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# Groundwater Assessment in Udham Singh Nagar, Uttarakhand, India using Multivariate Statistical Techniques, WQI, and HPI.

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**Abstract**

To assess the changes in Groundwater quality and metal pollution, we carried out a study and identify the sources in the U S Nagar district of Uttarakhand state of India using multivariate statistical techniques. The two essential indicators of any developed society are Safe drinking water and decontamination. This research aims to undertake drinking Water quality analyses of the groundwater and the sources of contamination in Udham Singh Nagar district, Uttarakhand. We produced results of 250 samples collected from hand pumps (Govt. and Private) and artesian wells. We measured 19 parameters which nine physicochemical parameters (pH, EC, TDS, DO, oxidation and reduction potential(ORP), salinity, fluoride, chloride, nitrate), 7 Heavy metals (Lead, nickel, chromium, copper, iron, manganese, zinc) along with three metals (potassium, magnesium, sodium). Water quality index, Heavy metal pollution index(HPI), Principal component analysis(PCA)/factor analysis(FA), and Cluster analysis (CA) methods were applied. WQI index shows five samples (2 %) comes under the excellent, 211 samples (84.4 %) fall under good quality, and 34 samples (13.6 %) have poor Water quality wqi status as per Yadav index. Further, referring to the Ramakrishnaiah index, 216 samples (86.4 %) fall under excellent quality and only 13 samples (13.6 %) come under good water quality. For HPI, as per Indian Standard, nearly 40.4% of samples show a low degree of pollution, 33.2% of samples show a medium degree of pollution, and 26.4% show a High degree of pollution. According to the International HPI standard, 46% of samples show a low degree of pollution, 38% have a medium degree, and 16% show a high-grade degree of pollution. The results of PCA show that groundwater has mainly geogenic (geochemical

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alteration and weathering of source rock like carbonate, dolomite, quartzite, etc.) followed by anthropogenic sources (agrogenic, domestic sewage and industrial wastes etc.). The results obtained through the PCA are also moderately supported by Cluster analysis. The cations which were over the limit in groundwater samples are presented in chronological sequence Fe > Pb > Ni > Mg > Mn > Zn > Cu, and significant anions were over the limit $F^{-}$ > $Cl^{-}$, and the rest was under the limit. The highly heavy metal-contaminated drinking groundwater sample, being used for drinking purpose, is deteriorating and need an appropriate treatment approach earlier than domestic water supply.

**Introduction**

Due to its extensive effects on human health, sustainable management of water and its contamination requires our full attention. The litho logy of the region, atmospheric input, climatic situation, and anthropogenic input are a few notable elements that can have an extensive impact on the quality of groundwater resources at any given location. Surface and groundwater are harmed by natural process for example variations in rain inputs, soil wearing away, and weathering of crustal rocks, which impair the utilisation of water resources for a variety of reasons, including drinking, industrial use, farming, recreation, and other uses. Surface run off is a cyclic phenomenon that is mostly influenced by the climate in the basin, unlike wastewater from municipal and industrial release, which contains a persistent pollute source.[1,2] Changes in water chemistry at both the temporal and spatial levels, as well as yearly variations in precipitation type and rate, surface runoff, groundwater flow rate, and water interception and detachment, all have a major effect on river discharge, which in turn has a result on pollutant concentrations in surface and groundwater.[3, 2]

If metal-containing solutions enter the surface with organic matter in the soil, the patches of natural heavy metals become poisoned. As a result, surface soil and water can contain up to several percent of heavy metal Pb and others. Geogenic or anthropogenic activities may cause trace metal contamination of groundwater, a few trace metals, e.g., zinc, copper and manganese is necessary for humans, high levels may result in physiological problems. Pb occurs as only one mineral galena(PbS) that are disseminated through largely mono-mineralized rock (quartzite, primarily SiO2), making the geological setting of our study area relatively simple. The main rocks types of the study area are gneisses, quartzite, schist, calc-silicate, and leucogranite dikes, especially at higher (northern) elevations.[4] Depending on the physiographic, geology and soil texture of the area, the chemical class of groundwater of shallow & deep aquifers varies widely. The Ca-Mg-$HCO_3$ and Ca-$HCO_3$ types of groundwater aquifers are dominated. Cr and Pb trace metals are noxious at low concentration.[5] Such as industrialization and urbanization types of anthropogenic activity have led to the result of environmental contamination on today's earth. As per 2002 UN reports, in urban areas, 50% of the world's residents lives and grows faster because of continued human subsistence. Environmental pollution has a feeble impact on air, land and water quality. Notably, Groundwater accounts for only 0.61 percent of the globe's total water resources, with oceans and frozen icebergs providing twenty percent of the globe's supply of freshwater.[6] The largest source of drinkable water that is currently available on a worldwide scale, out of all the freshwater, is groundwater. In developing nations like India, groundwater is used for household, industrial, and agricultural uses.

The main issue with the pollution of groundwater is the unbearable disposal of industrial, agricultural and home waste. Groundwater contamination has a detrimental result on both human health and aquatic environment. The swift industrialisation and urbanisation caused a buildup of trace metals in the soil & water, which has been reported in a abundant studies from India. The existence of natural heavy metals gives suitable places for assessing the form of heavy metals in groundwater, as indicated by high heavy metal concentrations.[7] Have also done a good job on drinking groundwater in this area with limited water samples. It is the first time that the entire area of Udham Singh Nagar district has been densely covered with a big quantity of samples to get the precise results and the data analyzed by WQI, HPI and multivariate statistical techniques simultaneously.

