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Water Quality Assessment of River and Groundwater from Morang and Gumani River Basin, Jharkhand

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ABSTRACT

Physiochemical parameters of river water and groundwater samples from Morang and Gumani river basin, Jharkhand was assessed to find out their suitability for domestic and irrigation uses. Water samples were categorized as $Ca^{2+} - Mg^{2+} - HCO_3^-$ hydrogeochemical facies and cation, anions were mainly derived from the rock. Individual concentration of Na⁺, Ca²⁺, Mg²⁺, K⁺, Cl⁻, F⁻ and SO₄²⁺ are within the prescribed limit of WHO and BIS standards. However, NO₃⁻ of one groundwater is higher than the permissible limit. River and groundwater is safe for irrigation as per the Soluble Sodium Percentage (SSP) or %Na, Sodium Adsorption Ratio (SAR) and salinity hazard parameter. Magnesium hazard (MH) river water is not suitable for the irrigation and special care needs prior to use.

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Introduction

In the Jharkhand state, nearly 76% of populations are living in rural areas and in the state only 13-15% have access to piped water facility (Census, 2011; Jharkhand Economic Survey 2016-17). Around 44 % of population depend up on hand pumps in Jharkhand, which is higher than the national average, 37% uses well and remaining 19% of population depends up on open sources (Census, 2011; Jharkhand Economic Survey 2016-17). In the most part of the state, groundwater quality is not safe for domestic uses. In the rural areas peoples are heavily depend up on the available open water sources like river, lake and ponds. Government has initiated National Rural Drinking Water Program (NRDWP) and under this program, safe drinking water will be supplied to the rural areas. Topographic condition of the rural areas in the state and time requisite for complete execution is a challenge and it require more time. Contamination of arsenic, fluoride and iron in the groundwater is already reported from different part of the state (Jharkhand Economic Survey 2016-17, Bhattacharjee et al. 2005; Nayak et al. 2008; Chakraborty et al. 2015). Therefore, it is important to assess the quality of surface and sub-surface water of different watershed of the state and to create awareness among the people for the cautious use of available natural water. In this study, water samples from Morang and Gumani watershed were collected for quality assessment. This assessment will help to find out suitability of river water and groundwater for domestic, agricultural and industrial uses.

Based on the various physiochemical parameter quality of natural water is determined. The chemical constituents present in the natural water are mainly derived from the rockwater interaction, atmospheric and anthropogenic input. Due to chemical weathering, minerals present in the source rock gets dissociated and different elements are mobilized through the water. If the source rock is having heavy metals and other toxic element bearing minerals, then during chemical weathering such elements will be transported through the natural water. Other than the toxic elements, level of major anions and cations in the natural water can also cause serious problem for regular use. Therefore, during assessment of natural water source of different chemical constituents are needs to be evaluated. Morang and Gumani watershed lies mainly over the Rajmahal trap basalt. Basalt is prone to chemical weathering and it controls the geochemistry of the natural water. Based on the different approaches and discrimination plot hydro-chemical facies of water and source of chemical constituents can be evaluated. For assessment of water quality, physiochemical parameters of the natural water can be directly compared with the World Health Organization (WHO) and Bureau of Indian Standard (BIS). In earlier studies emphasized mainly groundwater contamination of arsenic and their various health impacts around the Rajmahal (Bhattacharjee et al. 2005; Navak et al. 2008; Chakraborty et al. 2015). Nevertheless, other contaminants in the water system cannot be ignored in the aspect of health hazards. For instance, source of nitrate in the groundwater is associated to the anthropogenic activities and fertilizers usages for agricultural purpose. Nitrate and chloride abnormality with respect to permissible ranges in groundwater is also evaluated here. For agricultural and industrial purpose, it can also be evaluated based on the other parameters like acidity or alkalinity, electrical conductivity, salinity, Total Hardness (TH), Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC) and Soluble Sodium Percentage (SSP). These parameters are mainly consider the possible effect of natural/treated water on plant productivity, physiochemical condition of soil, crop yield and fertility of soil in the long term use of such water. In the present study, the above parameters were calculated and evaluated for river water and ground water collected from Morang and Gumani watershed (Figure 1).

