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Characterization of the Groundwater Quality in Udham Singh Nagar of Kumaun Himalaya, Uttarakhand

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Abstract

The Udham Singh Nagar district is affluent in fertile land, water resources, and even favoured for industrial advancement, thereby resulting in a rapid increase of industrialization and urban growth, which are the inevitable causes for groundwater contamination. During recent years the increased rate of urbanization and the establishment of Integrated Industrial Estate (IIE) at Pantnagar, Kashipur and Sitarganj area (of the district) have increased the demand for groundwater. A proper groundwater resource planning and monitoring on a regional scale is required to cope with the pace of rapid urbanization and industrialization along with dire irrigation needs. To suffice this strategy, the spatial distribution of water quality shall determine the kind of sustainable approach to be implemented in an area. The objective of this research is to assess the hydrochemical quality of the groundwater in Udham Singh Nagar district (areal extent 3055 Km^2), Uttarakhand. The groundwater samples collected from the aquifer have shown anomalous values of Total Hardness (TH), Total Dissolved Solids (TDS), Magnesium (Mg^{2+}), Iron (Fe^{2+}), and Lead (Pb^{2+}) on undergoing major elemental analysis which confirms about degradation in the groundwater quality. Moreover, the Piper Trilinear Diagram (PTD) has identified the hydrochemical facies, and characterization of groundwater. Based on the interpretation of TDS, most groundwater samples <500 mg/l dissolved solids, making it desirable for drinking. Therefore, this phenomenon attributes to suitable drinking water present in the aquifer of Udham Singh Nagar district, Uttarakhand.

1. Introduction

Groundwater wears the crown of being one of the significant drinking and domestic water sources worldwide, but the increasing industrialization and urbanization have overexploited this valuable resource, creating an extreme increase in demand for it (Bear, 1979; Foster, 1998; Gautam et al., 2017; Gyeltshen et al., 2019; Taloor et al, 2020; Adimalla et al., 2020, Adimalla and Taloor 2020). Likewise, in Udham Singh Nagar, Uttarakhand groundwater holds an essential role in domestic, agriculture and industrial uses, making it quite an important task to keep a strict check on its water quality (Milovanoic, 2007; Magesh and Chandrasekar, 2011; Nair et al., 2021). But in recent economies, the rapid rate of industrial, agricultural and domestic activities has contaminated the water quality with hazardous waste discharge, thus influencing poorly on drinking water (Haque et al., 2020; Sarkar et al., 2020; Karunakalage et al., 2021). The increase in water contamination not only takes a toll on water quality but also affects human health. Both quality and quantity of groundwater are equally significant for accomplishing several purposes (Sarath Prasanth et al., 2012; Wadie and Abduljalil, 2010; Gaur et al., 2013). As groundwater quality data gives compelling clues to the geological history, a slight trigger in water quality can determine an area's physical and chemical parameters (Walton, 1970; Subramani et al., 2005; Schiavo et al., 2006; Krishna Kumar et al., 2011; Jasrotia et al., 2019).

The water quality can be determined mainly by the geochemical processes, chemical and mineral composition of the aquifer rocks, residence period, and additional factors related to groundwater flow and effluents addition through human interference (Faniran et al., 2004; Lopez-Maldonado et al., 2017). Over the time, accelerated and unchecked population growth, urban and industrial growth have affected environmental condition of the surface and subsurface in different areas. Since groundwater is highly potential in accomplishing the water demand in future so it is imperative to avoid harmful activities of human which affect the groundwater system connected hydraulically thus reducing the accessibility of these alternate potable sources of water (Adekunle et al., 2007; Kumar and Divya, 2012). Once the groundwater gets contaminated, it is impossible in restoring its quality even by eliminating the pollutants from the source (Kumar and Ahmed, 2003; Jain et al., 2010). Various location and environments determine the quality of a water resource. For instance, the saline-alkali soils are affected by water quality used for irrigation. The suitability of irrigation water can be determined by saline and sodium hazard indicators (Nishanthiny et al., 2010). Assessment and sustainability check of groundwater is crucial in areas of critical economic and social significance like arid and semi-arid areas (Guo et al., 2019; Singh et al., 2020). Thus, groundwater quality is an effective parameter which pass on fundamental information to concerned citizens and policymakers (Sujatha and Reddy, 2003; Fagbote et al., 2014).

The groundwater chemistry also provides the information of atmosphere, soil, weathering, pollutants, saline intrusion, land clearance, domestic wastes along with lithology and dwelling time of water contact with rock layers (Pawar and Shaikh, 1995; Atulegwu and Njoku, 2004; Babiker et al., 2007). The seven major chemical parameters present in groundwater are Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, Na^+, K^+ and SO_4^{2-} which efficiently classifies and assesses groundwater quality (Jamshidzadeh and Mirbagheri, 2011). Monitoring the groundwater sources gives an idea about the water characteristics, the variability in water quality, emerging water problems, presence or invasion of hazardous waste and solution for treating the prevailing water pollution (Suk and Lee, 1999; Kumar et al., 2010; Kaown et al., 2012). Therefore, evaluation of quality in groundwater, establishing a database and also the development planning of water resources located in the Tarai region of Kumaun are fruitful steps taken towards the society. In respect to this perspective, Udham Singh Nagar district is selected for its groundwater quality assessment as groundwater is the primary source for water supply here and also Uttarakhand’s biggest industrial hub; State Industrial Development Corporation of Uttarakhand Limited (SIDCUL). The industries under SIDCUL produces poisonous effluents, of which a significant portion gets discharged as untreated waste (Seth et al., 2014; CGWB, 2011). Such kind of effluents that are treated partially becomes the main source for surface, groundwater and subsurface contamination, thus posing a harmful warning for groundwater resources where pollution is not noticeable with immediate effect. Since Udham Singh Nagar is also dominated by agriculture and domestic activities the harmful discharge and untreated wastes pollutes the groundwater thus taking a huge toll on health of the local population (Banerjee et al., 2009; Sharma et al., 2012; Panwar and Srivastava, 2012).

In this study, total 18 physico-chemical water quality parameters of pre-monsoon season (2016) have had been assessed in respect to Bureau of Indian Standard (BIS, 2005). This paper aims in characterizing the quality of groundwater which is dwelling within the shallow aquifers by determining its hydrogeochemical facies. This will assist in implementing reasonable knowledge on possible changes in groundwater with respect to the rapid development in industrial belt of Udham Singh Nagar. Therefore, it is very crucial to have adequate knowledge on the quality of natural baseline, so that any alarming changes in the environment can be measured with felicitous confidence (Edmunds et al., 2003).

