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Study of Evaluation of Water Quality of Himalayan Rivers in Uttarakhand (India)

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Abstract
As we know that the human activities, disposal of untreated or treated effluents, poor sewage and drainage systems, etc. have degraded Himalayan river water quality for decades. The water quality of three significant Kumaun Himalayan rivers—Gola, Kosi,and Ramganga, was examined in this study. All these rivers supply drinking and irrigation water to these Uttarakhand Kumaun districts. Recently, pre- and post-monsoon river water samples were examined for water quality. Most chemical properties correlate statistically. Figure shows all water samples are Ca–Mg–HCO3 hydrochemical facies. Water quality index showed that river water in both seasons is unsafe for drinking. According to sodium adsorption ratio, salt percentage, and residual sodium carbonate, all river water was appropriate for irrigation in both seasons. Eutrophication, tourism, anthropogenic, and geogenic activities may degrade all rivers' water quality, according to this study. Thus, a water resource planning programme is needed to revive all these rivers.

Keywords *Water Quality, Drainage system, Hydro chemicals, Sodium percentage Anthropogenic Activities etc.*

I. Introduction

Rivers provide residential and irrigation water. Population growth, urbanisation, industrialisation, and deforestation are threatening river water quality. River basin resources are depleting and deteriorating. River water quality varies spatially and temporally. Seasonal fluctuations in quality of surface water are crucial for assessing river contamination from nonpoint and point sources. Uttarakhand, a Himalayan Indian state, includes Garhwal and Kumaun. Hill state geography differs from India's plain states. Several holy streams and spring originate in this state. The Kumaun division's principal water sources are rivers, streams, springs, and lakes. These provide water for over 50% of the region's population. Locals conserve irrigation and drinking water using traditional methods. However, domestic garbage, the weathering of rocks, anthropogenic activity, and sewage effluents pollute these rivers' water, affecting its physico-chemical and morphological properties and river water quality. Rivers can no longer regenerate themselves, and as pollution increases, their water becomes unsafe for drinking, farming, and other uses. Thus, human safety requires river water quality study and management.

Some Uttarakhand river water quality studies have been published. However, literature review found insufficient research on Kumaun's Himalayan rivers' water quality. Thus, in continuation of our earlier work, the present study investigates the irrigation and drinking water quality status of three important rivers of Kumaun division of Uttarakhand, namely Gola, Ramganga, and Saryu, which flow through five districts: Nainital, Pithoragarh, Bageshwar, and Nainital. Thus, this study evaluates water quality in three Uttarakhand, India, rivers.

II. Materials And Methods

Examined rivers Pre-monsoon (PRM) and post-monsoon (POM) seasons in recent years were used to assess the drinking and irrigation water quality of three rivers in Uttarakhand that are significant for various drinking, domestic, and irrigating activities. The studied rivers' concise descriptions are summed up as follows in this regard:

Gola River

Gola River is mostly a spring-fed river that rises in the Lesser Himalayas. Water is obtained from this river by the towns of Haldwani and Kathgodam. Over this river in Kathgodam is a very lovely dam. Due to unlawful mining, this river has often been in the news. Tigers, elephants, and other wild species in this Terai region of Kumaun are in danger of extinction due to the continuous erosion of the Gola River forest corridor.

River Ramganga

The Ramganga River rises from the Namik Glacier in the Pithoragarh district of Uttarakhand's Kumaun division, between Birthi Falls and Kwiti Village, and runs east through a number of heavily forested areas. Many small and large rivers feed into this river, which eventually enters the Saryu River at Rameshwar, which is close to Pithoragarh's Ghat.

River Kosi

A significant tributary of the holy River Ganga, the Kosi River has a catchment area of 3,420 sq km and has its spring source in Rudradhari (district Almora, Kumaun division, Uttarakhand). There are 240 kilometres in the river overall. It is used for a variety of things, including drinking, washing and bathing, fishing, and disposing of waste, including solid waste, household waste, industrial waste, and cremation waste.