Geological of the Study area

Study area is situated between latitude of N24°50'52.08" N25°10'59.8", and longitude of E87°33'16.16" - E 87°42'36.8" (Figure 1); and situated in N-E part of the Indian state of Jharkhand. Catchment area of the Morang and Gumani river is mainly surrounded by Rajmahal basaltic outcrops. The fertile black color soil is mainly formed from the basaltic flow, whereas other soil types are Tal soil, eroded scarp soil, foothill soils, red soil and alluvial soil are present in the watershed. The Rajmahal flow is having maximum thickness of 600m with the multiple stage of volcanic eruption (Klootwijk 1971). It is believed that the basaltic flow is derived from the Kerguelen hotspot origin and is having age of ~117±1 Ma (Mahonev et al. 1983; Baksi 1989; Kent et al. 2002). This formation mainly consists of quartz-normative tholeiites with minor olivine-basalts and basaltic andesites. Thin sequence of Gondwana supergroup (Early Permian to Early Cretaceous sediments) overlain by segments of subaerial Rajmahal volcano, which in turn resting on highgrade Precambrian basement of Chotanagpur gneissic complex (Storey et al. 1992). In response to multiple past volcanic events, this prompted to be interbedded with thin sedimentary or volcanoclastic horizons, which encloses plant fragments of Lower Cretaceous age (Sengupta, 1988). W-S direction of the basaltic outcrop of Rajmahal hill is associated to the flank of Dubrajpur formation with the maximum thickness of nearly 137m. Dubrajpur formation mainly comprises ferruginous sandstone, coarse pink feldspathic sandstone, conglomerates and clay size particles. It occurs as narrow discontinuous bands which striking the Rajmahal formation along the western margin of the Rajmahal (Ball 1877).

Materials and methods

Water samples were collected from river (n=22) and bore well (n=4) from different location around the study area during post monsoon season of 2017. River water samples were collected from the middle of the flow. Locations were selected based on the confluence of the lower order stream to the main stream of Morang and Gumani River. River water sampling covered almost important tributaries, which originates from the smaller isolated valley. Nonmetallic bucket tied with nylon rope were used to collect the river water samples to avoid metal contaminations. Samples were collected from the middle of stream, where the flow was continuous. Collected water samples were immediately analyzed for pH, TDS, Salinity, Temperature and Conductivity with the help of pocket tester multi-parameter kit Eutech-PCTestrTM35 in a polypropylene beaker. Subsequently, alkalinity measurement was performed with the help of field test kit made of HANNA-HI3811. Prior to water sampling, the containers (500 mL carboy) were rinsed copiously with the ambient water. The collected samples were filtered on the same day using nylon membrane filter of 0.45 µm pore size with diameter the 47 mm to discard suspended particles. The filtration kit was made up of polypropylene material and setup was connected to the oil free automatic electric vacuum pump. Two aliquots of 125 mL water sample each were stored in a pre-washed and Milli-Q soaked polypropylene bottles. One aliquot of the filtered sample were immediately sent for the anion analysis, whereas another aliquot were acidified with the ultrapure nitric acid $(\sim pH = 2)$ for cation analysis. Major anion composition F, Cl, SO₄ and NO₃ in the water samples were measured in Ion Chromatography (Thermo Scientific - Dionex ICS 5000 plus). Cations and some trace elements such as Na, Mg, K and Ca analysis were performed in the quad-pole ICP-MS with the diluted (250x) samples. The analytical precision and instrumental drift was continuously monitored with the help of known concentration of the synthetic standard solution in periodic interval of sample analysis. Analytical uncertainties of the measurements were observed to be within the \pm 8%. **Result**

Statistical summary of the result is listed in the Table 1. The temperatures of the samples were ranged from 26.1-27.81°C. The pH values of river water and groundwater are ranged from 7.87-8.36 with the mean value of 8.1; and 6.55-6.94 with mean pH 6.68 respectively. The river water samples are alkaline in nature whereas groundwater is slightly acidic. EC value varies from 120.1-296 μ S/cm⁻¹ with mean value 200.37 μ S/cm⁻¹ for river water, whereas, for groundwater it shows 390-615 μ S/cm⁻¹ with mean EC value is 482.25 μ S/cm⁻¹. EC values are relatively higher in groundwater as compared to the river water samples. Similarly, the total dissolved solid (TDS) varies from 85.9-211 ppm with mean value 142.5 ppm in river water, whereas 276-435 ppm with the mean TDS is 342 ppm in groundwater are almost twice than the river water samples.