2. The Geology And Tectonics Of Study Area

The study realm, Udham Singh Nagar district is situated in Kumaun region, Uttarakhand within coordinates; 78.75 to 80.13°E longitudes and 28.88 to 29.38°N latitudes and covering an aerial extent of 3055 Km^2. Geologically, Kumaun Himalaya comprises four Himalayan subprovinces (Valdiya, 1979). The divisions are briefed down in Table 1.

Table 1
Geology of Kumaun Himalaya (Valdiya 1979)

Geologic subprovince	Lithology/Age	Grade of metamorphism
North Tethys zone (demarcated by Malari Thrust in south)	Sediments of Late Precambrian to Creteceous	
Great Himalaya (demarcated by Malari and Vaikrita Thrust)	Granite injected Early Precambrian metamorphic rocks of Vakrita group which is penetrated by granite of Tertiary age	Katazonal
Munsiari Formation (lying between Vaikrita and Munsiari Thrust) forming the root for Almora Nappe and four other klippen	Metamorphic rocks, Precambrian Augen gneiss and synkinematic granodiorites	Mylonitized and retrograded
Siwalik separated from Ganga plains by Himalayan Frontal Thrust	Molasse sediments	

The districts of Uttarakhand; Nainital and Champawat, districts of Uttar Pradesh; Moradabad, Rampur, Bareilly, Philibit, Bijnor and Nepal encompasses Udham Singh Nagar district along north, south & west and east boundary respectively. The study area falls in Survey of India Toposheet Nos. 53K, O, P and 62D. For administrative convenience, the district has been divided into seven developmental blocks and seven tehsils; Japsur, Bazpur, Kashipur, Gadarpur, Khatima, Sitarganj and Rudrapur (district headquarter) (Fig. 1). The study area receives 90% of rainfall during the South-West monsoon season between June and September and the remaining 10% non-monsoon period annually. The longer period of average annual rainfall in Udham Singh district is about 1296.85 mm (Year 2009).

3. Geomorphology And Hydrogeology Of The Study Area

Geomorphologically the study area is divided into Bhabar and Tarai hydrogeomorphic units located from north to south respectively. The Bhabar unit has high porosity and permeability, which allows the precipitation to infiltrate in quite abundant amount in brief period resulting in excellent reservoirs for groundwater. The lithology of Bhabar dominates in poorly sorted unconsolidated sediments like boulders, granules, pebbles, and cobbles, silt, coarse to fine sand and clay.

As Bhabar eventually merges with the Tarai in south, the contact between these two units forms the spring line which is defined by difference in slope gradient and the type of effluents present in groundwater and characterized by free-flowing zones. Thus, the Bhabar unit becomes the recharge front of the Tarai unit. The aquifers in these zones are mostly unconfined, but at some places, parched aquifers also exist. The water level depth recedes gradually towards south, finally emerging as the spring line. In Bhabar formation, the water level depth ranges from 2.07 to 5.25 mbgl and 1.26 to 3.78 mbgl in pre-monsoon and post monsoon 2015 respectively. Based on the aquifer parameters of exploratory drilling in the area, the hydraulic gradient estimated in this zone is approximately 2.97 m/km. The hydraulic gradient ranges between 4 and 16 m/km (CGWB, 2015).

Tarai belt is located to the south of Bhabar unit and consists of finer segments of talus material brought down by the streams and sorted to some degree by fluvial action. The lithology predominantly comprises clays and silts with well-sorted granular material like gravel, sand, occasional boulders, cobbles and pebble beds, of which the sands and gravels are the finer fractions of major aquifers in this zone. The groundwater occurring in the unconfined aquifer shows water depth level from 2.78 to 14.72 mbgl and 0.42 to 12.7 mbgl during the period of pre-monsoon and post monsoon (2015) respectively. Whereas, groundwater in deeper confined aquifers occurs under artesian conditions. The artesian flow of individual wells may vary from just a trickle at the surface from the confined aquifer to several hundred or in rare cases to even a thousand gallons per minute. Based on the aquifer parameters of exploratory drillings in the area, the transmissivity values, hydraulic conductivity values and hydraulic gradient values ranges between 1180 to 2500 m /day, 25 to 243 m/day, 1.35 and 4.0 m/km respectively (CGWB, 2015).

Figure 1-Location map representing geology and sampling points of the study area

4. Data And Methodology

Sample collection and its analysis

In May 2016, a complete 43 groundwater samples were acquired from hand pumps, dug wells, lying under 0.5 m below the water table, and pumped for more than 5 min distributed throughout the study area to evaluate groundwater quality. These collected samples were analyzed by applying the procedure suggested by Brown et al., 1983 and APHA, 2004. Samples were collected in 1-l-capacity polythene bottles, but prior to its collection, these bottles were washed thoroughly with diluted HNO_3 acid followed by distilled water in the laboratory and every other precautionary measure was taken, to avoid any possible contamination while filling up the bottles. The WTW portable EC and pH meters measured the hydrophysical parameters (such as pH and EC) in study area itself, while the atomic absorption spectrophotometer (AAS) determined the sodium (Na^+) and potassium (K^+) content in water. Simultaneously the Total hardness (TH) ($CaCO_3$, calcium (Ca^{2+}), chloride (Cl^-), and bicarbonate ($HCO^{-\,3}$)) is estimated using the volumetric methods, and Magnesium (Mg^{2+}) is calculated from the contents of Ca^{2+} and TH. However, the fluoride (F^-), the nitrate (NO_3^-) ion and sulfate (SO_4^{2-}) content are determined by fluoride meter, ion chromatography and spectrophotometric technique respectively. The concentrations of all the elements are expressed in milligrams per litre (mg/l) unit except for pH and EC. The analytical precision for cations and anions measurements is designated by the ionic balance error (IBE), computed on the basis of ions expressed in me/l unit and the IBE value lies within a limit of ± 5% (Mandel and Shiftan, 1980; Domenico and Schwartz, 1990). Some selective trace elements like Cu, Pb, Fe, Mn and Zn were analyzed using the inductively coupled plasma mass spectrometry (Balaram and Rao, 2004). The precise position of sampling points were ascertained in the field itself by developing GARMIN 12 Channel Instrument by applying Global Positioning System (GPS) principles and the exact latitudes and longitudes of sampling points (Fig. 1).

