity in river water.

**Sodium:** The sodium is a vital component required by the human body for a variety of tasks such as muscle and nerve function. Blood pressure and kidney failure are both linked to an increased concentration of Na+ in the blood. The Na level in the research area ranged from 7.00 to 7.88 mg/L (Avg. = 7.44 mg/L), 7.08 - 8.13 mg/L (Avg. = 7.59 mg/L) and 6.00 to 7.80 mg/L (Avg. = 6.90 mg/L) during PRM, MON and POM season, respectively. The occurrence of Sodium ($Na^+$) in groundwater is predominantly attributed to silicate weathering processes and salt demineralization processes such as sodium and aluminium silicate and sodium chloride. Slightly higher sodium concentration (fig. 2h) is caused by more chemical weathering of catchment area during monsoon.

**Chloride:** Chloride is a significant indication of water quality and is abundant in nature in the form of sodium chloride (NaCl), potassium chloride (KCl), and calcium chloride ($CaCl_2$). Chloride concentrated in a wide range in all natural water bodies. The $Cl^-$ concentration in the tested samples was found in the range from 4.23 to 5.85 mg/L (Avg. = 5.04 mg/L), from 4.10 to 5.41 (Avg. = 4.76 mg/L) and 4.0 to 4.80 mg/L (Avg. = 4.40 mg/L) in PRM, MON and POM season respectively. The fluctuation in chloride concentration (fig. 2i) is most probably due to the change in basement rock at various sites.

**Magnesium and Calcium:** Magnesium and Calcium are also significant indicators for evaluating water quality since they have a direct relationship with the development of water hardness of water. Natural water contains different concentrations of these two elements depending on the type of rocks in the area. The variations in the values in the concentration of Mg and Ca are shown in fig. 2j and k, respectively. The $Ca^{2+}$ concentrations in PRM water of river Kosi ranged from 80.25 to 94.75 mg/L, (Avg. = 87.50 mg/L) whereas $Ca^{2+}$ concentrations in MON and POM water ranged from 98.03 to 134.0 mg/L (Avg. = 116.01 mg/L) and 99.05 to 129.13 mg/L (Avg. = 114.09 mg/L) respectively. $Mg^{2+}$ was found to be present between 32.70-47.60 mg/L (Avg. = 40.15 mg/L) in PRM, and it ranged from 15.78 - 32.95 mg/L (Avg. = 24.36 mg/L) in Monsoon and 15.50-33.30 mg/L (Avg. = 24.40 mg/L) in POM season. These values were below the WHO recommended values for calcium and magnesium limits of (100 mg/L and 30 mg/L, respectively). The TH of the river falls in the range of moderately hard water [40].

**Nitrates:** Nitrate ($NO_3^-$) is a plant nutrient that can be found naturally in the environment. Excessive nitrate and nitrite levels in drinking water can result in significant ailments such as “blue baby syndrome”, increased cancer risk, starchy deposits, and spleen haemorrhage. In the PRM water, the concentrations of $NO_3^-$ ranged from 0.50 to 2.83 mg/L, with an average of 1.67 mg/L. On the other hand, in the MON water and POM water, the $NO_3^-$ concentrations were in the range of 0.62 to 1.49 mg/L (average = 1.05 mg/L) and 0.49 to 1.19 mg/L (average = 0.84 mg/L), respectively. A close view indicates that as the river enters the regions near to township (refer, fig. 1c) and towards the plain the nitrate values increase randomly (fig. 2l). Natural $NO_3^-$ concentrations in groundwater usually rise as a consequence of anthropogenic activities such as the discharge of domestic and septic tank effluent and agricultural activities [41]. Furthermore, water containing more than 3 mg/L of nitrite $NO_2^-$ should not be used for baby feeding.

**Sulphate:** Sulphate is a naturally occurring dissolved component in the water bodies that come through the rainwater. High concentrations of sulphate in the drinking water can have a laxative effect if associated with calcium and magnesium. $SO_4^{2-}$ concentration in PRM water was found to be 34.98 to 36.95 mg/L and 33.88 to 36.10 mg/L in the Monsoon, whereas 30.50 to 34.21 in POM season water with an average of 35.96 mg/L, 34.99 mg/L and 32.35 mg/L, respectively. The sulphate concentration graph shows almost leaner pattern in all seasons (fig. 2m). It is worth noting that all values fall within the acceptable limit for drinking water as per BIS (2012) guidelines. Sulfate is mostly found in water systems due to the dissolution of two types of rocks that contain sulfate; gypsum and pyrite [42]. These rocks are located beneath the springs, and their presence in the water system affects the course of the river Kosi. The river flows mainly over the Lesser Himalaya, which has relatively lower amounts of gypsum and pyrite compared to other areas [43].