In case of major cations, Ca^{2+} followed by Mg^{2+} and Na^{+} ions dominates in the river water samples. The elemental concentration of Ca²⁺ ranges from 4.35-16.89 mg/l with the mean value 9.65 mg/l, and Mg²⁺ varies from 4.97-11.68 mg/l with mean value 7.81 mg/l. The Na⁺ concentration ranged between 4.20-13.33 mg/l with the mean value 7.32 mg/l, whereas, K⁺ ranges between 0.50-2.89 mg/l with mean value 1.40 mg/l. Among the river water, nearly 86% of the water samples dominated by Ca^{2+} , 9% with Mg^{2+} and ~5% by Na⁺. The average Ca^{2+} composition is nearly 38% out of total cations. Potassium ($K^+ \sim 9\%$ of total cations) composition in the Mg2+ dominated water samples were almost two fold higher as compared to the Ca^{2+} dominated samples. Sodium fraction (~29% out of all cations) is almost similar in all the river water, even in the samples of Na dominated. The cationic fraction indicates 73% of river water samples are ordered as Ca>Mg>Na>K while 13% are in Ca>Na>Mg>K and 9% are in Mg>Ca>Na>K. Around 4% samples are Na dominated, where descending order of cations are Na>Ca>Mg>K. River water samples are dominated by HCO_3^{-1} ion. Other anions are significantly lower with respect to bicarbonate. Bicarbonate contributes to almost 95% to the total anions, whereas, Cl^{-} is only 2% and it followed by SO_{4}^{2} (1.5%) ion. Nitrate and fluoride concentration are very low and it account 0.3% and 0.13% respectively. Anion constituent such as HCO3 ranges from 95.16-223.26 mg/l with mean value 145.24 mg/l followed by Cl ion with their range 1.07-3.74 mg/l with mean value 2.24 mg/l. Concentration of NO₃ ranges from 0.07-0.79 mg/l and mean value is 0.31 mg/l. Concentration of SO₄ varies from 0.65-2.24 mg/l with mean value 1.28 mg/l and F ranges between 0.11-0.28 mg/l with mean value of 0.17 mg/l.

Among four groundwater samples, two samples (GW1 & GW2) shows dominance of Ca, accounting 40% of the total cations. Concentration of Ca in the groundwater varies from 19.90-41.87 mg/l with mean value 27.32 mg/l. Other major cation like Mg ranges from 5.07-22.38 mg/l with mean value 14.42 mg/l and Na concentration ranges from 22.92-31.92 mg/l with mean value 26.98 mg/l. Among cations concentration of K is lowest and it ranges from 0.20-1.30 mg/l with mean value is 0.80 mg/l.



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Table 1. Statistical summary of the	parameters measured	from the sample	es and calculated in	dices. Units are given in the
	nai	enthesis.		