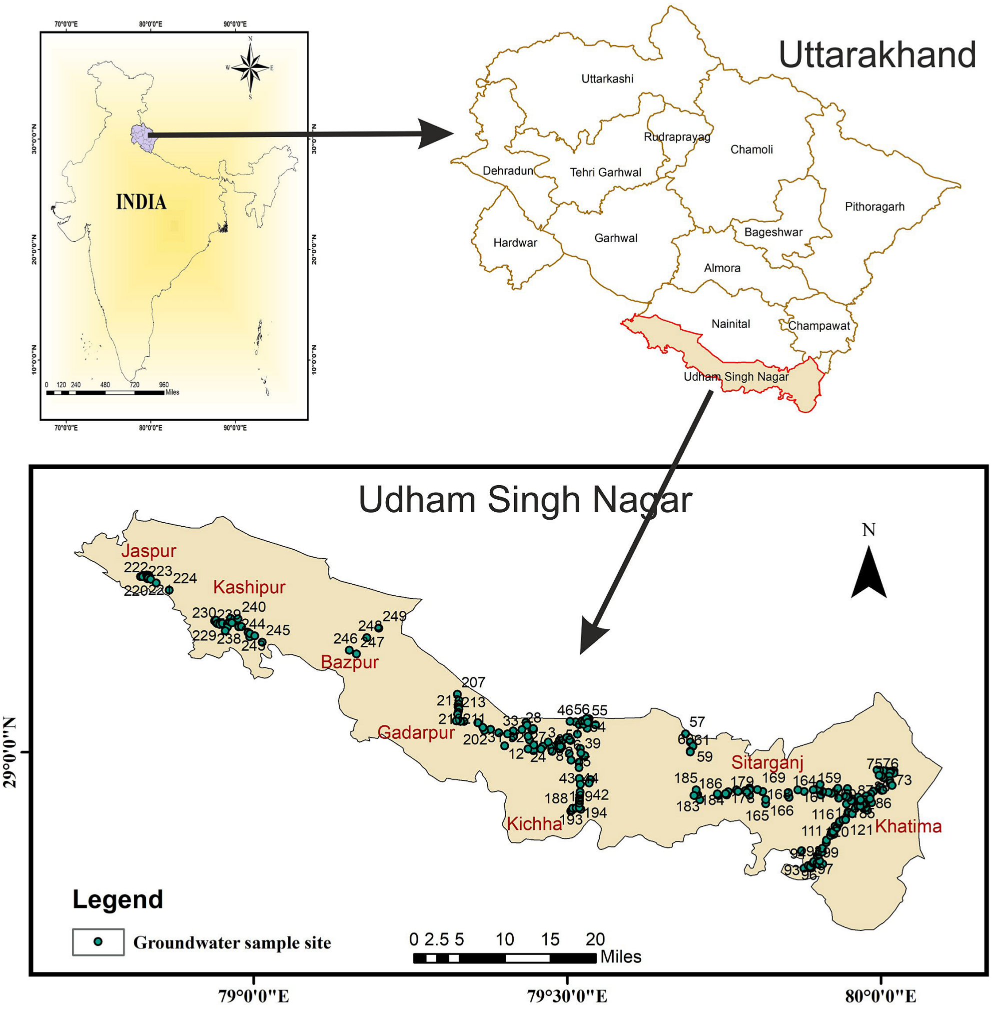


**Fig. 1: Studied location points of collected water Samples (a total of 250 samples were collected)**

## Study Area

U S Nagar District is the ninth-largest district in Uttarakhand State by area (3055 km2). It is located between latitudes 28° 53' and 29° 23' N and laterally stretches between longitudes 78° 45' and 80° 08' E; on the north, it is surrounded by the Uttarakhand districts of Nainital and Champawat; on the south, by the Uttar Pradesh districts of Rampur, Moradabad, Philibhit, and Bareilly, on the west, by the Uttar Pradesh district of Bijnor; and on the east, by Nepal. The international border between India and Nepal runs along the Sharada River in the east. District U S Nagar comes under the Tarai region and is part of the Kumaon Division of Uttarakhand. Tarai is the name it derived due to marshy condition. Southern part of the Bhabar Formation is the Tarai Formation, and Udham Singh Nagar and Haridwar districts cover Uttarakhand's Tarai belt. It features a substantial drainage network. The U S Nagar is the Meal Goblet of Uttarakhand State. As the geographical location is helpful, it is also known for industries and also for agriculture and irrigation on a synchronous pattern, it is known as the "Chawal ki Nagari" and has earned fame for its productivity in paddy fields throughout the state of Uttarakhand, making the district crucial for producing groundwater brochures.[8] The average annual rainfall is 128.2 cm, and the climate is sub-tropical and sub-humid with three distinct seasons: summer, monsoon, and winter. Approximately 90% of the rainfall falls during the monsoon period. The remaining 10% falls during non-monsoon periods.[8] The geology of the research region is expressed by Piedmont alluvial deposits, which play a significant part in determining the groundwater situation of an area. It can be broadly separated into the Bhabar and Tarai formations.[8] Fig.1 depicts a map of the research region.

**Sample Collection and Methodology**

We collected samples from main towns and surrounding villages along the National Highway and major sub-Highways. Once a hand pump was identified, its elevation, latitude and longitude were recorded using a handheld GPS receiver and a water sample was collected in 250 ml wide-mouth polypropylene bottles and noted down the temperature of the water. Additionally, the onsite occurrence of topography, land use, water access, and purpose of use was recorded. A total of 250 samples during monsoon season of the year 2021 were used for laboratory analysis. Samples were taken from government and private hand pumps and tube wells to identify potentially vulnerable sites. In this study, we have given the study area two types of code UAW (Artesian well) and UHP (govt. and private hand pumps). For water sampling and collection the APHA ("American Public Health Association") Recommended Procedures are used 9. The samples were first filtered with Whatmann's filter paper to remove the undissolved material. Following this, each water sample was tested for drinking specifications to decide the water quality and appropriateness for usage. The pH value, EC, TDS, ORP, DO and Salinity were measured, following the standard code of Indian Bureau[12] for testing procedures of physio-chemical analysis. Furthermore, Values were measured by digital water and soil analysis kit (Model-161). Chloride content was measured by the titration method, the measurements of Pb, Fe, Zn Cu, Cr, Ni, Mn, Mg, K, and Na were performed in the AAS (Atomic Absorption Spectrometer) of Varian (Model AA240FS) using air–acetylene flame and Fluoride, Nitrate, measured in Double Beam Spectrophotometer (Model 3375) in the Department of Geology, Kumaun University respectively. To get the best results, the preparation conditions were modified in accordance with the manufacturer's specifications, and metal quantification was based on calibration curves of standard solutions (in acidic medium), which were determined numerous times during the analysis. This equipment allows us to measure several elements to produce consistent results. The obtained results were then analyzed and compared with BIS standard[10] and WHO.[11] Above the permissible limit, the sources are to be discarded.[10] See Table 5: The physio-chemical parameter and heavy metals in the study area show Descriptive statistics.