Sample collection procedure

The water samples were collected from all five riversduring PRM and POM seasons in the recent yearsduring the month of April–June and October–December,respectively. The samples were collected from differentsites of all the rivers. The detail of sampling sites is shownin Fig. 1.

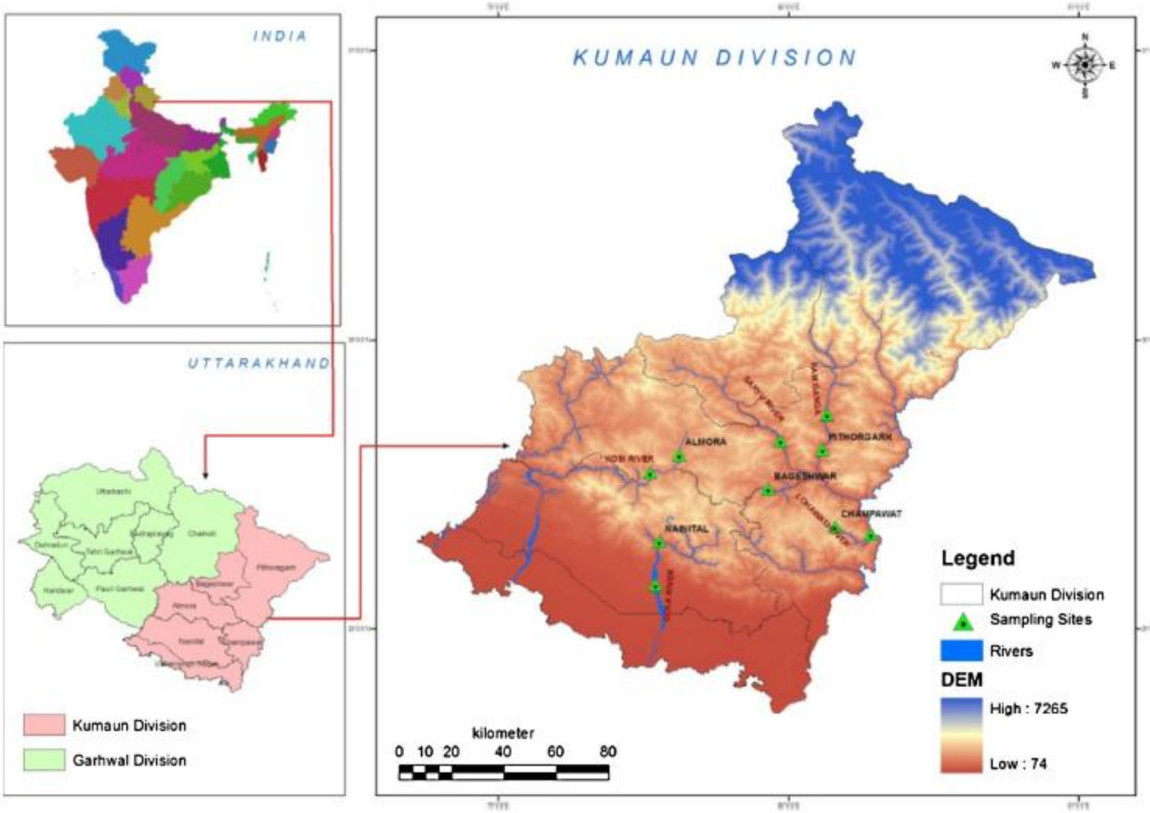

Fig. 1 Location map of sampling sites of studied rivers of Utttarakhand region (India)

Analytical methods

On-site analysis was done for physico-chemical variables such pH, alkalinity, and turbidity. The other parameters such as hardness, total dissolved solids (TDS), nitrate, chloride, fluoride, sulphate, sodium, potassium, calcium, magnesium, iron and total coliform (TC) and faecal coliform (FC) were analysed in laboratory after samples preservation as per Bureau of Indian Standards (BIS 1991) and American Public Health Association (APHA) guidelines.