Parameters/	River water (n=18)		Ground water (n=4)		BIS (2012)		WHO (1997)			
Indices										
	Range	Mean	Range	Mean	M.D	H.P	M.D	H.P		
рН	7.87 - 8.36	8.10	6.55 - 6.94	6.68	6.5-8.5	-	7.0-8.5	6.5–9.2		
Temp. (° <i>C</i>)	24.8 - 28	26.6	26.7 - 28.7	27.83						
EC (μS)	120.1 - 296	200.4	390 - 615	482.25	-	-	750	1,500		
TDS (mg/l)	85.9 - 211	142.5	276 - 435	342.00	500	2,000	500	1,500		
Salinity(mg/l)	61.1 - 144	98.2	188 - 299	233.7						
Ca (<i>mg/l</i>)	4.35 -	9.65	19.9 - 41.87	27.32	75	200	75	200		
	16.89									
Mg (<i>mg/l</i>)	4.97 -	7.81	5.07 - 22.38	14.42	30	100	30	150		
	11.68									
Na (<i>mg/l</i>)	4.2 - 13.33	7.32	22.92 -	26.98	-	-	50	200		
			31.92							
K (<i>mg/l</i>)	0.5 - 2.89	1.40	0.2 - 1.3	0.80	_	_	100	200		
F(mg/l)	0.11 - 0.28	0.17	0.08 - 0.2	0.16	1	1.5	0.6-0.9	1.5		
Cl(mg/l)	1.07 - 3.74	2.24	2.62 - 35.29	22.04	250	1,000	250	600		
$SO_4 (mg/l)$	0.65 - 2.24	1.28	3.2 - 16.81	7.89	200	400	200	600		
$NO_3 (mg/l)$	0.07 - 0.79	0.31	0.12 - 66.81	21.29	45	_	-	50		
$HCO_3(mg/l)$	95.2 -	145.2	183 - 307.4	239.7	200	600	200	600		
	223.3									
SSP (%)	31.6 - 20.5	24.0	50 - 25.4	33.8	Abbreviations: - M.D - Maximum Desirable, H.P - Highest					
RSC (meq/l)	2.0 - 0.9	1.26	2.26 - 0.2	1.38	Permissible,					
SAR (meq/l)	0.6 - 0.3	0.42	1.6 - 0.8	1.10	SSP- Soluble Sodium Percentage					
MH (%)	65.9 -53.1	57.7	51.5 - 29.5	44.5	RSC- Residual Sodium Carbonate					
					SAR- Sodium Absorption Ratio					
					PI – Permeability Index					
					MH – Magnesium Hazard					

Ca dominated samples have Ca>Na>Mg>K sequence of cations, whereas, sample GW3 and GW4 are dominated by Na (48%) and the sequence of other cations are Na>Ca>Mg>K. Similar to river water, bicarbonate dominance is observed in the groundwater and it ranges between 183-307.44 mg/l and mean value of 239.73 mg/l. Concentration of CI⁻ ranges from 2.62-35.29 mg/l with mean value of 22.04 mg/l. In case of SO₄²⁺ the concentration ranges from 3.20-16.81 mg/l (mean 7.89 mg/l) and NO₃ varies from 0.12-66.81 mg/l (mean 21.29 mg/l).

Discussion

Hydro-chemical facies and source of ions:

Based on the Piper diagram (Piper, 1953), hydrogeochemical facies of the water samples of Morang and Gumani watershed is categorized as $Ca^{2+} - Mg^{2+} - HCO_3^$ except on groundwater sample that lie between $Ca^{2+} - Mg^{2+} HCO_3^-$ and $Na^+ - K^+ - HCO_3^-$ category (Figure 2). It indicate that during rock water interaction calcium bearing minerals are dissociated and Ca^{2+} ion being transported via river and groundwater. In the catchment area of Morang and Gumani river, exposure of carbonate rock is not reported. Therefore, the natural source of Ca^{2+} and HCO_3^- is silicate weathering. Plagioclase and clino-pyroxene are the two major primary minerals in the basalt, and during basalt weathering Ca^{2+} is readily released to the aqueous phase. In addition to major mineral, presence of calcite in the amygdaloide and vesicles of basalt flow is reported. These calcite minerals may be another potential source of Ca^{2+} in the water. In the Piper plot, (Figure 2) samples are also plotted along with their TDS value and the bigger circle representing the higher TDS. Groundwater samples show higher TDS than the surface water, which is due to the longer rock-water interaction period. Three groundwater sample shows relatively higher Cl⁻ and SO_4^{2+} concentration compare other river and groundwater. In this study, it is found that the source of cation and anions are dominated by the rock (Figure 3, a & b). Gibbs plots (Figure 3) illustrate the mechanisms that are responsible for the dissolved chemical constituents of the natural water (Gibbs, 1970). Although all the samples are plotting in the rock dominance area, but river water samples are showing a trend towards the precipitation dominance field whereas, groundwater samples are falling towards evaporation dominance field (Figure 3, a). It indicates that atmospheric contribution towards dissolve species in the river water should be considered as important source of cations. After evapotranspiration loss, rainwater is percolated through soil and followed by the rock/sediments and finally reaches aquifer. During this process and subsequent interaction with aquifer, ions are enriched in the groundwater. Therefore, observed TDS in the groundwater is higher compare to the river water.