**WQI Determination**

In this study, the method adopted for calculating WQI is taken from.[12,13] A total of 9 parameters were considered, and on the whole quality of water, according to its relative importance a definite "Assigned Weightage" (*Wa*) was given to each parameter. This ranges from 1 to 5. The weightage 5 is assigned, which has the most influence on Water quality and 1 is assigned to one causative the least. Relative weights($W_r$) calculation:

$$W_r = \frac{W_{ai}}{\sum_{i=1}^{n} W_{ai}} \qquad ...(1)$$

Here each parameter represented by $W_a$ as "Assigned Weightage" and the number of parameters taken as "n" and the "Relative Weight" as $W_r$ for each parameter calculated as per equation (1). The calculated relative weightage is shown in Table 1. Subsequent to assigning relative weightage, calculate the "Quality Rating Scale" (Q) by dividing the concentration of the considered parameter ($C_i$) by its respective "Standard Value" ($S_i$) as mentioned in the guiding principle of the World Health Organisation and Bureau of Indian Standards.

$$Q_i = \frac{c_i}{s_i} * 100 \qquad ...(2)$$

For the two parameters, i.e., dissolved oxygen (DO) and pH, the Q value is calculated another way by using their "Ideal Values" (Vi).[12,13,14] For pH, the Ideal Value ($V_i$) is 7, and DO is 14, and the calculation for the above is given below.

$$Q_{i(pH,DO)} = \frac{c_i - v_i}{s_i - v_i} * 100 \qquad ...(3)$$

**Table 1: Each parameter's weightage and relative weightage.**

| A | B | C | D = C/29 |
|---|---|---|---|
| S. No | Parameter | Weight ($W_{ai}$) | Relative weight ($W_r$) |
| 1 | pH | 4 | 0.13793103 |
| 2 | TDS | 4 | 0.13793103 |
| 3 | EC | 5 | 0.17241379 |
| 4 | DO | 4 | 0.13793103 |
| 5 | Na+ | 1 | 0.03448276 |
| 6 | Mg++ | 2 | 0.06896552 |
| 7 | $F^-$ | 2 | 0.06896552 |
| 8 | $Cl^-$ | 3 | 0.10344828 |
| 9 | $NO_3^-$ | 4 | 0.13793103 |
| | | $\sum_{i=1}^{n} W_{ai} = 29$ | |

**Table 2: WQI, the two (Water quality) scales that have been referred to are as follows.**

| WQI (values) | | |
|---|---|---|
| **Water Quality Scale** | **Yadav Index[15]** | **Ramakrishnaiah Index[16]** |
| Excellent | 0-25 | < 50 |
| Good | 26-50 | 50-100 |
| Poor | 51-75 | 100-200 |
| Very Poor | 76-100 | 200-300 |
| Unsuitable | >100 | >300 |

**Table 3: Standards used for the WQI index computation.**

| **Chemical parameters** | **C** | **D = C/29** | | | | | |
|---|---|---|---|---|---|---|---|
| | **Weight ($W_{ai}$)** | **Relative weight ($W_r$)** | **Ci** | **Si** | **Oi** | **SI** | **WQI** |
| pH | 4 | 0.13793103 | 8.03 | 8.5 | 68.66667 | 9.471264 | |
| TDS ( mg/l ) | 4 | 0.13793103 | 350 | 500 | 70 | 9.655172 | |
| EC ( µmoh/cm ) | 5 | 0.17241379 | 500 | 750 | 66.66667 | 11.49425 | |
| DO ( mg/l ) | 4 | 0.13793103 | 10 | 5 | 44.44444 | 6.130268 | |
| Na ( mg/l ) | 3 | 0.10344828 | 11.4 | 200 | 5.7 | 0.589655 | 41.065 |
| Mg ( mg/l ) | 1 | 0.03448276 | 46.25 | 100 | 46.25 | 1.594828 | |
| $F^-$ ( mg/l ) | 2 | 0.06896552 | 0.057 | 1.5 | 3.8 | 0.262069 | |
| $Cl^-$ ( mg/l ) | 2 | 0.06896552 | 9.1 | 1000 | 0.91 | 0.062759 | |
| $NO_3^-$ ( mg/l ) | 4 | 0.13793103 | 5.89 | 45 | 13.08889 | 1.805364 | |

Note: ∑SI = 41.065

After computing Q values, the "Sub-Indices"(SI) are planned as a product of relative weight($W_r$) and Quality rating scale($Q_i$), and in the end, the WQI is the sum of all sub-Indices. The calculation of WQI is given by equ. (5).

$$SI=W_r * Q_i \quad ...(4)$$

$$WQI=\sum SI_i \quad ...(5)$$

**HPI Determination**

By assigning a rating or weightage(Wi) for each suitable parameter, the HPI was developed, its rating system is a random value between 0 and 1, expressing the relative significance of particular quality concern, and can be definite as inverted ratio to the standardised allowable value(Si) for each parameter.[17,18] The most liberal value for drinking water (Si), in the absence of a substitute water supply, denotes the BIS[10] upper limit permissible concentration. According to BIS,[10] the standard limits for the same characteristics in drinking water are denoted by the intended value (Ii). Below is the HPI Index given by Mohan.[18]

$$HPI = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi} \quad ...(1)$$

Where Qi is the i[th] Water quality parameter's sub-index. The weight associated with ith water's quality parameter is denoted by Wi. The parameter's sub-index (Qi) is calculated as follows:

$$Qi = \sum_{i=1}^{n} \frac{(Mi-Ii)}{(Si-Ii)} \times 100 \quad ...(2)$$

Where Mi as the monitor value, Ii as the ideal value and Si as the standard value of the i[th] parameter's heavy metal. The symbol (-) represents the difference in value between the two numbers, but the algebraic sign is ignored. In general, the important pollution index of HPI value for consuming water is 100.[18,19]

**Table 4: standard used for the HPI index computation (Unit in mg/l).**

| Elements | Mi | Si | Ii | Wi | Qi | Wi. Qi | HPI |
|---|---|---|---|---|---|---|---|
| Lead, Pb | 0.0990 | 0.05 | 0 | 20 | 198 | 3960 | |
| Chromium, Cr | 0.0131 | 0.05 | 0 | 20 | 26.2 | 524 | |
| Zinc, Zn | 0.0257 | 15 | 5 | 0.066666667 | -49.743 | -3.3162 | |
| Manganese, Mn | 0.0361 | 0.3 | 0.1 | 3.333333333 | -31.95 | -106.5 | 28.53 |
| Copper, Cu | 0.0279 | 1.5 | 0.05 | 0.666666667 | -1.52414 | -1.01609 | |
| Iron, Fe | -0.2201 | 0.3 | 0 | 3.333333333 | -73.3667 | -244.556 | |
| Nickel, Ni | -0.0054 | 0.02 | 0 | 50 | -27 | -1350 | |

Note: ∑Wi = 97.39, ∑Wi.Qi = 2778.612, HPI value = 28.529

**Multivariate Statistical Methods**

**Principal Component Analysis**

To generate new hidden factors that are orthogonal and not correlated, through a linear combination of original data, PCA reduces the dimensionality of data.[20] The covariance matrix of the initial variables extracts Eigen-values and eigenvectors.[21] In the PCs (principal components), Eigen-values are a measure of their connected inconsistency. The loadings provide the input of novel variables in PCs, and the geographic locations of the objects are referred to as scores.[22,23,24] In order to convey the variation in the data as succinctly as possible, PCA offers an intended method for finding these kinds of indices.[25] The experimental groundwater data has been statistically analyzed by GNU pspp 1.2.0 software and JASP 0.17.1.0.