**Phosphate:** Phosphates enter waterways from human and animal waste, phosphorus-rich bedrock, wastewater, industrial effluents, and fertilizer runoff. Higher concentration of phosphate in the water may provide favorable habitat to grow algae and weeds that consume a large amount of dissolved oxygen. Digestive problems could occur from extremely high levels of phosphate, leading to hypophosphatemia. Phosphate concentration in PRM water was found to be 0.0 to 0.023 mg/L and 0.0 to 0.0125 mg/L in the Monsoon, whereas 0.0 to 0.0373 in POM season water with an average of 0.012 mg/L, 0.006 mg/L and 0.019 mg/L, respectively. There is a random pattern shown in the spider diagram for the concentration of phosphate during all seasons. The randomness in phosphate concentration (fig. 2n) is most probably caused by anthropogenic activity.

### 1.5 Hydrochemical facies

Hydrochemical facies of river water can be calculated through piper trilinear diagram[44]. A Piper diagram is a graphic procedure proposed for presenting water chemistry data to help in understanding the sources of the dissolved constituent salts in water. This procedure is based on the premise that cations and anions in water are in such amounts to assure the electro neutrality of the dissolved salts, in other words the algebraic sum of the charges of cations and anions should be zero.It is assumed that the most abundant cations are two “alkaline earths” calcium and magnesium and one “alkali” sodium. The most common anions are one “weak acid” bicarbonate and two “strong acids” sulphate and chloride. In figure 3, the cations and anions are shown separately on ternary plots. In the cation plot, the apexes are represented by Ca, Mg, and Na, while in the anion plot, the apexes are designated by SO4-, Cl-, and CO3- anions. Both ternary plots are then projected onto a diamond.

The diamond is a matrix transformation of a graph of the anions and cations [44].A piper diagram was created for the pre-monsoon, during-monsoon and post-monsoon seasons using the analytical data obtained from the hydrochemical analysis (fig. 3). In general, the piper diagram classifies the water samples into six fields. They are 1. Ca-$HCO_3$ type; 2. Na-Cl type; 3. Ca-Mg-Cl type; 4. Ca-Na-$HCO_3$ type; 5. Ca-Cl type; and 6. Na-$HCO_3$ type. In the present attempt, piper diagrams of water of the Kosi River in the Ramnagar region of Uttarakhand during the PRM, MON and POM seasons are presented in figures 3a, b, and c. The major ion chemistry results show that Magnesium and calcium is the dominant cation and sulphate is the major anion in all the rivers. Moreover, the plots from the results revealed that in all the water, alkali earth metal elements ($Ca^{2+}$, $Mg^{2+}$) are higher than alkali elements ($Na^{+}$). Further, the piper diagram showed that the water samples collected during the PRM, MON and POM seasons were confined to the Ca-Cl type. The high proportion of Ca and Mg is most probably due to the presence of dolomite and limestone in the region. The chemical composition of the studied water is also could be influenced by rainfall, climate, and various human activities [45].

