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Groundwater hydrochemistry and consumption patterns in Chandwara community development block of Jharkhand state in India

Arun Kumar Pramanik[1] · Deepanjan Majumdar[2] · Abhik Chatterjee[1]

Abstract

Groundwater quality in rural Chandwara block in Jharkhand State in India is crucial to human livelihood in the region. A study undertaken to examine groundwater quality and consumption patterns in the region revealed that average water consumption per family and per capita were 200–517 and 19.7–47 L per day, respectively, while per capita potable water consumption was 1.2−4.37 L per day. Groundwater samples were collected primarily from tube-wells and a few from dug-wells ($n = 143$) in the block during post-monsoon season of 2018–2019 (October 2018 to March 2019). Water quality parameters like Fe, TDS, Total hardness, Ca and turbidity were above the permissible limits of Bureau of Indian Standards (BIS) and WHO in 68%, 36%, 39%, 58% and 15.4% of groundwater samples, respectively. Most of the samples (67.9%) belonged to Ca–Mg–HCO$_3$ class while a few (28.6%) were Ca-Mg-SO$_4$-Cl type and the rest (3.6%) were in Ca–Mg–Cl class. As per Gibbs Plot, most samples belonged to the rock weathering region, implying contribution of rock forming minerals to groundwater chemistry. Factor analysis revealed that water quality was controlled by four principal factors to the extents of 43.3, 13.5, 10.9 and 7.3%, respectively, making a cumulative contribution of about 75%. Parameter loading in Factor 1 strongly indicated to various salts dissolving in groundwater from the rocks while Factor 2 was loaded by Fe coming from Fe-bearing rocks and turbidity that is positively influenced by the former. Factor 3 is loaded by pH and alkalinity, pointing to the role of carbonates contributed by the rocks while factor 4, which is loaded by F$^-$ and Na, indicates to F$^-$ incorporation in water from NaF-bearing rocks.

Keywords Dug well · Factor analysis · Iron · Socio-economic condition · Water quality indices

Introduction

Groundwater is the primary source of potable water in many regions across India where surface water is mostly found unsuitable for drinking or falls short of demand. Groundwater also finds major use in agriculture and industry. Like India, large populations in several countries in Asia and Africa have a strong dependence on groundwater (Singh et al. 2017; Ishwar et al. 2014). Groundwater is constantly under threat of contamination from fertilizers and pesticides used in agriculture (Krishnakumar et al. 2014), human and animal wastes and clandestine dumping of industrial effluents on land (Kumar and Shah 2006). Groundwater quality is also largely influenced by lithological, pedogeochemical compositions, anthropogenic activities and local geochemistry (Adimalla et al. 2018). In mountain regions also, groundwater quality may be substantially influenced by geology and anthropogenic activities that could significantly control chemicals facies and TDS content, depending on extent of interaction with aquifer materials (Thakur et al. 2018).

As per Kumar and Shah (2006), arsenic (As), fluoride (F$^-$), nitrate (NO$_3^-$), iron (Fe), salinity and heavy metals are the major pollutants in groundwater in India. Inadequate strategy on groundwater management, rampant industrial development, improper waste disposal, perpetually growing population, urbanization, improper usage of fertilizers etc.

✉ Abhik Chatterjee
abhikchemistry@gmail.com

1 Department of Chemistry, Raiganj University, Raiganj 733134, India

2 Kolkata Zonal Centre, CSIR-National Environmental Engineering Research Institute, i-8, Sector C, EKADP, EM Bypass, Kolkata 700107, India

are the predominant reasons for deterioration of groundwater quality in India (SubbaRao et al. 2018; Adimalla et al. 2019; Khanoranga Khalid 2019).

As per Central Ground Water Board (CGWB) in India, groundwater in various places in Jharkhand state suffers from contamination of Fe, NO_3^- and F^- but Koderma District is not listed amongst Fe affected districts (http://cgwb. gov.in/gw_profiles/st_Jharkhand.htm). Govt. of Jharkhand reports that groundwater in Koderma is Calcium-Magnesium bicarbonate dominated while Satgawan and Koderma Blocks are affected by unsafe levels of F^- in groundwater. In Bokaro District of Jharkhand, groundwater is slightly acidic to slightly alkaline and Ca^{2+} and Na^+ are the dominant cations, while HCO_3^- and Cl^- were dominant anions during pre-monsoon season and post-monsoon seasons. TDS, hardness, Ca^{2+}, Na^+, HCO_3^-, and Cl^- are the major parameters of concern while groundwater is mostly suitable for irrigation (Singh et al. 2018). In Ranchi city of Jharkhand, high urban built-up area (39.0%) and population growth (32.6%) were found to have put pressure on groundwater and on the top of this, existence of hard rock formations and ever growing urbanization retarded recharge of groundwater (Krishna Kumar et al. 2015).