**Factor Analysis**

is differs from PCA in that an experiential correlation matrix is created for both the extraction and underpinning theory. The FA aim can be accomplished by twisting the PCA line in accordance with well-established concepts and adding additional factors, commonly referred to as variable factors (VF). The coefficient of correlation matrix assesses how well the variation of each component can be explained by how it's related to the others. "Strong," "Moderate," and "Weak" terms are used to denote factor loadings, and they apply to comparative loading levels of 0.75, 0.75-0.50, and 0.50-0.30, respectively, according to.[26] The experimental ground water data has been statistically analyzed by GNU pspp 1.2.0 software and JASP 0.17.1.0.

**Hierarchical Clustering Analysis (HCA)**
is an approach that groups together variables that are connected in a cluster. Each cluster is distinguished by homogenous variables from the other clusters. A graphic summary of the algorithm's results might be used to illustrate the results of the grouping process in form of a Dendrogram. The HCA next to the square Euclidian distance and the single linkage method is successfully performed in the current study by using statistical software. Past 4.03.

## Results and Discussion

### Groundwater Quality for Drinking Purposes

The determined Groundwater quality is represented in Table 5, where all parameter values are compared with BIS standard 2012 and shown by Mean, Standard deviation, Minimum, and Maximum. The pH value varies from 6.31 to 8.54, having an average value of 7.637 ± 0.416 in the study area, which indicated the groundwater has somewhat acidic to somewhat alkaline samples. Only two samples showed the over limit of pH in groundwater samples. The EC value varies from 59 to 738 (µmoh/cm) Having an average value of 333.204 ± 143.214 (µmoh/cm). The TDS value varies from 38 to 486mg/l having an average value of 214.212 ± 92.161mg/l. The DO, ORP, and salinity values varies from 4.1 to 8.6 mg/l, -82 to 38 mV, and 80 to 500mg/l, respectively, Having an average value of 5.216 ± 0.509mg/l, -33.62 ± 23.016 mV, 158.016 ± 83.472mg/l respectively. The concentration of cations Cr, Zn, Cu, K, and Na, ions varies from -0.008 to 0.016mg/l, -0.196 to 7.467mg/l, -0.03 to 0.492mg/l, 0.023 to 7.957mg/l, 0.356 to 335.68mg/l, Having an average value of 0.007 ± 0.004mg/l, 0.173 ± 0.684mg/l, 0.006 ± 0.034mg/l, 1.897 ± 1.377mg/l, 22.22 ± 43.938mg/l, respectively. The concentration of dissolved anion, $NO_3^-$, varies from 8.873 to 26.089mg/l, having an average value of 16.412 ± 3.942mg/l.

**Table 5: The physio-chemical parameter and heavy metals in the study area show Descriptive statistics (N=250).**

| Parameter | Mean | Std. Deviation | Minimum | Maximum | Acceptable limit as BIS 10500-2012 | Permissible limit as BIS 10500-2012 | Standard WHO (2011) |
|---|---|---|---|---|---|---|---|
| pH | 7.637 | 0.416 | 6.31 | 8.54 | 6.5-8.5 | No Relaxation | - |
| EC (µmoh/cm) | 333.204 | 143.214 | 59 | 738 | - | - | - |
| TDS (mg/l) | 214.212 | 92.161 | 38 | 486 | 500 mg/l | 2000 mg/l | - |
| DO (mg/l) | 5.216 | 0.509 | 4.1 | 8.6 | - | - | - |
| ORP mV | -33.62 | 23.016 | -82 | 38 | - | - | - |
| Salinity (mg/l) | 158.016 | 83.472 | 80 | 500 | - | - | - |
| Pb (mg/l) | 0.032 | 0.083 | -0.27 | 0.395 | 0.01 mg/l | No Relaxation | 0.01 mg/l |
| Cr (mg/l) | 0.007 | 0.004 | -0.008 | 0.016 | 0.05 mg/l | No Relaxation | 0.05 mg/l |
| Zn (mg/l) | 0.173 | 0.684 | -0.196 | 7.467 | 5 mg/l | 15 mg/l | - |
| Mn (mg/l) | 0.03 | 0.106 | -0.366 | 1.025 | 0.1 mg/l | 0.3 mg/l | 0.4 mg/l |
| Cu (mg/l) | 0.006 | 0.034 | -0.03 | 0.492 | 0.05 mg/l | 1.5 mg/l | 2 mg/l |
| Fe (mg/l) | 0.563 | 0.569 | -0.328 | 1.625 | 0.3 mg/l | No Relaxation | - |
| Ni (mg/l) | 0.013 | 0.016 | -0.021 | 0.043 | 0.02 mg/l | No Relaxation | 0.07 mg/l |
| K (mg/l) | 1.897 | 1.377 | 0.023 | 7.957 | - | - | - |
| Na (mg/l) | 22.22 | 43.938 | 0.356 | 335.68 | - | - | - |
| Mg (mg/l) | 24.717 | 10.942 | 1.7 | 46.53 | 30 mg/l | 100 mg/l | - |
| $F^-$ (mg/l) | 0.619 | 0.608 | -0.947 | 2.558 | 1.0 mg/l | 1.5 mg/l | 1.5 mg/l |
| $Cl^-$ (mg/l) | 54.68 | 106.297 | 0.801 | 755.29 | 250 mg/l | 1000 mg/l | 200-300 mg/l |
| $NO3^-$ (mg/l) | 16.412 | 3.942 | 8.873 | 26.089 | 45 mg/l | No Relaxation | 50 mg/l |

The Fe value varies from -0.328 to 1.625mg/l having an average value of 0.563 ± 0.569mg/l, and the Iron value in out of 250 samples, 185 samples crossed the desirable limit as per BIS. According to,[27] the higher content of Fe alters the flavour and look of water while fostering the development of iron bacteria. Continuous usage of too much Fe can result in sluggishness, liver difficulties, joint discomfort, weight loss, and eventually heart disease, diabetes issues, and hemosiderosis.[28, 29]

The Pb value varies from – 27 to 0.395mg/l, having an average value of 0.032 ± 0.083mg/l. The Lead concentration out of 250 samples, 180 samples crossed the desirable limit of BIS. The high concentration of Lead in the human body causes blood disorders, hearing loss, reduced mental capacity, and interference with renal and neurologic functions, hypertension, and high-level deaths. The treatment of Pb in water is possible by ion exchange, distillation, activated carbon, and reverse osmosis.