5. Inferences From The Elemental Analysis

5.1. Evaluation of groundwater chemistry

The groundwater quality determines its adequacy in domestic, drinking, industrial and agricultural ventures (Subramani et al., 2005). Physical, statistical and chemical measures like minimum, maximum, mean, standard deviation (SD), permissible limits (mg/l), numbers of samples exceeding allowable limits and its percentage alongwith their relative health hazards (as per WHO standards) are briefed in Table 2. The values of EC vary from 395 µS/cm to 1350 µS/cm, with 872.5 µS/cm as the average value, while the values of pH vary from 7.56 to 8.42, with 7.99 as an average value. These values infer that groundwater in Udham Singh Nagar is alkaline in nature. But on comparing these hydrogeochemical data with drinking water standard of WHO (2004), it could be seen that; 13.95% (EC), 9.3% (TDS), 18.60% (TH), 6.97% (Ca^{2+}), 37.21% (Mg^{2+}), 2.32% ($HCO^{-\,3}$), 2.325% (Cu), 48.83% (Fe), 4.65% (Mn) and 41.86% (Pb) of the samples exceeds the study area's upper limit, thereby indicating a significant water quality deterioration here.

Table 2

Summary statistics of the analytical data and related health hazards as indicated by WHO

Serial No.	Parameters	Minimum	Maximum	Mean	SD	Permissible Limits mg/l (BIS 2004) and (WHO 2004) (mg/l)	Numbers of samples exceeding allowable limits	Percentage of samples exceeding allowable limits	Health Hazards
1	pH	7.56	8.42	7.99	0.608	6.5–8.5	NIL	NIL	Irritation in skin, eye and mucous membrane
2	EC	395	1,350	872.5	675.28	750	6	13.953	Adverse effects
3	TDS	252.8	864	558.4	432.187	500	4	9.302	Irritation in gastrointestinal
4	TH	150	600	375	318.198	300	8	18.60	Encrustation in supply of water
5	Ca^{2+}	28	104	66	53.7401	75	3	6.976	Formation of scale
6	Mg^{2+}	7	85	46	55.154	30	16	37.209	Diarrhea, cramps in stomach
7	Na^{+}	6.7	110	58.35	73.044	200	Nil	Nil	High blood pressure
8	K^{+}	1	12	6.5	7.77817	25	Nil	Nil	Bitterness in taste buds
9	Cl^{-}	7.1	155	81.05	104.581	250	Nil	Nil	Saltiness in taste buds
10	SO_4^{2-}	1.8	95	48.4	65.9023	200	Nil	Nil	Laxative problems
11	HCO_3^{-}	162	708	435	386.080	600	1	2.3255	Renal failure with bleeding
12	NO_3^{-}	0.02	9	4.26	5.9962	45	Nil	Nil	Methaemoglobinaemia
13	F^{-}	0.1	1	0.79	0.9758	1.5	Nil	Nil	Fluorosis
15	Cu	0.001	0.213	0.107	0.1499	0.05	1	2.325	Nausea & gastric problems
16	Fe	0.0021	4.79	2.40	3.3855	0.3	24	55.813	Hemochromatosis
17	Mn	0.001	1	0.342	0.482	0.5	2	4.651	Diarrhea
18	Pb	0.001	1	0.5405	0.762	0.01	18	41.86	Cardiovascular failure, renal failure and reproductive failure
19	Zn	0.002	2	0.996	1.405	5	Nil	Nil	Nausea and stomach cramps

pH: -log $_{10}$ H $^{+}$ at 25∘C; EC in µS/cm, All Ions in mg/l; samples collected on May 2016 SD **standard deviation;** TH **total hardness as $CaCO_3$**

5.2. Evaluation of the cation chemistry

The presence of Ca^{2+} concentration in groundwater varies from 28 to 104 mg/l, while the concentrations of Mg^{2+} detected in 37.21% samples are above the 30 mg/l permissible limit (WHO 2004). However, sodium (Na^{+}) concentration in freshwaters is lower than that of Ca^{2+} and Mg^{2+} contents in general. The concentration of Na^{+} vary from 6.7 and 110 mg/l with an average value of 58.35 mg/l. The water quality effect on the cations concentration is quite evident as Udham Singh Nagar is dominated by anthropogenic activities due to presence of industries here. On the other hand, the concentration of potassium has an average of 6.5 mg/l and falls under the permissible limit. The estimated value of total hardness (TH) lies between 150 and 600 mg/l which doesnot match the WHO International standard, where the maximum allowable limit of TH for drinking is 300 mg/l, and the most acceptable limit is 75 mg/l–100 mg/l. So, groundwater value surpassing the limit of 300 mg/l is treated as hard water (Sawyer and McMcartly, 1967; Freeze and Cherry, 1979). This is justified by the lithology of Tarai unit which is comprises predominantly with boulders, pebbles and coarse to fine sand. Also, Udham Singh Nagar is mainly known for industries and agriculture, alongwith several small and large industries, the State Industrial Development Corporation of Uttarakhand Limited (SIDCUL) is located here that covers an area of about 1500 hectare with 500 industries; mainly food production, automobiles, plywood etc. which are the potential sources for contaminating the groundwater quality and even the trace elements have been found more than permissible limits of drinking water standard.

5.3. Evaluation of the anion chemistry

The concentration of chloride (Cl^-) present in the groundwater samples vary from 7.1 to 155 mg/l with 81.05 mg/l as the average value, which are under the permissible limit. At the same time, 2.32% of the dug well sample (WSP-28) shows that bicarbonate (HCO_3^-) concentration crosses the permissible limit, with concentration varying from 162 to 708 mg/l and an average value of 435 mg/l. The sulphate and nitrate concentration found in the samples ranges from 1.8 to 95 mg/l and 0.02 to 9 mg/l (average of 4.26 mg/l) respectively, lying under the permissible limits. Similarly, the fluoride value calculated from the study area samples lies between 0.1 and 1 mg/l, contrary to the permissible limit of 1.50 mg/l (WHO 2004).

5.4. Characterization of the hydro-geochemical facies

The chemical analysis of groundwater samples are plotted on a Piper trilinear diagram, paving a convenient way in classifying as well as comparing the different types of water (Piper, 1953). The major anions and cations concentration are plotted in two trilinear diagrams and a Piper diagram's diamond shaped field. The chemical analysis of water is divided mainly into two types; Mg-type, Ca-type, Na + K-type and no dominant type water in cation facies & SO_4^{-2} type, HCO_3-type, and Cl-type and no dominant type water in anion facies (Fig. 2) (Table 3). The observations infer that Cl type facies dominates the study area, and the percentage of samples categorized under the Mg-type, Ca-type, Na + K-type & no dominant type water in cation facies and Cl-type & no dominant type water in anion facies are 18.60%, 32.56%, 2.33%, & 46.51%, and 95.35%, & 4.65% respectively.