Chandwara community development block in Koderma District of Jharkhand state of India represents an area that does not have abundant rainfall and is classified as a semi-arid area. This block is mostly covered by hills and has lateritic soil where villages depend primarily on groundwater for drinking, domestic uses and irrigation. Koderma district has 105 piped water schemes (PWS), 77 open wells, 1401 hand pumps and 445 other types of tube wells as per Govt of Jharkhand estimate in 2013 (http://documents.worldbank. org/curated/en/369471468041971982/pdf/E41820v60E A0P10MF0JHARKHAND0Vol-0I.pdf). Therefore, groundwater quality is extremely important for livelihood and sustainability of the predominantly rural and tribal populace of the region. We report groundwater quality over a large area in 39 villages within Chandwara Community Development Block in Koderma District of Jharkhand state in India, where micro-level baseline information on groundwater quality is lacking. Water quality was assessed comprehensively in terms of its suitability for drinking and irrigation and hydrochemistry is evaluated in terms of chemical facies. Spatial variation in groundwater quality and possible sources of anthropogenic and geological contamination were evaluated. This study also presents new information on regional groundwater consumption patterns by different economic and social classes that would go on to add valuable clues for understanding and assessing regional water management issues, environmental carrying capacity and policy implications with respect to groundwater quality, availability and consumption.

Materials and methods

Study area

Chandwara (24°23′42″ N and 85°29′4″E) community development block is a region in the northern end of Chotanagpur Plateau in Koderma district in Jharkhand state of India. Average altitude is about 397 m (1306 ft.) above mean sea level and has 232.05 km^2 coverage. The hilly topography is mostly covered by forests, wasteland, pasture lands and cultivated lands. Upper part of Chandwara block consists of dissected plateau and lowest part by pediplain. About three-fourth the area is covered by biotite granite gneiss and one-fourth by Phyllite mica-schist and Quartzite (Govt. of Jharkhand, https://cdn.s3waas.gov.in/s3087408522c31e eb1f982bc0eaf81d35f/uploads/2018/05/2018050235.pdf). Alluvium is also present in South and South-West part of the District (Govt. of Jharkhand, https://cdn.s3waas.gov.in/ s3087408522c31eeb1f982bc0eaf81d35f/uploads/2018/06/ 2018062339.pdf). The study area is also a part of a laterite soil belt and is dominated by rural areas with 40–50% of families living below poverty line. Chandwara CD Block has a population of 84,914 (all rural) and sex ratio of the block is 932. Majority of cultivated land in India is fully dependent on monsoon rain. The proportion of main workers is 22.82% in Chandwara CD Block. The Chandwara CD Block consists of 15 numbers of Gram Panchayats (i.e. smallest local governing body in India) consisting of 88 villages in which 75 are inhabited (Census of India, 2011). Barakar River with its tributaries is the main river flowing through southern part. This area is dry except in the monsoon season (June to August). Average rainfall is 127 cm per annum while temperature varies from 5 to 45 °C annually.

Socio-economic survey

A socio-economic survey was conducted in 39 villages involving 2507 family members within the study area. Feedback on the number of family members, mean family income, profession, sources of potable water, potable and non-potable water consumption per family, perceptible problems of water quality etc. was noted in a questionnaire through personal interviews conducted by the survey team. It was also attempted to understand popular perception on local water quality issues *vis a vis* economic conditions and awareness levels and also, their willingness to address drinking water quality problems.