The Nickel value varies from -0.021 to 0.043mg/l, having an average value of 0.013 ± 0.016mg/l. The Ni concentration in 117 groundwater samples crossed the desirable limit of BIS. According to,[30 and 31] ingesting too large a quantity of Ni in groundwater increases the chance of developing lung cancers, larynx nose, prostrate, congenital disabilities, respiratory failures, and heart disorders.

The Mg value varies from 1.7 to 46.53mg/l having an average value of 24.717 ± 10.942mg/l. The Mg value in 82 groundwater samples crossed the desirable limit of BIS.[10] As per[32] Magnesium is an essential nutrient for people, and the micro-element Mg is necessary for the development of muscles, DNA replication, membrane function, and stimulation of nerve transmission.

The Mn value varies from -0.366 to 1.025mg/l, having an average value of 0.03 ± 0.106mg/l. The Mn value in 24 groundwater samples crossed the desirable limit of BIS. Manganese is important for humans, and a lack of it may impair development, cause skeletal malformations, and cause reproductive disorders. Consuming more Mn, on the other hand, may be responsible for a condition known as manganism, which may induce muscular weakness.[33,34] observed that high Mn in potable water can cause adult neurological problems.

The Fluoride value varies from -0.947 to 2.558mg/l having an average value of 0.619 ± 0.608mg/l, the $F^{-}$ out of 250 samples 63 crossed the desirable limit of BIS. Fluoride is a crucial micronutrient that the human body needs in small quantities. Drinking water with 1 mg/l of fluoride reduces dental plaque and girds the apatite matrix tissues.[35 and 36] At a higher level of concentration, which is as follows, fluoride causes various diseases of teeth and bones when the content in drinking water exceeds 1.5mg/L: Constant exposure to high fluoride (F-) exceeding (4–10 mg/l) in drinking water causes skeletal fluorosis and a disabling condition characterised by over-mineralization of joints and bones.[37]

The Chloride value varies from 0.801 to 755.29mg/l having an average value of 54.68 ± 106.297mg/l, the $Cl^{-}$ out of 250 samples, 12 crossed the desirable limit of BIS. Although chloride ions are safe at low quantities, well water with high chloride ions concentrations may harm plants if used for irrigation or gardening, and it may also impart an unpleasant taste to drinking water if consumed.[38]

The cations which were over the limit in groundwater samples are presented in chronological order Fe > Pb > Ni > Mg > Mn > Zn > Cu, and significant anions were over the limit $F^{-} > Cl^{-}$, and the rest was under the limit. from this research found that a large amount of the groundwater samples showed high concentrations of Fe, Pb, Ni, Mg, Mn, $F^{-}$ and $Cl^{-}$ values in the study area. Weathering of rocks and discharge of industrial waste could be the primary sources of groundwater contamination.[8] reported that the anomalous values of TH, TDS, Mg, Fe, and Pb in the U S Nagar area confirm about degradation in the groundwater quality. So that previous study agrees that Fe concentration in groundwater of samples in the study area exceeded the Desirable limit of 0.3mg/l, the results were somewhat similar to ours. According to,[39] the presence of Lead in groundwater samples of Uttarakhand was high compare to the BIS standard limit. The research area of this article was Dehradun, Vikasnagar, Dakpathar, Haridwar, and Roorkee, which supports our research that lead concentration is above the desirable limit in U S Nagar.

**Water Quality Index Results**

WQI was implemented in the research region to assess groundwater quality for drinking water purposes. WQI index was calculated for 250 samples, and for this, we used the parameters pH, Electric conductivity, Total Dissolved solid, Dissolved Oxygen, Mg, Na, $F^{-}$, $Cl^{-}$, and $No_3^{-}$. The result of wqi varies from 17.83 to 67.60, with an average value of 43.42. We have used two WQI index categories (Yadav and Ramakrishnaiah) to evaluate the WQI result. According to,[15] if WQI is smaller than 25, the water class is classify as excellent, if the WQI is between 26 and 50, it is considered to be of Good Water class type. poor Water class type is defined as being between 51 and 75, very poor Water class type is defined as being between 76 and 100, and unsuitable for drinking water type is defined as being greater than 100(see Table 2). Out of two fifty groundwater samples Water class of 5 samples (2 %) comes under the excellent, 211 samples (84.4 %) fall under good class, and 34 samples (13.6 %) have poor Water quality WQI status as per Yadav index (see Table 6). Further, referring to the 16 index if WQI is smaller than 50, the Water class is classify as excellent, if the WQI is between 50 and 100, it is considered to be of good Water class type. poor Water class type is defined as being between 100 and 200, very poor Water class type is defined as being between 200 and 300, and unsuitable for drinking water type is defined as being greater than 300 (see Table 2). Out of two fifty groundwater samples Water quality of 216 samples (86.4 %) fall under excellent quality and only 13 samples (13.6 %) come under good water quality. (see Table 6). Standards used for the WQI index computation are shown in Table 3. The spatial variation of WQI has been illustrated in Figure 4. As per the overall WQI, the studied groundwater in this area appears good and suitable for drinking purposes, except 34 samples showed the critical value of WQI.