Table 3
Hydrochemical facies of groundwater

Water type	Sample numbers Numbers	Numbers of samples	Percentage of Samples (%)
(i) Cation Facies			
A) Mg- type	WSP-21,22,23,25,29,31,32,43	8	18.60
B) Ca- type	WSP-1,3,4,5,8,14,15,18,19,24,33,36,38,41	14	32.56
C) Na + K- type	WSP-39	1	2.33
D) No dominant type	WSP-2,6,7,9,10,11,12,13,16,17, 20,26,27,28,30,34,35,37,40,42	20	46.51
(i) Anion Facies			
A) SO_4- type	Nil	0	0.0
B) HCO_3- type	Nil	0	0.0
C) Cl- type	WSP-1,2,3,4,5,6,7,8,9,10,11,13,14,15, 16,17,18,19,20,21,22,24,25,26,27,28,29, 30,31,32,33,34,35,36,37,38,39,40,41,42	41	95.35
D) No dominant type	WSP-23 and WSP-43	2	4.65

5.5. Evaluation of drinking water quality

The physical and chemical parameters of groundwater's analytical results were compared with the standard guideline values recommended by the World Health Organisation (WHO, 2004) for drinking and public health standards, exhibiting the maximum allowable limits of various parameters (Table 2). The concentration of cation shows values 6.98% and 37.21% for Ca^{2+}, and Mg^{2+} ions respectively, thereby exceeding the WHO limit.

5.6. Estimation of the Total dissolved solids

To ascertain groundwater's suitability for different activities, it is crucial to sort the samples based on their TDS. The classification of groundwater based on TDS, shows that 90.69% of water samples are desirable for drinking and 9.30% of water samples are permissible for drinking. It also determines that 96.69% of the water samples lying below 500 mg/l of TDS is fit for quenching thirst without any threat (Table 4). Contour maps of TDS (Fig. 3) clearly illustrates that the TDS value > 500 mg/l is observed in the nearby middle part (Bazpur & Gadarpur blocks) covering 9% of the area, particularly at the well locations WSP-23, 24 and WSP-28. Similarly, well WSP-2 in the Eastern part is also affected with higher TDS values 524 mg/l. It is noticed that the wells of central and eastern parts, WSP-2, 23, 24 and WSP-28 are comparatively populated, have a larger number of industries and high concentration of water outflow. The estimated TDS value is 252.8 mg/l, detected in and around the Bidhora village well (WSP-11), indicating ample availability of adequate groundwater quality because it lies close to Nanak matta tank and recharge area.

Table 4
Groundwater classification based on Total dissolved solids (mg/l)

Total dissolve solids(mg/l)	Classification	Sample numbers	Number of samples	Percentage of samples
< 500	Desirables for drinking	WSP1,3,4,5,6,7,8,9,10,11,12,13,14,15, 16,17,18,19,20,22,24,26,27,29,30,31,32, 33,34,35,36,37,38,39,40,41,42,43	39	90.69
500–1000	Permissible for drinking	WSP 2, 23,24 and WSP-28	4	9.302
1000–3000	Useful for irrigation	Nil	Nil	Nil
> 300	Unfit for drinking and irrigation	Nil	Nil	Nil
Total			**43**	**100**

5.7. Estimation of the Total hardness

The groundwater classification based on total hardness (TH) (Table 5) shows that most groundwater samples fall in the hard water category and the remaining groundwater samples in the very hard category. TH of the groundwater was calculated using the formula given below (Sawyer 2003).

TH (as $CaCO_3$) mg/l= (Ca^{2+} + Mg^{2+}) meq/l x 50

The hardness values range from 150 to 600 mg/l (Table 2). The maximum permissible limit for Total Hardness in water is 300 mg/l which makes it fit for drinking. But WHO International has standardized 100 mg/l as the most desirable limit of TH to be present in the drinking water. Out of the 43 samples of groundwater collected, only eight of them surpass the maximum permissible limit of 300 mg/l (Fig. 4). The excess value of TH is observed in and around the Bazpur and Gadarpur blocks and Middle Northwest of the study area because of untreated effluents getting discharged from the industries. The rest of the study area falls in the hard water zone due to dissolved unconsolidated solid and rocks, mostly limestone, silt, gypsum and calcium.

Table 5
Groundwater classification based on total hardness as $CaCO_3$ (Sawyer and McMcartly, 1967)

Total Hardness as $CaCO_3$ (mg/l)	Type of water	Sample numbers	Number of samples	Percentage of samples
< 75	Soft	Nil	Nil	Nil
75–150	Moderately Hard	Nil	Nil	Nil
150–300	Hard	WSP1,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,1,8,19,20,21,24,25,27, 31,32,33,34,35,36,37,38,39,40,41,42	35	81.40
> 300	Very hard	WSP-2,22,23,26,28,29,30,43	8	18.60
Total			**43**	**100**

5.8. Estimation of Magnesium (Mg^{2+}) ion concentration

The Magnesium (Mg^{2+}) concentration vary between 7 and 85 mg/l with 46 mg/l as an average value (Table 2). But the Magnesium ion concentration in groundwater samples surpasses the maximum permissible limit of 30 mg/l in water samples no. WSP-2, 7, 21, 22, 23, 25, 26, 27, 28, 29, 30, 31, 32, 35, 40 and WSP-43. Excess in Magnesium concentration is found in most of Bazpur block & Gadarpur block, and some part of Kashipur (WSP-35 & 43), Jaspur (WSP-40), Sitarganj (WSP-7) and Khatima (WSP-2) blocks in the Udham Singh Nagar district due to the untreated discharges from the industries. The spatial distribution of concentration in groundwater of the study area is illustrated in Fig. 5.