Figure 2. Piper diagram (Piper, 1953) to identify the hydro-geochemical facies of the water samples. This plot was prepared using origin software.



Figure 3. Gibbs (1970) plot to identify the mechanisms that are responsible for the dissolved constituents of water samples. a) TDS vs Na/ (Na+Ca) and b) TDS vs Cl/(Cl+HCO₃) plot (in mg/l) shows rock dominance in the samples.

Water quality assessment for domestic use

Geochemical data for various elements were further analyzed to assess for their quality to the purpose of drinking, irrigation and other domestic uses. The range of the physiochemical parameters and dissolve constituents were compared (Table 1) with the recommended specifications of WHO (1997) and BIS (2012) to find out their suitability for domestic use. Electrical conductivity, pH, TDS and salinity range of most water samples are within the maximum limit prescribed by these desirable organizations. Groundwater samples are falling towards higher end. TDS in groundwater samples are closed to maximum desirable limit, though their ranges are within the highest permissible limit. High EC and TDS in groundwater cause various health issues and among them common problem face by the user is gastrointestinal irritation (Singh 2008). Hard water is generally due to the effects of salts dissolved in it, primarily calcium and magnesium. Nearly 77% of the river water samples are soft in nature and the total hardness (TH) ranges between 31 - 59 ppm, whereas 23 % are marked as moderately hard and ranged between 69.5 - 90 ppm. Groundwater samples are hard in nature, which is ranging from102 - 195 ppm. Various health issues such as cardiovascular disease, growth retardation and reproductive failures are being reported due to the high TH in drinking water (Sengupta, 2013). In case of domestic use High TH water prevent forming lather with soap, increases boiling temperature and occurrence of unnecessary salt coating and encrustation in the containers or utensils.

Concentration of individual major cations like Na⁺, Ca²⁺, Mg^{2+} and K^+ , and anions like Cl⁻, F⁻ and SO_4^{2+} are within the prescribed limit of WHO and BIS standards. However, concentration of NO_3^{-1} in one of the groundwater is higher than the highest permissible limits, and other river water and ground water are within the permissible limit. The abnormal concentration of nitrate in drinking water may cause methemoglobinemia, or blue baby disease, gastric cancer, goiter and hypertension (Majumdar and Gupta, 2000). In case of HCO₃⁻ three river water samples, two tributaries of Morang river and one tributaries of Gumani river, shows higher concentration compare to the maximum desirable limit (200 mg/l), however it is lower than the highest permissible limit (Table 1). Three out of four groundwater samples having higher HCO₃⁻ concentration compare to the maximum desirable limit (200 mg/l). One groundwater sample collected from the upper reach of Morang river, is falling under the permissible limit HCO₃⁻ concentration. The high intake of Mg salts may also cause a change in bowel habits to the user (Sengupta, 2013). The standard water treatment and systematized sanitization planning is required to supply safe drinking water and for other domestic uses. Water quality required for livestock is similar as for human drinking water with miner deviation in terms of suspended solids, salinity and Mg (salinity <1500 ppm, Mg<250 ppm) content (Singh 2008: Avers and Wescot 1985: Shuval et al. 1986). The freshwater and groundwater samples of the studied area are within the standard and suitable to livestock.

Water quality assessment for agricultural use

Suitable freshwater is required for cost-effective agricultural production and plant growth. Therefore, water quality assessment would results the constructive beneficial to appropriate crops selection. The careful management of the cropping techniques may diminish the effect on yields. Salinization in irrigation water is a major cause to loss in agricultural production. Several techniques are included in agricultural strategies, such as leaching, altering irrigation technique and period, mounting sub-surface drainage, altering tillage techniques (Singh 2008). All such techniques are cost-effective and also necessitate local suitability in the field. Salinity of the water is the factors essentially influence the crops. It affects soil structure, permeability and indirectly affects the growth. Soluble sodium percentage (SSP) or it expressed as sodium content (%Na) in the water is an important tool to classify water for irrigation. It can be calculated using following equation (Kelly, 1957), where concentrations are expressed in meq/l (milli-equivalents per litre).