Using a pH metre and a nephelometer, respectively, the pH and turbidity were determined. Using a DR 5000 Spectrophotometer, colorimetric tests for sulphate, fluoride, and nitrate were measured. The Atomic Absorption Spectrophotometer Varian-AA240 was used to conduct the metal ions studies (AAS). The membrane filter technique was used to calculate the number of colonies/100 ml of the sampled water for microbial analysis.

Utilizing SPSS 13, a statistical analysis was performed to determine the association between the chosen water quality measures. In order to get conclusive information regarding the hydrogeochemical facies of all the rivers, piper diagrams were created using the Aqua- Chem software. To determine if a river is suitable for drinking, the weight arithmetic water quality index (WQI) of all the rivers has been constructed using 11 water quality criteria. To establish if river water is suitable for irrigation, variables like the sodium adsorption ratio (SAR), sodium percentage (Na%), and residual sodium carbonate (RSC) were calculated.

III. Results And Discussion

The analyzed results of water quality parameters in PRM and POM seasons of three rivers of Uttarakhand region Himalayan Rivers are presented in Table 1.

Parameter	**Gola River (Nainital)**		**Koshi River (Almora)**		**Ramganaga River (Pithoragarh)**	
	PRM	**POM**	**PRM**	**POM**	**PRM**	**POM**
Turbidity, NTU	**5.9 ± 2.62**	**28.4 ± 3.93**	**5.4 ± 1.08**	**20.7 ± 5.86**	**5.9 ± 1.60**	**7.4 ± 1.61**
pH	**8.48 ± 0.14**	**7.68 ± 0.14**	**8.09 ± 0.14**	**7.61 ± 0.22**	**8.46 ± 0.13**	**8.07 ± 0.30**
Total hardness, mg/l	**570 ± 86.16**	**135 ± 12.66**	**342 ± 19.69**	**70 ± 23.18**	**372 ± 41.78**	**206 ± 35.77**
Alkalinity, mg/l	**461 ± 12.57**	**115 ± 11.12**	**222 ± 14.41**	**57 ± 10.13**	**325 ± 52.60**	**186 ± 34.79**
Chloride, mg/l	**25 ± 8.06**	**10.2 ± 3.76**	**40.3 ± 29.12**	**12.3 ± 7.08**	**17.3 ± 1.92**	**14.0 ± 1.41**
TDS, mg/l	**884 ± 124.88**	**224 ± 17.69**	**469 ± 39.02**	**127 ± 19.91**	**555 ± 92.66**	**344 ± 43.05**
Sodium, mg/l	**4.31 ± 0.61**	**3.97 ± 1.23**	**6.00 ± 1.96**	**3.85 ± 0.98**	**4.80 ± 0.70**	**4.22 ± 0.42**
Potassium, mg/l	**2.07 ± 0.39**	**1.49 ± 0.31**	**2.16 ± 1.32**	**1.18 ± 0.57**	**1.30 ± 0.25**	**1.45 ± 0.51**
Calcium, mg/l	**119 ± 75.72**	**37 ± 3.90**	**62 ± 43.83**	**19 ± 8.14**	**86 ± 7.89**	**34 ± 11.05**
Magnesium, mg/l	**36 ± 7.81**	**12 ± 0.01**	**12 ± 5.19**	**6 ± 0.73**	**25 ± 10.28**	**20 ± 8.94**
Sulphate, mg/l	**39 ± 2.87**	**16 ± 5.00**	**21 ± 15.42**	**5 ± 2.60**	**15 ± 6.61**	**8 ± 2.49**
Nitrate, mg/l	**0.9 ± 0.43**	**0.5 ± 0.45**	**1.7 ± 0.86**	**0.6 ± 0.22**	**2.7 ± 0.73**	**1.1 ± 0.71**
Fluoride, mg/l	**0.59 ± 0.04**	**0.31 ± 0.14**	**0.42 ± 0.21**	**0.23 ± 0.06**	**0.35 ± 0.14**	**0.33 ± 0.06**
Iron, mg/l	**0.662 ± 0.74**	**0.018 ± 0.01**	**2.076 ± 1.10**	**0.139 ± 0.10**	**1.408 ± 1.99**	**0.227 ± 0.13**
TC, colonies/100 ml	**105 ± 11.51**	**52 ± 8.58**	**56 ± 11.52**	**26 ± 5.40**	**64 ± 6.04**	**42 ± 5.87**
FC, colonies/100 ml	**23 ± 4.97**	**10 ± 1.58**	**11 ± 4.27**	**8 ± 2.55**	**10 ± 1.92**	**11 ± 1.79**