5.9. Estimation of the Iron (Fe^{+2}) concentration

The Iron (Fe) ion concentration varies from 0.002 to 4.79 mg/l with an average value of 2.4 mg/l in Rudrapur, Gadarpur, Sitarganj, Khatima, Jaspur, Kashipur and Bazpur blocks of the district. But the Fe ion concentration in groundwater samples crosses the acceptable limit of 0.3 mg/l in sample numbers; WSP-1, 2, 8, 9, 11, 12, 14, 15, 16, 17, 18, 22, 23, 24, 25, 29, 31, 33, 34, 35, 36, 38, 39 and WSP-41. The highest value of Fe was found in well number WSP-15 of the Rudrapur block. All blocks showed higher iron ion concentration in the study area. On comparing the different blocks, the excess iron concentration is found in most of Gadarpur, Rudrapur, Bazpur, Khatima & Kashipur blocks and some part of Sitarganj and Jaspur block of the Udham Singh Nagar district. This is because of lowering in pH and slightly reducing conditions, that lead to the reduction of Fe^{+3} and their oxides and in turn increased the mobility of Fe (Hodgson, 1963; Prasad et al., 1991; Kumar et al., 2018). The spatial distribution of iron concentration in groundwater of the study area is illustrated in Fig. 6.

6. Conclusion

Udham Singh Nagar district is rich in fertile land, water resources and industrial development. The increased urban growth and establishment of Integrated Industrial Estate (IIE) at Pantnagar, Kashipur and Sitarganj area have increased groundwater demand in recent years. In May 2016, 43 groundwater samples were taken from hand pumps and dug wells lying under 0.5 m below the water table in evaluating the groundwater quality. The collected samples were analyzed by applying the procedure suggested by Brown et al., 1983 and APHA, 2004, while the precise location of sampling points was determined in the field by developing GARMIN 12 channel Instrument based on GPS principles and exact coordinates of these locations. After elemental analysis, it gets confirmed that TDS, TH, Mg^{2+}, Fe^{2+} and Pb^{2+} are present above the WHO's permissible limit, thus indicating a deterioration in groundwater quality. Along with that the Piper Trilinear diagram characterized groundwater by identifying the hydrochemical facies; Mg, Ca, Na + K type under cation facies and SO_4^-, HCO_3^-, Cl^- type under anion facies. Despite the presence of harmful elements in groundwater, the amount of total dissolved solids in most groundwater samples is < 500 mg/l dissolved solids which makes it desirable for drinking. This phenomenon tries to associate with suitable drinking water dwelling in the aquifer of the study realm.

Declarations

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Code availability- The authors haven’t used any software or programming language for accomplishing this research work.

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Figures

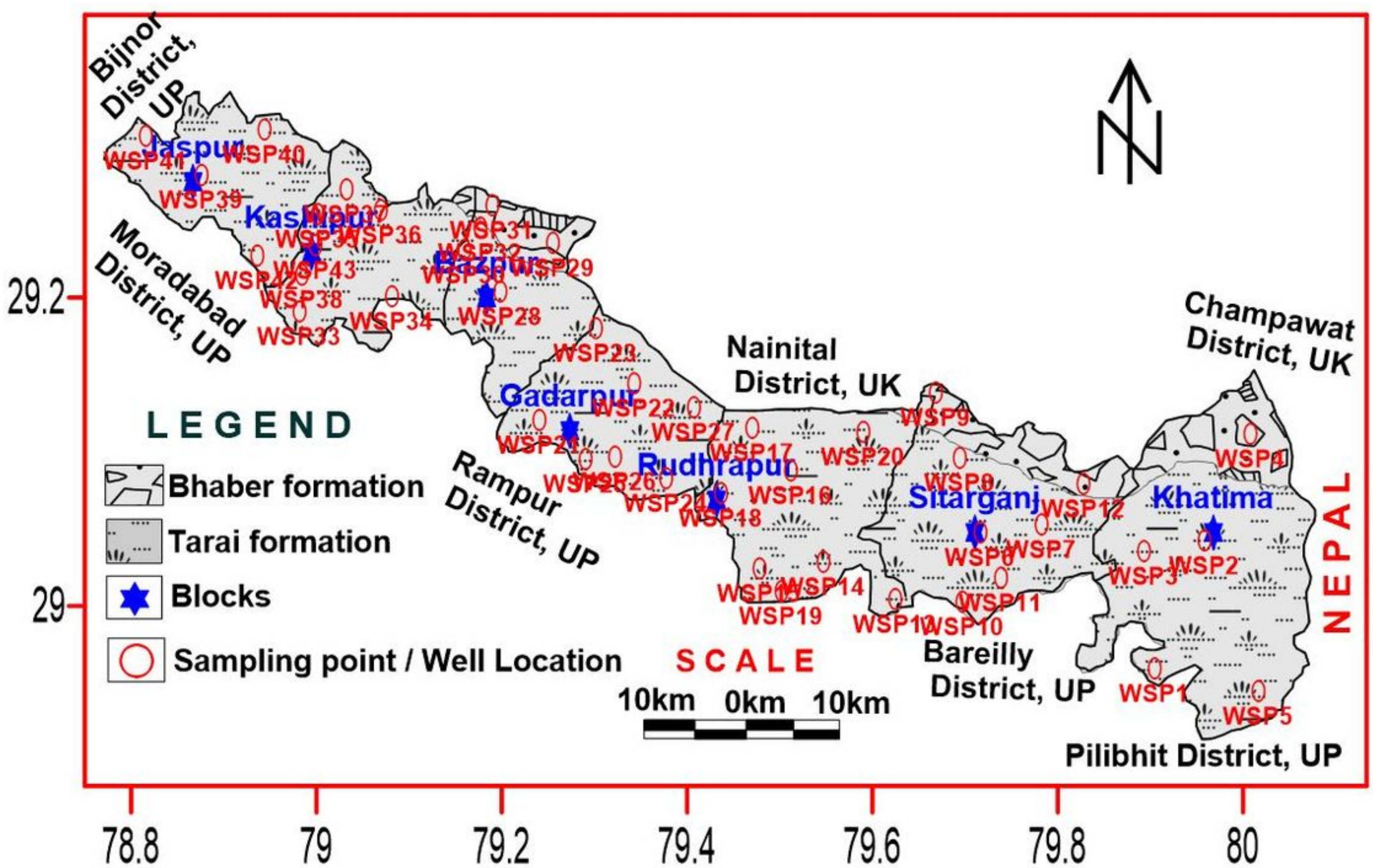

Figure 1

Location map representing geology and sampling points of the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