**Table 6: Analysis of Water Quality Indices is as follows.**

| Water Quality Index | Yadav Index[15] | | Ramakrishnaiah Index[16] | |
|---|---|---|---|---|
| | No. of samples | Percentage of the samples | No. of samples | Percentage of the samples |
| Excellent | 5 | 2 | 216 | 86.4 |
| Good | 211 | 84.4 | 34 | 13.6 |
| Poor | 34 | 13.6 | - | - |

**Heavy Metal Pollution Index Results**

A HPI rating was also used to measure the class of groundwater in research region. Because the role of heavy metals in drinking water is significant, the amount of these heavy elements in groundwater can be used to determine how polluted it is. The result of the HPI index varies from -107.95 to 227.60 and an average value of 54.35. We have used two HPI categories (Indian and International standards) to evaluate groundwater quality. According to Indian Standard, it is classified as a low-grade degree of pollution type if it is smaller than 50, if it is between 50 and 100 medium grade degree of pollution type, and a High-grade degree of pollution classify if it is larger than 100 (see Table 7). Out of two fifty groundwater samples, nearly 40.4% of samples show a low degree of pollution, 33.2% of samples show a medium degree of pollution, and 26.4% show a High degree of pollution. According to International Standard, it is classified as a low-grade degree of pollution type if it is smaller than 60 if it is between 60 and 120, medium grade degree of pollution type, and High-grade degree of pollution type classify if it is larger than 120, and out of two fifty groundwater samples 46% samples show low degree of pollution, 38% samples medium degree of pollution and 16% show high grade of degree of pollution (see Table 7). Standards used for the HPI index computation are shown in (Table 4). According to both standards of the HPI, overall values (except for some individual sites) lie under low to moderate groundwater pollution. Figure 5 depicts the spatial distribution of WQI in the research region.

**Table 7: Categories of Groundwater Pollution Indices.[40]**

| Index method | Category | Degree of pollution | No. of samples | Percentage of the samples |
|---|---|---|---|---|
| HPI (International | <60 | Low | 115 | 46 |
| Standard) | 60–120 | Medium | 95 | 38 |
| | >120 | High | 40 | 16 |
| HPI (Indian | <50 | Low | 101 | 40.4 |
| standard) | 50–100 | Medium | 83 | 33.2 |
| | >100 | High | 66 | 26.4 |

**Principal Component Analysis (PCA)/Factor Analysis (FA)**

PCA is used to identify sources of heavy metals according to standard procedures. To better explain the many groups and sources that might have an impact on water systems, to maximise the total variance of factorial coefficients, varimax rotation is performed.

**Table 8: Total Variance Explained.**

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of variance | Cumulative % | Total | % of variance | Cumulative % | Total | % of variance | Cumulative % |
| 1 | 3.08 | 16.19 | 16.19 | 3.08 | 16.19 | 16.19 | 2.86 | 15.06 | 15.06 |
| 2 | 2.38 | 12.52 | 28.71 | 2.38 | 12.52 | 28.71 | 2.17 | 11.4 | 26.47 |
| 3 | 1.83 | 9.64 | 38.35 | 1.83 | 9.64 | 38.35 | 2.01 | 10.59 | 37.06 |
| 4 | 1.47 | 7.76 | 46.11 | 1.47 | 7.76 | 46.11 | 1.48 | 7.81 | 44.87 |
| 5 | 1.33 | 6.98 | 53.09 | 1.33 | 6.98 | 53.09 | 0.04 | 0.2 | 45.07 |
| 6 | 1.2 | 6.34 | 59.43 | 1.2 | 6.34 | 59.43 | 0 | 0.03 | 45.09 |
| 7 | 1.09 | 5.75 | 65.18 | 1.09 | 5.75 | 65.18 | 0 | 0 | 45.09 |
| 8 | 1.02 | 5.39 | 70.58 | 1.02 | 5.39 | 70.58 | 0.32 | 1.67 | 46.76 |
| 9 | 1.02 | 5.37 | 75.94 | 1.02 | 5.37 | 75.94 | 1.49 | 7.85 | 54.61 |
| 10 | 0.96 | 5.05 | 80.99 | | | | | | |
| 11 | 0.86 | 4.54 | 85.53 | | | | | | |
| 12 | 0.73 | 3.82 | 89.35 | | | | | | |
| 13 | 0.68 | 3.56 | 92.91 | | | | | | |
| 14 | 0.58 | 3.03 | 95.94 | | | | | | |
| 15 | 0.48 | 2.53 | 98.48 | | | | | | |
| 16 | 0.25 | 1.3 | 99.77 | | | | | | |
| 17 | 0.04 | 0.2 | 99.97 | | | | | | |
| 18 | 0 | 0.03 | 100 | | | | | | |
| 19 | 0 | 0 | 100 | | | | | | |

The cumulative percentage and percentages of variance are described together with the total variance in Table 8. The scree graph also helps determine how many PCs should be kept in order to comprehend the structure of the underlying parameters (see Fig. 2), it shows the rough outline of the component's Eigen-values. Its collective Eigen-values % yield nine PCs with Eigen values >

1, This scree plot reveals a considerable variation in slope, accounting for 72.17% of the overall variance in the dataset, from the 1st to the 2nd Eigen-value, thus because PC_1 is responsible for 16.19% of the variation in the water quality, PC_2 is accountable for 12.52%, PC_3 Showing 9.64%, PC_4 Showing 7.76%, PC_5 Showing 6.98%, PC_6 Showing 6.34%, PC_7 Showing 5.75%, PC_8 Showing 5.39%, and PC_9 Showing 5.37%, respectively. In the research, the factor loading matrix is produced on the basis of groundwater quality markers. An Eigen-value quantifies the importance of a factor. The variables with the highest significance have the greatest Eigen-values, Eigen-values of 1.0 or above are considered significant.[41] For the whole dataset after varimax rotation, the Factor Loadings matrix is listed in Table 9. More than 16.19 % of the total variance explains by the first PC_1. It contains EC, TDS, and salinity, indicating the physio-chemical variability source. The PC_2, explaining 12.52 % of the total difference, is laden with Na and $Cl^{-}$, indicating natural causes like the geogenic process from the salty type of rocks. The PC_3 is loaded with pH and ORP (Oxidation-Reduction Potential), accounting for 9.64 % of the total variance. The pH indicates groundwater's acidity and alkalinity by the rocks' leaching. The occurrence of an oxidising agent is indicated by an ORP value, it is an essential indicator of pollution levels, and a low reading suggests the presence of a reducing agent. Pollution of the water levels tends to rise when ORP levels are low and fall when they are high.