Due to suspended solids like clay, silt, colloidal organic matter, planktons, and other organisms, turbidity measures the clarity of the water. During the PRM and POM seasons, respectively, the average turbidity values ranged from 5.4 to 1.08 to 14.3 to 3.10 and from 7.4 to 1.61 to 47.3 to 8.12 NTU. Drinking turbid water increases your risk of getting gastroenteritis. pH often identifies the acidic or alkaline nature of water quality. All of the river water samples used in the study have pH values that are within the 6.5–8.5 range that is set by BIS. In the water samples that were tested, the average pH value varied between 7.66 and 8.48 and 0.14 during the PRM season and between 7.61 and 8.12 and 0.34 during the POM season. Higher pH levels affect mucous membranes, corrosion, and aquatic life in addition to giving water a bitter taste.

Water that is too hard makes it difficult for soap to form a lather. Calcium and magnesium are the main cations that contribute to hardness. Hardness is also influenced by other cations like strontium, iron, and manganese. Bicarbonate and carbonate are the major anions that cause hardness. In river water samples, the mean concentration of hardness varied from 342 mg/l to 570 mg/l during PRM and from 70 mg/l to 206 mg/l during POM season. All river water samples taken during the PRM season had concentrations that were higher than the preferred level for hardness, which is 300 mg/l, however none of the samples taken during POM exceeded the standard. Although water hardness itself has no harmful effects on health, a higher concentration of it can lead to kidney stone problems and heart disease. During the PRM and POM seasons, respectively, the mean alkalinity in water ranged from 218 7.60 to 461 12.57 and from 57 10.13 to 186 34.7 mg/l. All river water samples were found to have concentrations that were higher than the desired limit for alkalinity, or 200 mg/l, during the PRM seasons, but the concentration was found to be well below the limit during the POM seasons.

Water becomes alkaline due to carbonates, bicarbonates, and hydroxide constituents, which can come from dissolved sediments, salts, or rocks.

TDS is a quantitative measurement of all dissolved particles in water, both organic and inorganic. TDS has a desirable limit of 500 mg/l and a permissible limit of 2,000 mg/l, according to BIS. TDS levels in water samples varied from 127 to 344 mg/l in the POM season and from 427 to 884 mg/l on average during the PRM season. During the PRM season, the TDS mean value in the Gola, Ramganga, and Saryu River water samples exceeded the desired limit, or 500 mg/l, whereas during the POM season, none of the samples did. High TDS affect other aspects of water, including taste, hardness, corrosion resistance, and osmoregulation of fresh water organisms. These effects are not typically removed by conventional methods, which reduces the usefulness of water for irrigation and drinking.

In the study of all the river water, the concentration of chloride was found to be quite low. In PRM season, the average concentration varied from 14.8 mg/l to 40.3 mg/l, and in POM, it varied from 10.2 mg/l to 14.7 mg/l. The presence of chloride in the water is caused by irrigation runoff, seawater intrusion, and the weathering and dissolution of salt deposits. Water with an excessive amount of chloride has a salty taste and may develop hypertension, osteoporosis, renal stones, or asthma.