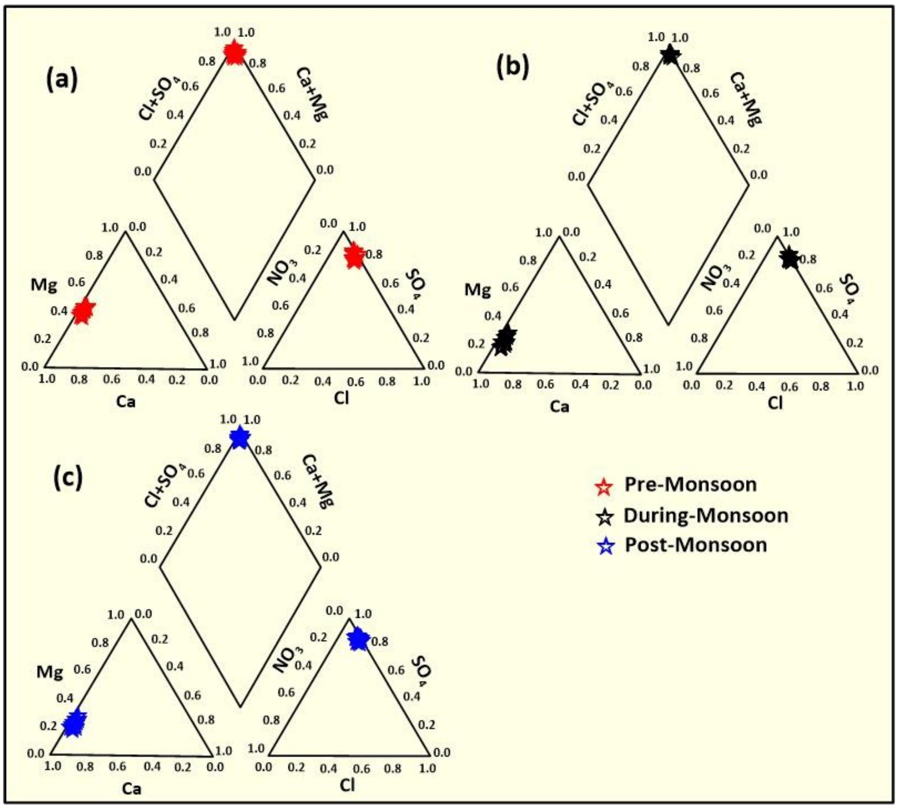



**Fig 3.** Piper diagram for Pre-monsoon, Monsoon and Post monsoon season

### 1.6 Water Quality Index (WQI)

The Water Quality Index (WQI) is an effective tool used to evaluate the quality of spring water for drinking purposes. It groups various parameters and dimensions into a single score, providing a picture of the overall water quality. The Weight Arithmetic WQI was used to determine the WQI of the Kosi River at eleven different sites during different seasons, and the average results are shown in Fig. 4. During the post-monsoon season, the WQI is lower (26.47-41.55; Avg. 33.80), while during the pre-monsoon and monsoon seasons, it is higher (41.43-48.33; Avg. 44.97 and 34.98–42.26; Avg. 38.79 respectively). The WQI exhibits a significant variation in POM, indicating a gradual change in the water volume from the rainy season to the dry season that may cause a change in the physical parameters of water.

Based on the average values of WAWQI, the water of river Kosi falls in the good category in all the three seasons i.e., PRM, MON and POM. This seasonal variation in the WQI can be explained based on a shift in the values of various parameters during the monsoon season. The low water quality of springs is usually due to high levels of turbidity, total hardness, magnesium, total alkalinity, nitrate, dissolved oxygen (DO), and biological oxygen demand (BOD). Scientists believe that this happens because rainwater interacts with sedimentary rock in the area, causing ions to dissolve into the water [41]. Alternatively, it could be due to improper waste disposal, cottage activities, agricultural and urban run-off, sewage, overuse of inorganic fertilizer, and poor operation and maintenance of septic systems (WHO, 2004).

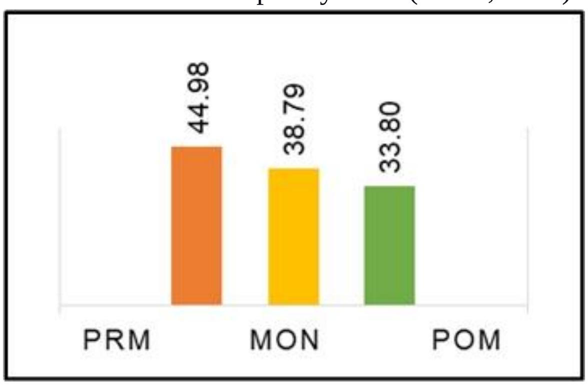



**Fig 4.** Weighted Arithmetic Water Quality Index of the study sites

### 1.7 Irrigation water quality analysis

The river Kosi is also being used for irrigation purposes but the river water so far has not been analyzed for suitability for irrigation purposes. In view of the same, the water of the river Kosi was also analyzed for its suitability and usefulness to meet the irrigational needs of farmers and local population of the area. The suitability of water for irrigation purposes has been evaluated through the parameters namely, SAR; sodium percent (Na %); Kelly's Index (KI) and Magnesium Hazard (MH) or Magnesium adsorption ratio.

#### 1.7.1 Sodium adsorption ratio

Sodium adsorption ratio (SAR) is used to assess the excess of Na, Ca and Mg. The higher amount of Na in water adversely affects the permeability of the reservoir. In addition to this, excessive SAR levels can also cause soil crusting, poor seedling and poor aeration.

The following equation is used for the calculation of SAR values[46].