Sampling of groundwater

Groundwater samples were collected from 143 numbers of tube-wells and dug-wells in the selected villages of CD
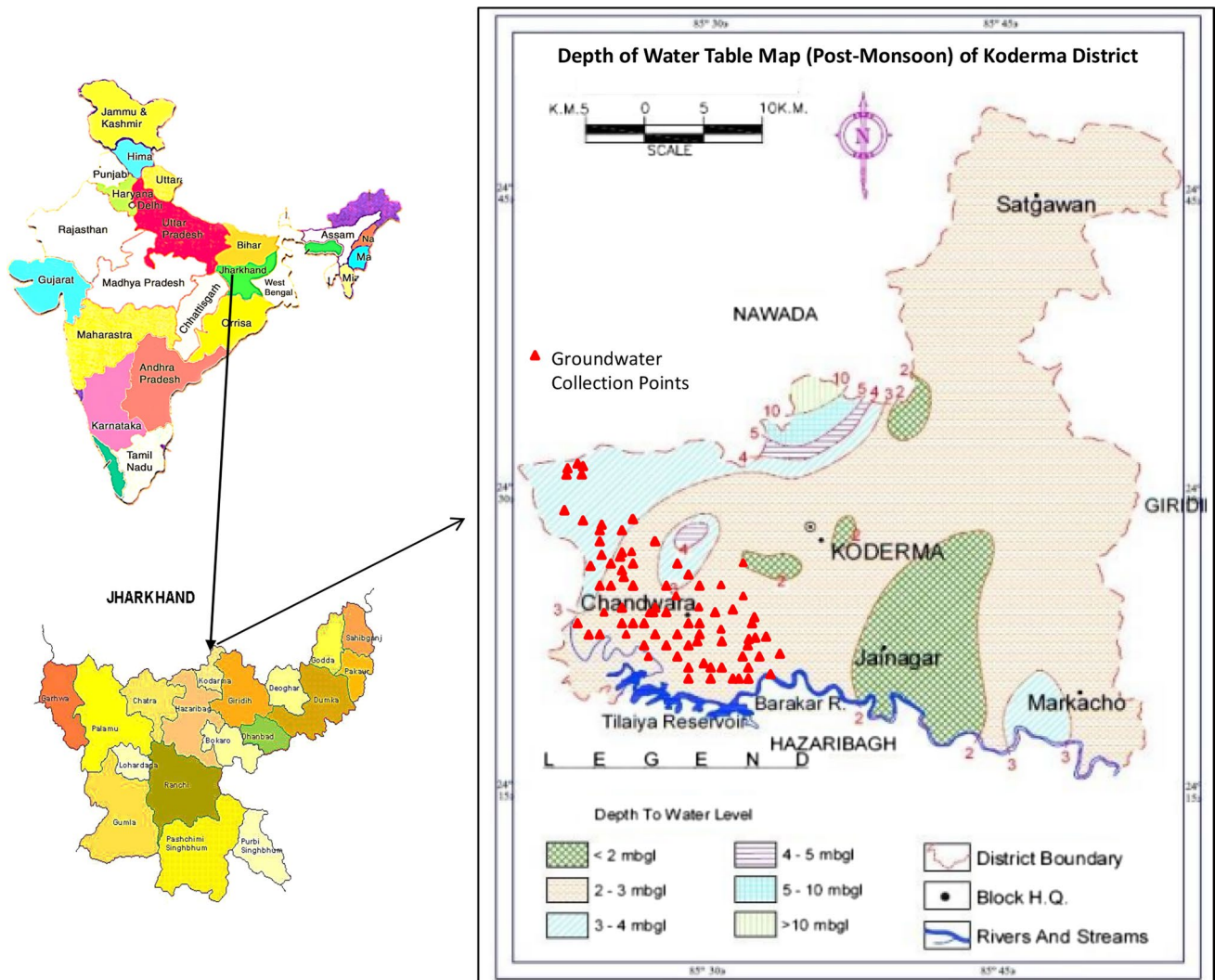
Fig. 1 Villages selected for groundwater collection in Chandwara block *vis a vis* Koderma District in Jharkhand State in India (Depth of Water Table Map Courtesy: Govt. of Jharkhand, https://cdn.s3waas.gov.in/s3087408522c31eeb1f982bc0eaf81d35f/uploads/2018/05/2018050235.pdf)

block during post-monsoon season (October 2018 to March 2019) (Fig. 1). Information on the depth of tube wells and dug wells were collected from respective owners and neighbours and also, local municipal offices wherever available. Depth of the selected dug wells ranged from about 20−50 feet while the tube wells had depths ranging from about 60–550 feet. In post-monsoon, depth of groundwater table varies between 3−4 and 2−3 m below ground level (mbgl) in northern and southern parts, respectively, as per District Survey Report of Koderma, indicating elevated water table near Tilaiya reservoir and Barakar river (Govt. of Jharkhand, https://cdn.s3waas.gov.in/s3087408522c31eeb1f982bc0eaf81d35f/uploads/2018/05/2018050235.pdf). The well water samples were collected only from those predominantly used by villagers for drinking and domestic purposes. Water samples were collected in clean polypropylene bottles for analysis of physico-chemical parameters while