A fluoride concentration in drinking water of about 1.0 mg/l effectively reduces dental caries while having no negative health effects, but a high concentration can lead to dental and skeletal fluorosis.

River water contains very little fluoride, with average values ranging between 0.35 and 0.14 and 0.59 and 0.04 mg/l in PRM season and between 0.22 and 0.07 and 0.39 and 0.13 mg/l in POM season.

Gypsum and other common mineral sources cause sulphate to naturally occur in water. According to BIS, the sulphate concentration in the water samples from all the rivers is within the acceptable range of 400 mg/l and the desirable range of 200 mg/l. During the PRM and POM seasons, the mean concentration ranged from 4 to 16 mg/l and from 6 to 61.95 mg/l, respectively. Sulphate is typically non-toxic, although drinking water with a lot of sulphate causes digestive issues in healthy people.

The presence of coliform bacteria in water indicates that it has been contaminated with human or animal faeces. Coliform bacteria are markers of harmful organisms. Typhoid, hepatitis, and other waterborne illnesses including diarrhoea are brought on by contaminated water with human waste. The data analysis revealed that total and faecal coliform are present in the water of every river. A high level of coliform counts in water tests points to a contaminated source, insufficient post-treatment steps, inappropriate solid waste handling practises, and inadequate treatment or post-treatment defects.

Correlation matrix

The statistical analysis has been carried out by Pearson'scorrelation coefficient between different pairs of waterquality parameters of river water to develop the significant correlation among the parameters. The data analysis yielded anR-value, which is a correlation representing the linearrelationship between the data pairs. A linear associationimplies that as one variable increases, the other increases ordecreases linearly. Values of the correlation coefficientclose to -1 (positive correlation) imply that as one variableincreases, the other increases nearly linearly. On the otherhand, a correlation coefficient close to -1 implies that asone variable increases, the other decreases nearly linearly.Values close to 0 imply little linear correlation between the variables or no correlation . When data are truly independent, the correlation between data point is zero. The values of coefficient correlation were determinedusing SPSS software version13 in both PRM andPOM seasons. Pearson's correlation in PRM and POMseasons showed strong positive and negative correlationsamong the parameters as shown in Table 2. The strongpositive correlation of pH with Mg^{2+} in PRM (r = 0.901)and in POM (r = 0.915) is due to hydrolysis of ion onsurface of water. Hardness showed strong positive correlationsin both seasons of PRM and POM with alkalinity(r = 0.901 and 0.975) and TDS (r = 0.975 and 0.948)while hardness is also strong positive correlated with Ca^{2+}(r = 0.922). The result showed that there was great dependenceof hardness on calcium, TDS, and alkalinity. The correlationanalysis indicates that river water samples are hard.Alkalinity in PRM season strong positively correlated withTDS (r = 0.964) andwithMg^{2+} in POMseason (r = 0.901),TDS strong positive correlated with Ca^{2+}(r = 0.909) duringPRM season and SO_4^{2-} negative correlated with NO_3^-(r = -0.892). The positive and negative correlation amongthe parameters could be taken as representing the majorsources of seasonal changes in water quality.

Hydrochemical facies

The hydrochemical facies of river water can be obtainedthrough Piper trilinear diagram (Piper 1994). This diagrameffectively classifies the water quality by the distribution ofmajor cations like Na^+, K^+, $\mathrm{Ca}^{2+}$and $\mathrm{Mg}^{2+}$and some major anions like Cl^-, $\mathrm{SO}_4^{2-}\mathrm{CO}_3^{2-}and\mathrm{HCO}_3^-$Thisdiagram represents the cations and anions composition ofsamples on a single graph in which major groupings ortrends in the data can be distinguish visually (Pradhan andPirasteh 2011). It consists of geometrical combination oftwo outer triangles and a middle or inner diamond shapedquadrilateral. The distribution of major cations and anionsin meq/l are shown by the left and right and these plottedpoints in the triangular fields are projected further into thecentral diamond-like quadrilateral structure, which providesthe overall characteristics of the water samples.