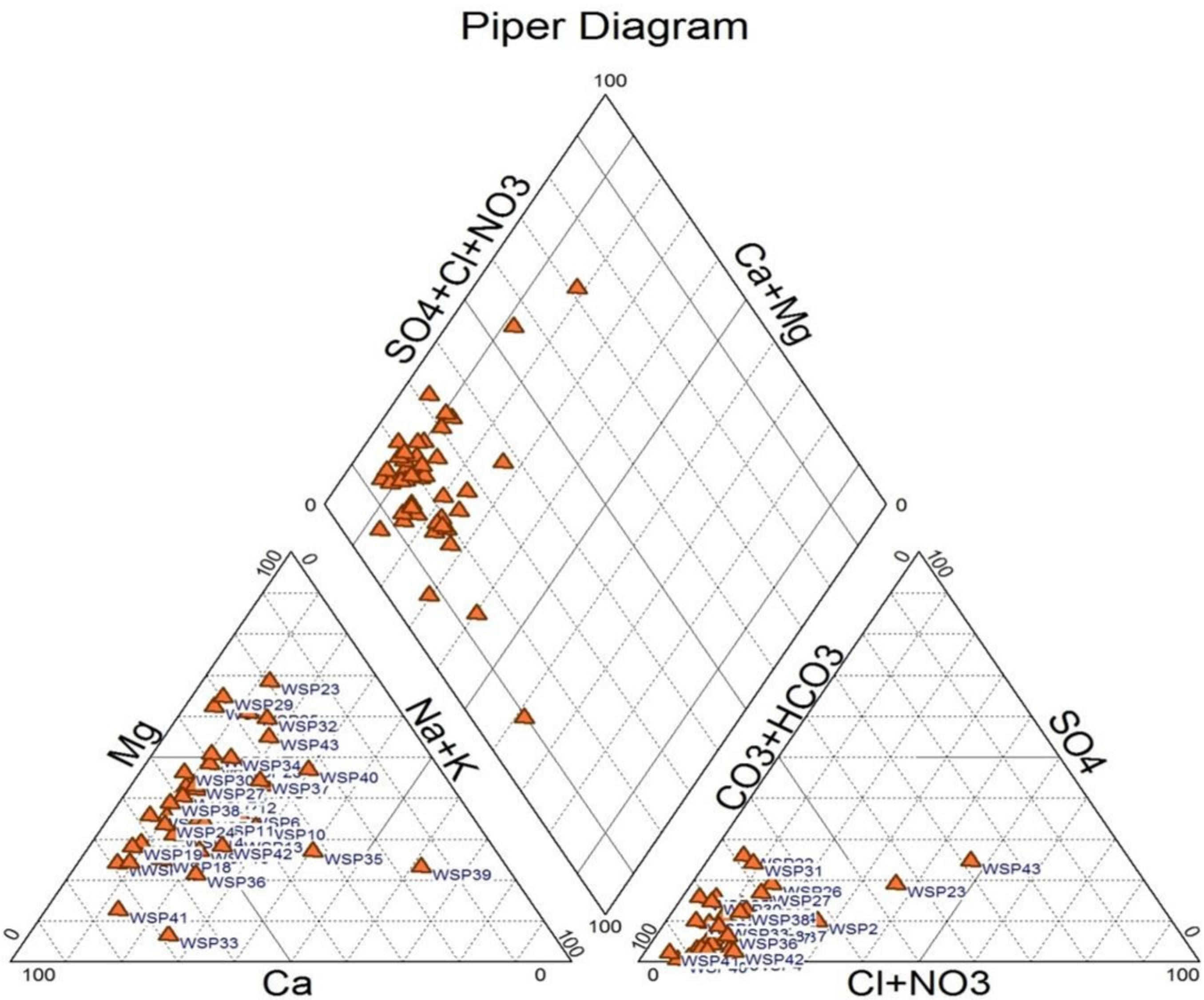

Figure 2

Piper Tri-linear Diagram representing the chemical analysis of samples

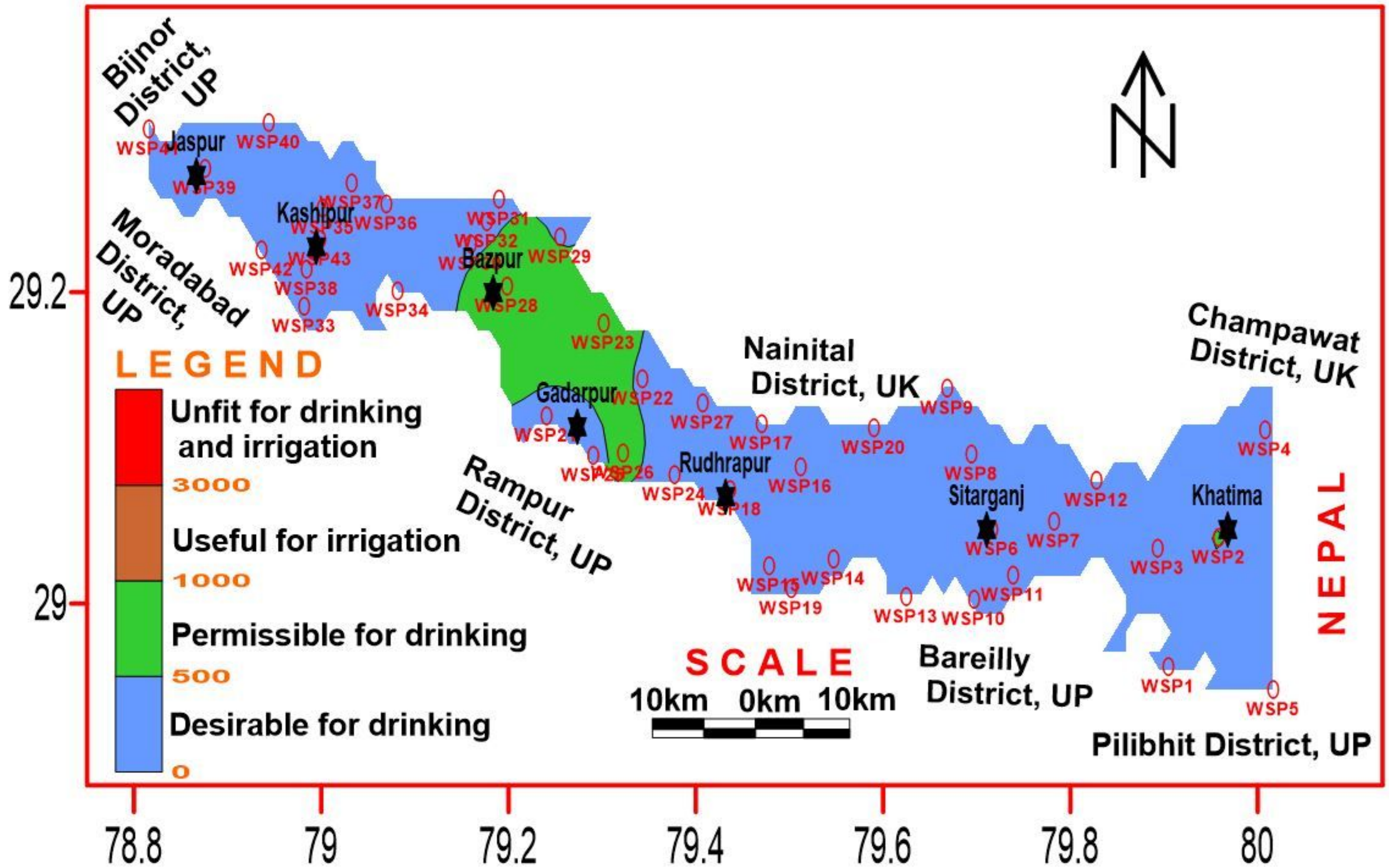

Figure 3

Spatial distribution of Total Dissolved