The SAR for river water in current study is found within the range 0.16-0.18 meq/l with an average of 0.17

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+}Mg^{2+})}{2}}}$$

meq/l during PRM season; 0.16-0.26 meq/l with an average of 0.20 meq/l during Monsoon season and 0.15–0.25 meq/l with an average of 0.17 meq/l in POM season. Based on classification represented in Table 10, it is observed that water of the river Kosi was excellent for irrigation purposes.

**Table 10.** Classification of river water for irrigation purposes based on SAR

| SAR scale | Water class | PRM | MON | POM |
|---|---|---|---|---|
| 0 - 10 | EXCELLENT | 0.17 | 0.20 | 0.17 |
| 10 - 18 | GOOD | - | - | - |
| 18 - 26 | FAIR | - | - | - |
| >26 | POOR | - | - | - |

#### 1.7.2 Kelly's Index

KI is employed to assess alkali hazards to soil in the context of irrigation. An index value exceeding 1 describe unsuitability for irrigation.

The KI in water samples was calculated by following equation:

$$KI = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}.$$

where, all the concentrations of ions are in meq/l. The KI in water ranged from 0.0555 to 0.0637 with an average of 0.0583 during PRM season; 0.0464-0.0632 with an average of 0.0541 during Monsoon season and 0.0475-0.0581 with an average of 0.0498 during POM season. The calculated KI showed that water of the Kosi River is suitable for irrigation purposes.

#### 1.7.3 Magnesium Hazard (MH) or magnesium adsorption ratio

The magnesium content relative to the total divalent cations in water used for irrigation purpose is calculated to measure its adverse impact on crops. High magnesium absorption can affect the physical properties of souls. Harmful effects become apparent when the ratio falls below 50. The MH in water samples was calculated by following equation:

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100.$$

The MH in water ranged from 27.036 to 33.977 with an average of 31.453 during PRM season; 13.805-19.736 with an average of 17.354 during Monsoon season and 13.237-21.525 with an average of 17.619 during POM season. The calculated MH showed that water of the river Kosi was suitable for irrigation needs.

#### 1.7.4 Sodium percentage (Na %)

Sodium percentage is another important parameter should be measure in water used for irrigation purposes. Excess sodium in water reacts with soil, reduces soil permeability and supports little or no plant growth (Wilcox 1955).

The Na% in the water sample was calculated by the following equation:

$$\mathrm{Na\%} = \frac{\mathrm{Na^+ + K^+}}{(\mathrm{Ca^{2+} + Mg^{2+} + K^+ + Na^+})} \times 100$$

where all the concentrations of ions are in meq/l. The Na% in water ranged from 5.03 to 5.86 meq/l with an average of 5.26 meq/l during PRM season; 4.44-5.95 meq/l with an average of 5.13 meq/l during Monsoon season and 4.08-5.38 meq/l with an average of 4.35 meq/l during POM season. The calculated Na% showed that water of the river falls within the excellent water quality (Table 11) for irrigation needs.

**Table 11.** Classification of river water for irrigation purposes based on Na %

| SAR scale | Water class | PRM | MON | POM |
|---|---|---|---|---|
| <20 | EXCELLENT | 5.26 | 5.13 | 4.35 |
| 20-40 | GOOD | - | - | - |
| 40 - 60 | PERMISSIBLE | - | - | - |
| 60-80 | DOUBTFUL | - | - | - |
| >80 | UNSUITABLE | - | - | - |

## V. CONCLUSION

The hydrogeochemistry of Kosi River at Ramnagar is significantly influenced by various factors, including oceanic limestone weathering, evaporation, rock-water interaction, and anthropogenic activities. The thorough investigation of various parameters of the river Kosi at Ramnagar, Uttarakhand helped to trace their seasonal variation and were found within the permissible limit of the WHO (2004) standards for drinking water that helped to measure the water quality of the river. It was found that all the water quality parameters showed significant variation throughout the year. No samples were deemed unsuitable for irrigation based on indices such as the Kelly's Index (KI), Magnesium Adsorption Ratio (MAR), Soluble Sodium Percentage ($Na^+$ %), and Sodium Adsorption Ratio (SAR). Analysis using the Piper plot revealed that calcium-chloride water types in different parts of the region indicate leaching of ions due to dilution. The dominance of calcium carbonate and magnesium carbonate is confirmed by the presence of an ion exchange process resulting in the limestone dissolution in the area. Latest tools like machine learning, isotope studies and geophysical methods would improve the research dealing with system of systems.

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