**Table 9: After varimax rotation Factor Loadings matrix for the whole dataset.**

| Parameters | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 | PC9 |
|---|---|---|---|---|---|---|---|---|---|
| pH | -0.12 | 0.06 | 0.99 | 0.00 | -0.03 | -0.01 | -0.05 | 0.08 | 0.11 |
| EC | 0.99 | 0.00 | -0.07 | -0.06 | 0.13 | 0.03 | -0.01 | 0.02 | -0.01 |
| TDS | 0.98 | 0.00 | -0.08 | -0.05 | 0.14 | 0.04 | -0.01 | 0.03 | -0.02 |
| DO | 0.06 | 0.10 | 0.07 | 0.14 | 0.02 | -0.12 | -0.14 | 0.05 | 0.02 |
| ORP | 0.10 | -0.05 | -0.94 | -0.03 | 0.07 | 0.10 | -0.03 | -0.07 | -0.02 |
| Salinity | 0.79 | -0.01 | -0.10 | -0.01 | -0.17 | -0.13 | 0.04 | 0.01 | 0.21 |
| Pb | 0.01 | -0.12 | 0.02 | -0.09 | 0.58 | -0.07 | 0.16 | -0.02 | -0.23 |
| Cr | -0.02 | -0.08 | -0.01 | -0.01 | -0.09 | 0.07 | 0.12 | -0.38 | -0.02 |
| Zn | 0.09 | -0.02 | -0.09 | 0.06 | 0.51 | 0.13 | -0.03 | 0.04 | 0.11 |
| Mn | -0.03 | -0.1 | -0.06 | 0.00 | 0.07 | 0.81 | -0.05 | -0.13 | 0.03 |
| Cu | 0.04 | -0.03 | 0.05 | -0.04 | 0.00 | 0.00 | 0.05 | 0.07 | 0.25 |
| Fe | -0.09 | -0.06 | 0.01 | 0.98 | -0.03 | 0.05 | 0.13 | 0.00 | -0.17 |
| Ni | -0.10 | -0.08 | -0.01 | 0.39 | 0.39 | -0.07 | -0.14 | 0.16 | 0.11 |
| K | 0.28 | -0.1 | -0.02 | 0.07 | -0.18 | -0.11 | 0.27 | 0.47 | 0.19 |
| Na | -0.02 | 0.99 | 0.05 | -0.03 | -0.09 | -0.08 | 0.06 | -0.06 | -0.04 |
| Mg | 0.02 | 0.05 | -0.04 | -0.01 | 0.00 | 0.00 | -0.02 | -0.19 | -0.02 |
| $F^{-}$ | 0.00 | 0.12 | 0.15 | 0.00 | 0.11 | -0.14 | 0.43 | 0.03 | -0.03 |
| $Cl^{-}$ | -0.01 | 0.98 | 0.06 | -0.04 | -0.09 | -0.08 | 0.05 | -0.06 | -0.04 |
| NO3- | -0.02 | 0.00 | 0.10 | -0.03 | 0.04 | -0.06 | -0.30 | 0.01 | -0.16 |
| Eigenvalues | 3.08 | 2.38 | 1.83 | 1.47 | 1.33 | 1.2 | 1.09 | 1.02 | 1.02 |
| % of Variance | 16.19 | 12.52 | 9.64 | 7.76 | 6.98 | 6.34 | 5.75 | 5.39 | 5.37 |
| Cumulative % | 16.19 | 28.71 | 38.35 | 46.11 | 53.09 | 59.43 | 65.18 | 70.58 | 75.94 |

The PC_4, accounting for 7.76 % of the total difference, is allied with the high Fe loading and weak Ni loading, indicating a geogenic factor. The PC_5 has weak to moderate loadings of Ni and Pb, Zn, respectively, with the 6.98 % of the total variance and which is linked to explain the leaching of minerals and partial natural weathering processes from rocks like carbonate rocks (limestone, dolomite), and quartzite and transported to the underground seepages. Lead also occurs from anthropogenic activities like paints, automobile parts, batteries, and sewage. The PC_6 is linked to geogenic sources and has a significant Mn loading, accounting for 6.34% of the total variation. Mn often occurs naturally in sedimentary rocks or from mining and industrialized wastage. The PC_7 has weak loadings of $F^{-}$ containing 5.75 % of the total variance, which is linked to fluoride occurring, dissolution in groundwater is favorable in an alkaline environment. The PC_8, explaining 5.39 % of the total variance, is weighed down with K, indicating the source of silicate minerals by the geogenic process.