for microbiological analyses, sterilized glass bottles were used. Water pumped out from hand-pumps was allowed to flow for about 1–2 min before sampling to dispose of stagnant groundwater in the pipes, if any, and temperature, pH and electrical conductivity (EC) were measured in situ. The groundwater samples were visibly non-turbid, colourless and odourless immediately after withdrawal and were later analysed for other physico-chemical parameters {$n = 143$, except for As (29), Na^+ ($n = 41$), K ($n = 41$)} e.g. TDS, total hardness (TH), Ca^{2+}, Mg^{2+}, Na^+, K^+, alkalinity, Cl^-, SO_4^{2-} by methods prescribed by American Public Health Association (APHA 2005). The pH and EC were measured by a pH meter (TOSHCON) and portable conductivity meter (HANNA, France). Flame emission photometry method for Na^+ and K^+ (Flame Photometer model 129, Systronics), turbidimetric method for SO_4^{2-} (Merck, model Spectroquant Move 100), visible spectrophotometric method for Fe and phosphate

Table 1 Indices for evaluation of potable water

Index	Formula	Reference
Water Quality Index (WQI)	$WQI = \frac{\sum_{i=1}^{n} QnWn}{\sum_{i=1}^{n} Wn}$	Horton (1965), Brown et al. (1970)
Pollution Index (PI)	$PIj = \sqrt{\frac{(Ci/Lij)_M^2 + (Ci/Lij)_R^2}{2}}$	Mishra et al. (2016), Sidabutar et al. (2017), Yadav et al. (2018)
Comprehensive Pollution Index (CPI)	$CPI = \frac{1}{N} \sum_{i=1}^{n} (C_i/S_i)$	Liu et al. (2010), Effendi et al. (2015), Krishna Kumar et al. (2015), Mishra et al. (2016), Wang et al. (2018)

Table 2 Indices for evaluation of irrigation water

Index	Formula	Reference
Sodium Percentage	$Na(\%) = \frac{(Na+K)}{(Ca+Mg+Na+K)} \times 100$	Wilcox (1955)
Sodium Absorption Ratio (SAR)	$SAR = \frac{Na}{\sqrt{\frac{(Ca+Mg)}{2}}}$	Richards (1954)
The Kelly' Ratio (KR)	$KR = \frac{Na}{(Ca+Mg)}$	Kelly (1963)
Puri's Salt Index (PSI)	$PSI = (\text{Total } Na^+ - 24.5) - (\text{Total } Ca^{++} - Ca^{++} \text{ as } CaCO_3) \times 4.85$	Puri (1949)
Index of Magnesium Hazard (MH)	$MH = \frac{Mg}{(Ca+Mg)} \times 100$	Raghunath (1987)
Potential Salinity	$PS = Cl^- + \frac{1}{2}SO_4^{2-}$	Doneen (1964)

(Merck, model Spectroquant NOVA 60A) and nephalometric method for turbidity (model HI98703, HANNA Instruments) were used. Classical physico-chemical methods were followed for the rest of the parameters viz. filtration followed by drying and gravimetric method for TDS, Argentometric Method for Cl^-, EDTA titrimetric method for TH, Ca^{2+}, Mg^{2+} and Titrimetric method for alkalinity. Arsenic was analysed by Arsenic Test Kit (Merck), F^- by ion selective electrode (Thermo Fisher Scientific and Orion Ion Selective Electrode, Orion 9609BNWP), total bacterial count (TBC) and *E. coli* by Bactaslyde (Rakiro Biotech Systems Pvt. Ltd).

Water quality indices

Water quality indices viz. Water Quality Index (WQI) calculated by using weighted arithmetic index method (Satish Chandra 2017; Gupta et al. 2017), Pollution Index (PI) (Sidabutar et al. 2017; Yadav et al. 2018), Comprehensive Pollution Index (CPI) (Krishna Kumar et al. 2015; Wang et al. 2018) were determined to classify groundwater and understand its quality for drinking and irrigation. Table 1 presents a summary of applied indices for groundwater evaluation with their respective formulae. Details on the classification of water under selected indices are presented in Supplementary Tables 1, 2, 3.