Drinking and irrigation water quality analyses

Drinking water quality analysis

An all-encompassing analysis of water quality and its suitability for drinking is provided by the water quality index. The fundamental goal of WQI is to transform complicated data about water quality into information that regular people can use to understand the condition of water sources in a specific area. The 11 water quality characteristics, including turbidity, pH, total hardness, alkalinity, chloride, total dissolved solids, calcium, magnesium, sulphate, nitrate, and iron, which showed the greatest seasonal variations and also significantly varied at different sampling sites, are used in the current case to calculate the weighted arithmetic index using the following equation:

$$\mathrm{WQI} = \sum \mathrm{W_i Q_i} / \sum \mathrm{W_i} \qquad (1)$$

Table 2 Pearson’s correlation for different water quality parameters of rivers during PRM and POM seasons

Parameter	Season	Turbidity	pH	Hardness	Alkalinity	Cl^-	TDS	Ca^{2+}	Mg^{2+}	SO_4^{2-}
Turbidity	PRM	1								
	POM	1								
pH	PRM	0.307	1							
	POM	0.108	1							
Hardness	PRM	0.243	0.58	1						
	POM	-0.198	0.770	1						
Alkalinity	PRM	-0.029	0.732	0.901	1					
	POM	-0.197	0.860	0.975	1					
Cl^-	PRM	-0.203	0.045	-0.081	-0.120	1				
	POM	0.147	0.753	0.457	0.481	1				
TDS	PRM	0.130	0.700	0.975	0.964	-0.007	1			
	POM	-0.204	0.597	0.948	0.856	0.441	1			
Ca^{2+}	PRM	0.495	0.767	0.922	0.853	-0.223	0.909	1		
	POM	0.188	0.640	0.447	0.596	0.016	0.164	1		
Mg^{2+}	PRM	0.350	0.901	0.380	0.586	-0.330	0.485	0.661	1	
	POM	-0.127	0.915	0.781	0.901	0.460	0.549	0.811	1	
SO_4^{2-}	PRM	0.841	0.586	0.647	0.398	0.091	0.581	0.783	0.419	
	POM	-0.160	-0.258	0.129	0.117	-0.805	0.066	0.424	0.077	1

The unit weight ($\mathrm{W_i}$) for each water quality parameter is calculated using the following equation:

$$\mathrm{W_i} = \mathrm{K/S_i} (2)$$

where, K is appropriately constant and Si is the standard permissible value of the ith parameter. The quality rating ($\mathrm{Q_i}$) of Eq. (1) is calculated as under.

$$\mathrm{Q_i} = (C_i/S_i) \times 100 (3)$$

where, C_i is estimated concentration of ith parameter in the analyzed water. The standard rating of water quality according to WQI is given below in Table 3. The calculated WQI for water samples of all the three major rivers for determining their suitability for drinking purpose is given in Table 4.

The outcome demonstrated that in river water, PRM season had a higher value of WQI than POM season. Except for the rivers shown in Fig. 3, all of the rivers' water conditions throughout the PRM season were deemed unsatisfactory with a grade of "E." The water quality of the rivers in POM ranged from good to unfit, with grades "B" and "E." River water's unsuitability during PRM and POM seasons is mostly caused by high levels of turbidity, iron, and total coliform, all of which are documented beyond the allowable limit. A significant number of anthropogenic activities near river banks, including sewage discharge, cremations, detergents from bathing and laundry, as well as agricultural runoff, also contribute to the high water quality index in river water.

Irrigation water quality analysis

All of the rivers are used for irrigation, although none of the river water has been examined to date for its appropriateness for irrigation. Accordingly, the water of all five rivers was examined to determine whether it would be suitable and practical to meet the local population's and farmers' irrigation needs. Three factors—SAR, sodium percent (Na%), and RSC—have been used to assess the water's appropriateness for irrigation.