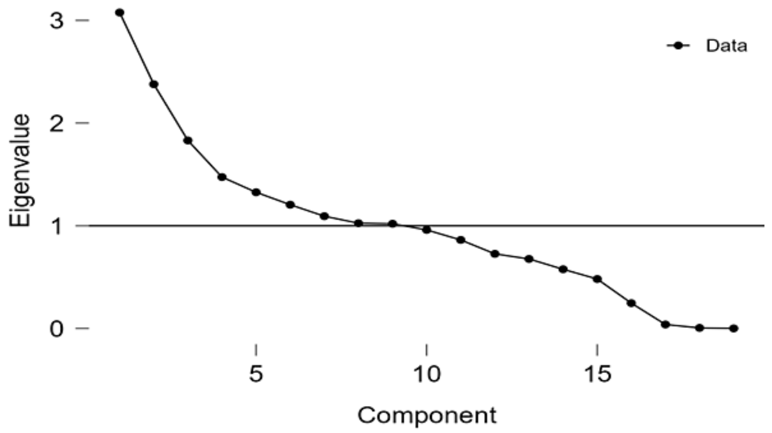


**Fig. 2: Scree plot showing Eigenvalues of PCA.**

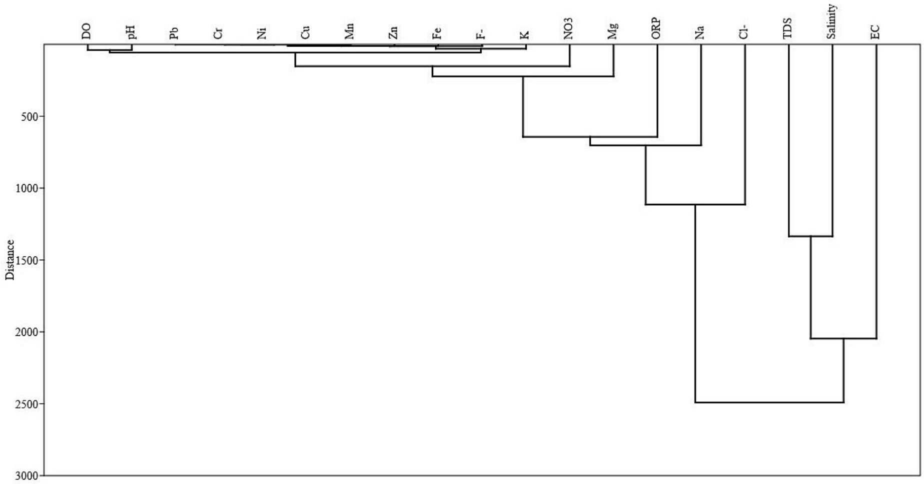


**Fig. 3: The hierarchical clusters of analyzed parameters shown by Dendrogram.**

**Hierarchical Clustering Analysis (HCA)**

The findings of R-mode groupings analysis were used to forecast physicochemical categories in groundwater data sets, and they are displayed in Fig. 3. Although the results of HCA and PCA are not exactly matched. However, there are some similarities within the current study. The parameters belonging to similar groups are to be expected to have originated from the same resource. The HCA shows two main groups of analyzed parameters. The physicochemical indices in cluster 1$^{st}$ (EC, TDS, and Salinity) are primarily governed by natural processes such as mineral dissolution and soil leaching, whereas the cluster 2$^{nd}$ exhibits a combination of natural and human processes. Including dissolution of carbonates and other minerals released from rocks like limestone, dolomite, and quartzite and carrying of trace earth elements and nitrification due to farming, improper disposal of lead lithium batteries, sewage effluents, and contaminant river percolation.

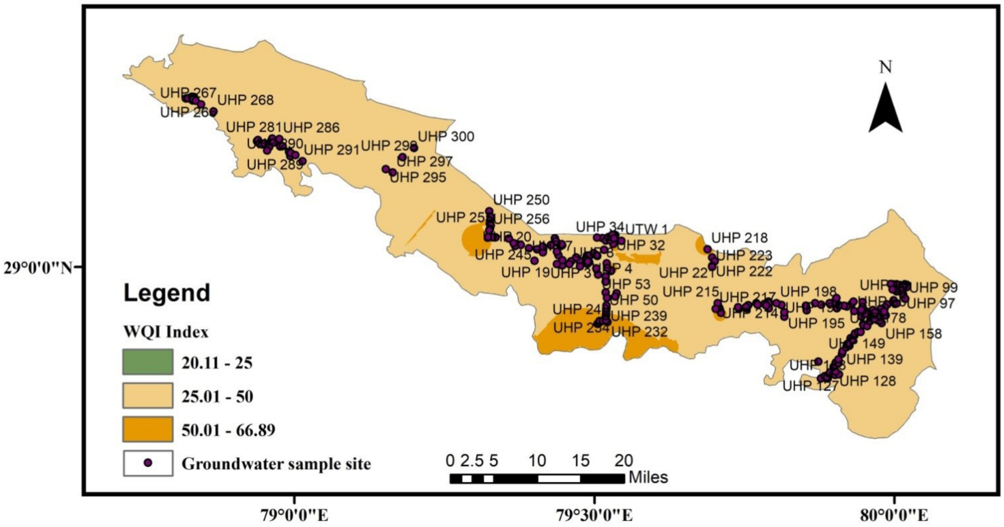


**Fig. 4: Map of U S Nagar District Uttarakhand showing WQI values of samples.**

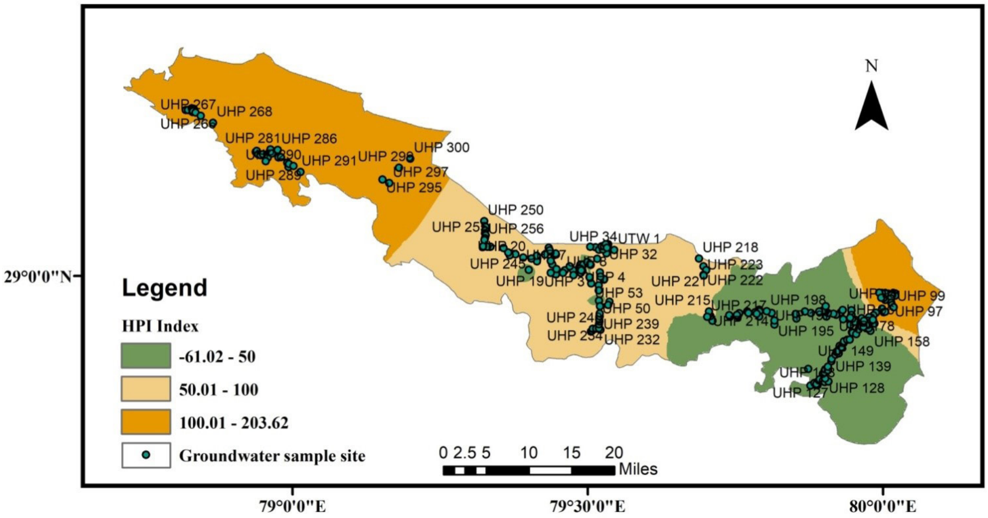


**Fig. 5: Map of U S Nagar District Uttarakhand showing HPI values of samples.**

## Conclusions

We have done research to undertake the drinking Water quality analyses of the groundwater and the sources of contamination in Udham Singh Nagar district, Uttarakhand. We measured 19 parameters, and the Water quality index, HPI index; PCA / FA, and CA methods were applied. The exposed sediments of the Ganga Alluvium Plain during the late Pleistocene to Holocene represent the alluvial filling of sediments derived from the Himalayas and northern Indian Craton.[42] The cations which were over the limit in groundwater samples are presented in chronological order Fe > Pb > Ni > Mg > Mn > Zn > Cu, and significant anions were over the limit $F^{-}$ > $Cl^{-}$, rest was under the limit. The study reveals that the results of HPI and WQI of groundwater in Uttarakhand are good to moderate for drinking purposes. The primary sources of Lead, Iron, Nickel and other heavy metals in this area are natural sources, Himalayan rocks with carbonated limestone, dolomite, quartzite, gneiss, meta-sedimentary rocks, which were eroded by rivers, springs and water table (below the surface) and then water was transported by rivers and underground seepages. The second source is anthropogenic activities like paints, automobile parts, batteries, sewage and industrial waste. This is because Udham Singh Nagar is a vast industrial district of Uttarakhand state. Thus, the wastage of industries is drained openly into water steams and other potable water sources. From the above results, the highly heavy metal-contaminated groundwater sample used for drinking is deteriorating. We conclude that regular monitoring of the hydro-chemical characteristics of the groundwater and using proper filtration treatment techniques will be helpful for sustainable water management so that we can avoid heavy metal contamination from groundwater in high-alert areas. It will be helpful for many hazardous diseases in that area.

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**Conflict of Interest**

The author(s) declare no conflict of interest.

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