Solids across the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

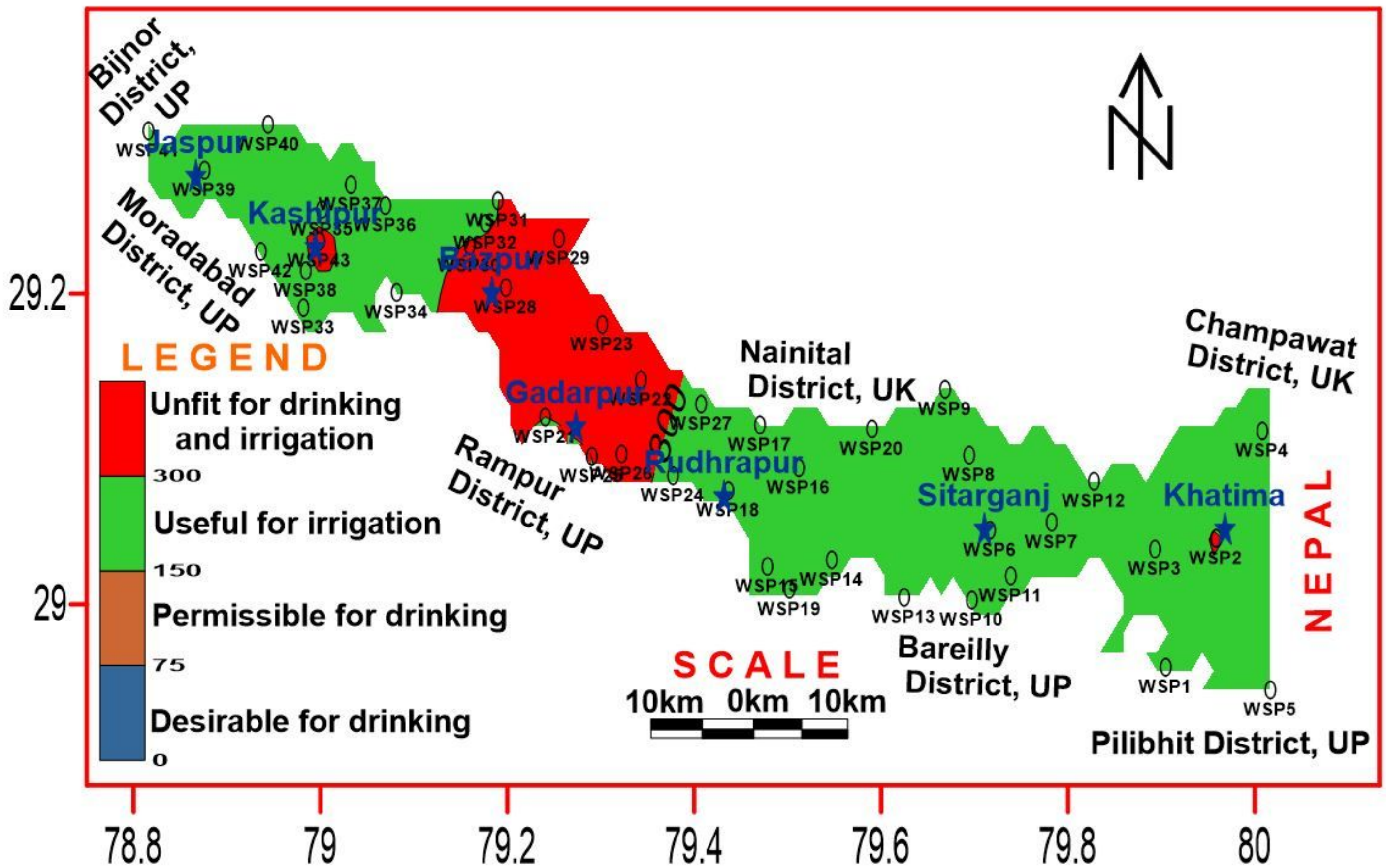

Figure 4

Total Hardness distribution in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