Water quality for irrigation was evaluated by various other indices and ratios as prescribed by various researchers over the last few decades (Table 2). Most of the indices are fundamentally based on Na content of water viz. Sodium

index, Sodium Adsorption Ratio (SAR), Kelly's ratio, Puri's Salt Index. Irrigation water containing high Na enhances the exchange of alkaline earth metals (e.g. Ca^{2+} and Mg^{2+}) between water and soil, affecting soil permeability, rendering the soil hard, increasingly impermeable and unsuitable for seedling emergence (Karanth 1987). The Na/alkali hazard is also customarily expressed as SAR, an index that quantifies the proportion of Na^+ to Ca^{2+} and Mg^{2+} ions in water (Richards 1954).In Kelly's Ratio (KR) (Kelly 1963). Na^+ is quantified against Ca^{2+} and Mg^{2+} and water KR > 1 is generally considered unsuitable for irrigation. Puri's salt index (PSI) (Puri 1949) also uses Na content to determine quality of water for irrigation. On the other hand, Magnesium Hazard (MH) that addresses the equilibrium between Ca^{2+} and Mg^{2+} and potential decline in crop yield with increasing concentrations of Mg in water, is also used to determine suitability of groundwater for irrigation. Source of Mg^{2+} in groundwater is mainly dolomitic rocks (Keesari et al. 2016) and intake of water with high Mg^{2+} levels causes laxative effect while Mg^{2+} deficiency may cause structural and functional changes in human body. According to this index, a low MH value (i.e. < 50) of water is suitable for irrigation while high values (i.e. > 50) makes soil more alkaline upon application, badly affecting yield of crops. Another index, Potential Salinity (PS) of water (Doneen 1964) works on the logic that suitability of irrigation water (PS < 10) not only depends on soluble salts but also on the proportion of sparingly soluble salts that precipitate and accumulate in soil with time.

Table 3 Descriptive statistics of water quality data

Parameter	Average	SD	CV (%)	90th Percentile	Range
Water Temp (°C)	26.5	1.2	4.53	28	24–28
T.H. (mg l^{-1})	311.3	203.2	65.27	558.8	66–1684
Fe (mg l^{-1})	0.8	0.8	105.00	1.7	0.018–6.64
Cl$^-$ (mg l^{-1})	108.8	95.3	87.59	214.1	4.5–600
TDS (mg l^{-1})	455	242.6	53.32	781.7	75.3–1272
Turbidity(NTU)	6.2	7.2	116.13	12.1	0.57–59.4
pH	7.1	0.3	4.23	7.4	6.46–8.32
E. Conductivity (µS cm^{-1})	758.3	404.3	53.32	1302.8	125.5–2120
Ca (mg l^{-1})	94.6	63	66.60	168.5	15.2–496
Ca -Hardness (mg l^{-1})	236.5	157.5	66.60	421.2	38–1240
Cu (mg l^{-1})	–	–	–	0	0.01–0.06
Mg (mg l^{-1})	18.2	14.7	80.77	32	1.94–107.8
Mg-Hardness (mg l^{-1})	74.9	60.5	80.77	132	8–444
Total Alkalinity (mg l^{-1})	186.9	88.3	47.24	294.4	28–456
Si (mg l^{-1})	25.8	7.9	30.62	37.5	10.9–48.9
SO$_4^=$ (mg l^{-1})	45.7	24.4	53.39	75	10–150
F$^-$ (mg l^{-1})	0.5	0.2	40.00	0.8	0.2–1.2
Na (mg l^{-1})	50.1	21.2	42.32	85.1	21.5–88.8
K (mg l^{-1})	1.9	0.9	47.37	3.1	1.02–5.2

N.B. Parameters not detected were not included (PO$_4^=$, As, O&G, FRC, *E. coli* etc.)

[*] Cu was mostly below LDL i.e. < 0.02 mg/l, hence mean, SD and 90th percentile not calculated

$n = 143$, except Na and K ($n = 41$)

Statistical analyses

Apart from descriptive statistical analysis (mean, SD, range, 90th percentile), Pearson Correlation analysis was undertaken to understand inter-relationships amongst water quality parameters. Further, Factor Analysis preceded by Principal Factor Extraction was undertaken to evaluate number of principal factors influencing groundwater quality. All statistical analyses were undertaken by Statistica (Dell Software, USA). Kriging method, a tool used in geostatistical analysis, that involves interpolation estimates for points not actually sampled from values at adjacent locations and information on spatial relationships in the data set (Datta Chowdhury et al. 2017) was undertaken to generate isotropic variograms. The said interpolation analysis (ordinary Kriging) based on available data points, was used to construct spatial distribution maps of Fe and TDS present in groundwater. Before generation of the said maps, cross-validation analysis of data was conducted to plot and validate estimated versus actual values within in the domain.