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

The maximum Na % >60 is generally not recommended for irrigation. Na% ranged in freshwater and groundwater are 20.5 - 31.54 and 25.3 - 50 respectively. Wilcox (1955) classification is based on the Na% and electrical conductivity of water that suggests suitability of the water for the purpose of irrigation. All the water samples are falling in the excellent field of the Wilcox diagram (figure 4). Water samples are required strategic and thorough investigation for further classification to the purpose of irrigation. For irrigation, Magnesium Hazard (MH) is also used for quality assessment (Szabolcs and Darab, 1964). MH is calculated as (MH %) = Mg / (Mg+Ca)*100, where concentrations are in meq/l. If the MH percentage is higher than the 50% then the water is not suitable for the irrigation. In the studied river system all sample shows >50% MH (Table 1) which indicate river water is not suitable to use directly for the irrigation and special care needs to be taken to tackle higher MH. Groundwater is safe in terms of magnesium hazard but two groundwater samples are having MH close to the 50%. Sodium Absorption Ratio (SAR) is calculated using following equation where concentrations are in meg/l. . .

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

For SAR calculation, generally ion concentrations are measured from water is extracted from saturated soil. Here the natural waters are believed to be interacted with soil, therefore measured ion concentrations are being used for calculation of SAR. High concentration of sodium in irrigation water may leads the soil to be alkaline by the process of evaporation and consequently residual salt deposit. SAR ranged from 0.32 - 0.64 in river water and 0.85 - 1.65in groundwater samples. SAR value from 0-10 is also called as low Sodium hazard and considered to be little or no hazard for the purpose of irrigation. Higher SAR values are categorized as Medium Sodium hazard (10-18), High Sodium hazard (18-26), Very high Sodium hazard (>26). Salinity hazard and SAR value is used in the US salinity diagram (USSL) to classify water into different categories for irrigation purpose. Studied water samples are plotted in USSL diagram (figure 5) to determine their suitability for irrigation. As per the USSL diagram, river water samples are ranging from Low (C1) to Medium (C2) in salinity hazard and occupy Low (S1) in sodium hazard field. River water sample occupies C1S1, C2S1 field, whereas, ground water samples are occupying C2S1 field. All the samples are classifies to be suitable for irrigation. Crops with low range salinity tolerance may be cultivated for the healthier growth.

In addition, effects of carbonate and bicarbonate on crops are assessed with Residual Sodium Carbonate (RSC). RSC

quantifies the carbonate, bicarbonate in alkaline earth (Ca + Mg) (Raghunath 1987). RSC is calculated as (in meq/l)

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

Although this parameter is less used nowadays, but it has greater impact on soil health and crop growth. For irrigation, excess of Ca and Mg in carbonate and bicarbonate possibly results to complete precipitation (Raghunath 1987). RSC > 5 meq 1^{-1} are harmful for the crops, whereas >2meq 1^{-1} are unsuitable (Eaton 1950). The studied river water shows RSC from 0.86 – 2.02 meq 1^{-1} and groundwater ranges from 0.20 – 2.26 meq 1^{-1} . In respect of RSC, samples are within the prescribed limit and are suitable for irrigation purpose.



Figure 4. Wilcox (1955) diagram used for identifying suitability of the water for the purpose of irrigation.



Figure 5. Classification of water based on US salinity (USSL) diagram for the purpose of irrigation. Conclusions

From this study, it is observed that river water samples from Morang and Gumani river basin is alkaline in nature. River and groundwater samples are mostly of $Ca^{2+} - Mg^{2+} - HCO_3^-$ hydro-geochemical facies. Cation and anions are mainly derived from the rock and the natural source of Ca^{2+} and HCO_3^- is chemical weathering of silicate minerals. Groundwater samples show higher TDS than the surface water, which is due to the longer rock-water interaction period.

Concentration of individual major cations and anions, pH, TDS and salinity are within the prescribed limit of WHO

and BIS standards. However, one groundwater collected from upper reach of Morang river shows high NO₃⁻ concentration than the permissible limit. Wilcox and USSL diagram shows all the water samples are safe for irrigation purpose. In terms of Magnesium hazard (MH) river water is not suitable for the irrigation and special care needs to be taken before use. Groundwater is safe in terms of magnesium hazard. A detailed regional groundwater investigation is required for the water quality assessment.

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