Sodium adsorption ratio

To assess the excess sodium with calcium and magnesium, sodium adsorption ratio is utilised (Richards 1954). The presence of too much salt in water generally causes a decrease in permeability. Continuous use of water with a high SAR level can cause the Na level to rise over time, which in turn can have a negative impact on the rates of soil infiltration and percolation. Additionally, high SAR levels might result in soil crusting, poor seedling development, and insufficient aeration.

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

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

Table3 Water quality index of the river water during PRM and POM seasons

Name of rivers	**PRM**		**POM**	
	WQI	WQR	WQI	WQR
Gola River	139.22	Unsuitable	64.61	Poor
Kosi River	204.01	Unsuitable	47.93	Good
Ramganga River	163.67	Unsuitable	59.37	Poor

Residual sodium carbonate

If the water has a higher concentration of bicarbonate ions, the sodium hazard also rises. There is a propensity for calcium and magnesium to precipitate as carbonates as the soil solution becomes more concentrated, increasing the relative fraction of sodium as a result. RSC was utilised in this instance to measure the impact of the carbonate and bicarbonate (Eaton 1950). In order to calculate RSC, the following equation was used:

$$RCS = \left(CO_3^{2-} + HCO_3^{-}\right) - (Ca^{2+} + Mg^{2+})$$

Table 4 Classification of river water for irrigation purposes based on SAR

SAR scale	**Water class**	**PRM**	**POM**
0–10	Excellent	All rivers	All rivers
10–18	Good	-	-
18–26	Fair	-	-
>26	Poor	-	-

Table 5 Classification of river water for irrigation purposes based on RSC

SAR scale	**Water class**	**PRM**	**POM**
$\mathbf{< 1.25}$	Safe/Good	All rivers	All rivers
1.25-2.50	Marginal/doubtful	-	-
>2.50	Unsuitable	-	-

Table 6 Classification of river water for irrigation purposes based on Na%

SAR scale	**Water class**	**PRM**	**POM**
$\mathbf{< 20}$	Excellent	All rivers	All rivers
20-40	Good	-	-
40-60	Permissible	-	-
$\mathbf{60 - 80}$	Doubtful	-	-
>80	Unsuitable	-	-

Sodium percentage

Another factor to consider while assessing the quality of water for irrigation is the sodium content. A high salt content in water reacts with the soil, diminishing its permeability and promoting minimal to no plant development (Wilcox 1955). The following equation was used to determine the Na% in the water sample:

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

IV. Conclusions

The monitoring program's findings mark the first analysis of its kind to evaluate the quality of water for irrigation and drinking on the Kumaun region of Uttarakhan's five Himalayan rivers. Indicating successful ionic leaching from dilution, all water quality measures recorded higher values in PRM compared to POM and displayed considerable seasonal change. All of the river water samples, according to a Piper diagram, were of the Ca-Mg-HCO3 type. Water quality index analysis of all the rivers' drinking water quality came to the same conclusion that the water was unsuitable for consumption but appropriate for irrigation. The findings showed that the area needs sufficient sanitary facilities to manage the most severe problem, which is bacterial pollution in the rivers system.

In addition, installing urban drainage and rainwater harvesting systems in the region can reduce the spread of pollution from agricultural and urban runoff into the river. Additionally, there is an urgent need to develop strategies for sustaining the water quality of Uttarakhand's three rivers, which are valuable resources for the Himalayan region.

The results of the analysis showed that while the concentration of iron exceeded both desirable and permissible limits as a result of anthropogenic and geogenic activities, other parameters, including turbidity, TDS, alkalinity, hardness calcium, and magnesium, were above desirable limits but within permissible limits. All of the river water samples' higher total and faecal coliform contamination levels indicated that the river water is contaminated by sewage systems as well as runoff from areas where people defecate in the open along the banks.

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