Results and discussion

Water quality

Groundwater in the region is characterized by notable levels of EC, TH, TDS, turbidity and dominant presence of Cl$^-$ and Fe. Groundwater pH was always alkaline while electrical conductivity ranged from 125.5 to 2120 µS cm^{-1} (90th percentile: 1303 µS cm^{-1}). Total hardness ranged from 66 to 1684 mg l^{-1} while Ca^{2+} and Mg^{2+} hardness ranged from 15.2 to 496 and 8 to 444 mg l^{-1}, respectively. Mean TDS was found to be 455 mg l^{-1}, while a maximum TDS of 1272 mg l^{-1} was observed (Table 3). Water samples were categorized into various groups based on coefficient of spatial variation (CV) in water quality parameters viz. < 20% CV (pH, temperature), 20− < 50% CV (TA, Si, F$^-$, Na, k), 50−80% CV (TH, TDS, EC, Ca^{2+}, Ca-Hardness, SO$_4^{2-}$), and > 80% CV (Fe, Cl$^-$, turbidity, Mg^{2+}, Mg-hardness) for understanding the extents of spatial variation in terms of dispersion of data points around respective means. The spatial variation in TDS and Fe was also studied by geospatial data analysis where distribution of Fe and TDS concentration was converted into spatial coverage format (Fig. 2a, b). Groundwater in the southern and central areas of the block is mostly affected by breaching levels of Fe i.e. > 1 mg l^{-1}

while groundwater in the northern part of the block is mostly affected by TDS of > 500 mg l^{-1}.

As per Pearson's correlation analysis, TH, EC, Ca^{2+}, Mg^{2+} and total alkalinity were significantly correlated ($r = 0.91, 0.91, 0.98, 0.82, 0.55$, respectively, $p = 0.01$) (Table 4), confirming that these parameters positively influenced one another. Further, EC also had strong positive correlations with Cl$^-$ ($r = 0.93$, $p = 0.01$), SO$_4^{2-}$ ($r = 0.59$, $p = 0.01$) and alkalinity($r = 0.61$, $p = 0.01$). The Ca^{2+}, Mg^{2+}, Na$^+$ and Cl$^-$ had concomitantly linear increase with TDS (Fig. 3), indicating that high TDS build-up at some pockets can be attributed to geogenic hydrochemical processes involving long interaction of groundwater with rocks. Factor analysis revealed that water quality was mainly controlled by 4 principal factors to the extents of 43.3 and 13.5, 10.9 and 7.3%, respectively, making a cumulative contribution of about 75% (Table 5). Factor 1 can be explained by strongly correlating TH, Cl$^-$, TDS, EC, Ca^{2+}, Mg^{2+} and Ca^{2+} and Mg^{2+} hardness which is indicative of geochemical influence via salt incorporation in water while Factor 2 was dominated by strongly correlating Fe (geochemical dominance of Fe) and turbidity, the latter known to be influenced by the former. Evidently, Fe is the crucial geochemical factor influencing water quality of this region and it also had a strong influence on turbidity imparted to groundwater of this region. Factor 3 is loaded by pH and alkalinity, pointing to the role of carbonates contributed by the rocks

while factor 4, which is loaded by F$^-$ and Na$^+$, indicates to F$^-$ incorporation in water from NaF-bearing rocks (Biglari et al. 2016). On the other hand, high groundwater Fe observed in some pockets is a manifestation of release of Fe from ferruginous lateritic soil present in Chandwara block, as subsurface weathering and release of Fe into groundwater from Fe-bearing rocks is well known (Raju 2013; CGWB 2013). As per partially available data, depth of tube wells ($n = 56$) and dug wells ($n = 6$) ranged from about 60–550 feet and 20–50 feet, respectively, and no statistically significant correlation of depth of tube wells was found with most water quality parameters except for Si (-0.42, $p = 0.01$) and K (-0.27, $p = 0.05$), indicating that levels of Si and K decreased with increasing depth of tube wells.