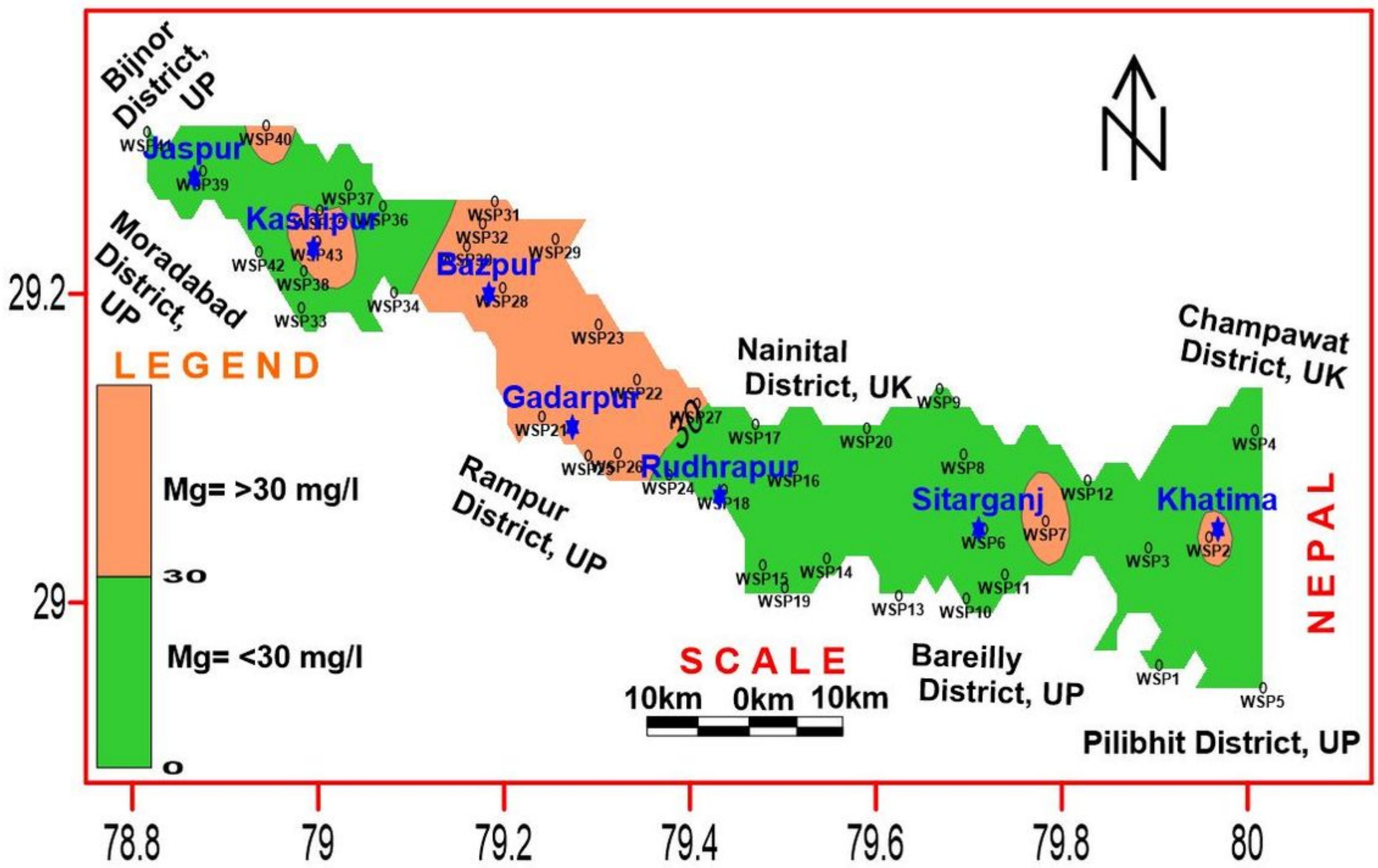

Figure 5

Spatial distribution of magnesium concentration in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

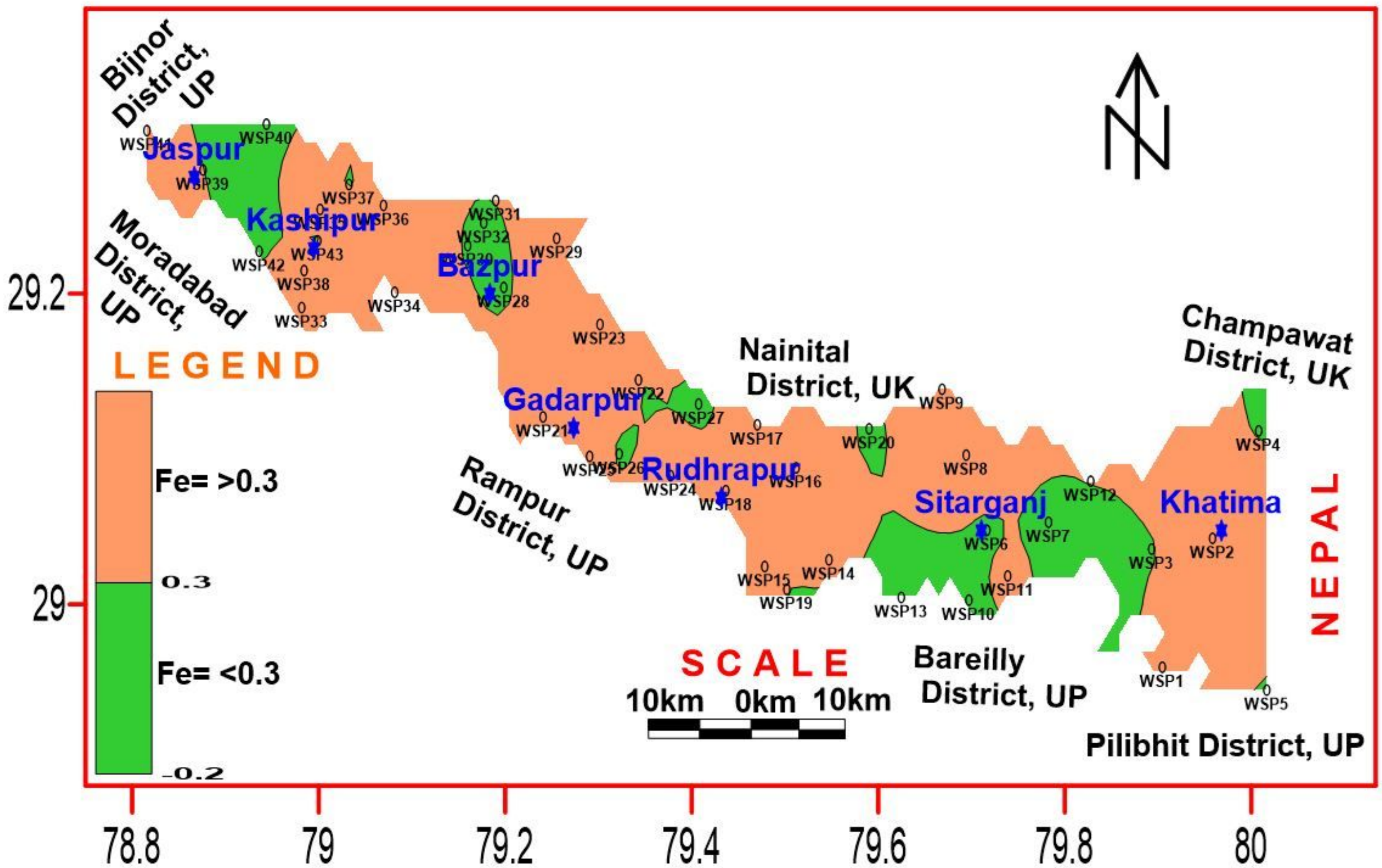

Figure 6

Spatial distribution of iron concentration in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.