Hydrogeochemistry

Hydrochemistry and hydrochemical facies of water are crucial benchmarks to evaluate possible sources of contamination and chemistry of water. Piper diagram was used to understand the sources of dissolved constituents in water and identification of hydrochemical facies while Gibbs Diagram was used to establish the relationship of water composition with aquifer lithological characteristics under three distinct fields viz. precipitation dominance, evaporation dominance and rock–water interaction dominance. A 6-segment Piper Diagram indicated the following dominant water classes:
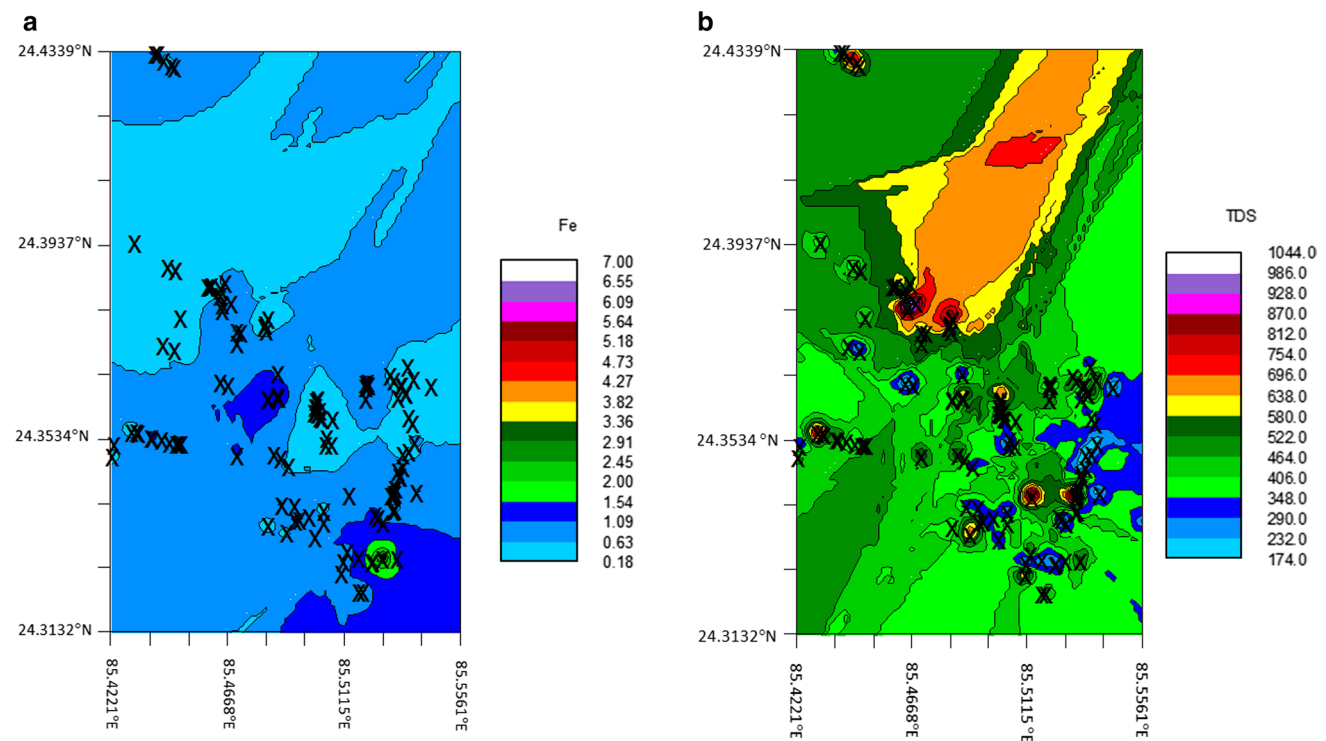

Fig. 2 Spatial distribution map of **a** iron and **b** TDS in the groundwater of Chandwara Block [sampling points are marked as 'X' on the maps]

Table 4 Correlation matrix depicting parameter inter-relationships

	T.H. (mg l⁻¹)	Fe (mg l⁻¹)	Cl⁻ (mg l⁻¹)	TDS (mg l⁻¹)	Turbidity (NTU)	pH	E. Cond. (µS cm⁻¹)	Ca (mg l⁻¹)	Mg (mg l⁻¹)	Total Alkalinity (mg l⁻¹)	Silica (mg l⁻¹)	SO₄⁼ (mg l⁻¹)	F⁻ (mg l⁻¹)	Na (mg l⁻¹)	K (mg l⁻¹)
T.H. (mg l⁻¹)	1														
Fe (mg l⁻¹)	−0.03	1													
Cl⁻ (mg l⁻¹)	0.92*	0.02	1												
TDS (mg l⁻¹)	0.91*	0.00	0.93*	1											
Turbidity(NTU)	0.12	0.74	0.14	0.13	1										
pH	0.06	−0.25	0.00	0.06	−0.15	1									
E. Cond. (µS cm⁻¹)	0.91*	0.00	0.93*	1.00*	0.13	0.06	1								
Ca (mg l⁻¹)	0.98*	−0.03	0.90*	0.90*	0.12	0.01	0.90*	1							
Mg (mg l⁻¹)	0.82*	−0.02	0.76*	0.71*	0.09	0.18	0.71	0.67	1						
Total Alkalinity (mg l⁻¹)	0.55	−0.10	0.48	0.61	−0.04	0.47	0.61	0.55	0.39	1					
Silica (mg l⁻¹)	0.06	0.03	0.08	0.06	0.14	−0.18	0.06	0.05	0.07	−0.12	1				
SO₄⁼ (mg l⁻¹)	0.44	0.03	0.54	0.59	0.10	0.07	0.59	0.41	0.39	0.17	0.08	1			
F⁻ (mg l⁻¹)	−0.06	−0.07	−0.05	0.05	0.02	0.22	0.05	−0.06	−0.03	0.08	0.01	0.15	1		
*Na (mg l⁻¹)	0.66	−0.01	0.73*	0.81*	0.05	0.08	0.81	0.64	0.46	0.50	−0.03	0.45	0.21	1	
*K (mg l⁻¹)	0.21	0.40	0.29	0.28	0.35	0.02	0.28	0.19	0.18	0.23	−0.24	0.24	−0.04	0.32	1

*Significant at 1% confidence level

$n = 144$ (*$n = 15$)

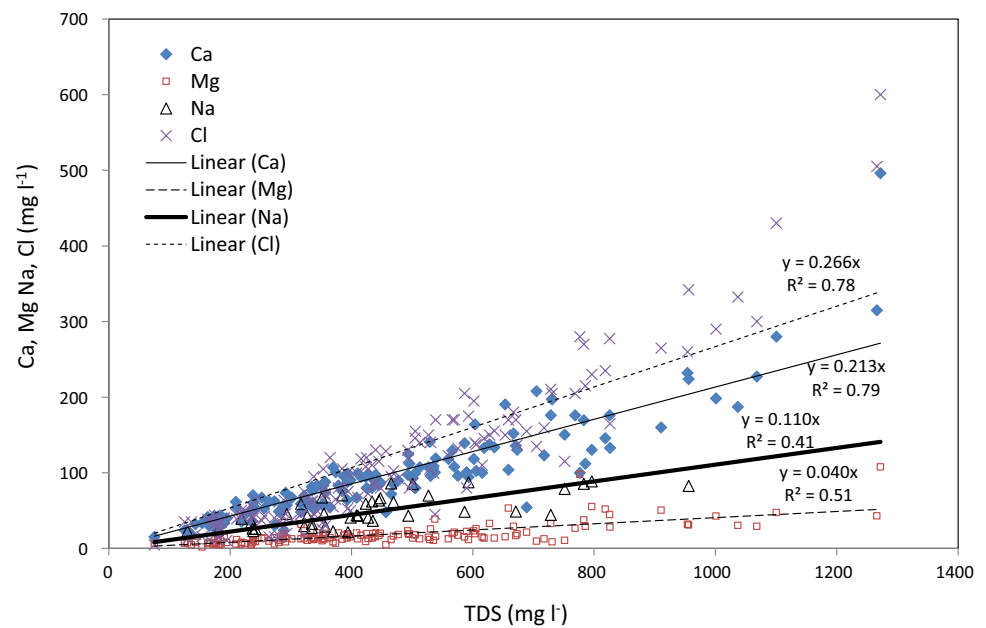**Fig. 3** Concomitant increase in Ca, Mg, Na and Cl concentration with increasing TDS in groundwater

Table 5 Factor loadings analysed by factor analysis

Parameter	Factor 1	Factor 2	Factor 3	Factor 4
T.H	−0.95	0.04	0.00	−0.15
Fe	0.13	−0.92	−0.04	−0.07
Cl⁻	−0.90	−0.08	−0.25	0.04
TDS	−0.96	0.01	−0.04	0.10
Turbidity	0.09	−0.84	0.13	0.04
pH	−0.06	0.18	0.88	−0.06
EC	−0.96	0.01	−0.04	0.10
Ca	−0.91	0.07	0.00	−0.12
Ca-H	−0.91	0.07	0.00	−0.12
Mg	−0.79	−0.04	−0.01	−0.18
Mg-H	−0.79	−0.04	−0.01	−0.18
Alkalinity	−0.37	0.17	0.76	−0.08
Si	0.15	0.41	−0.55	0.03
$SO_4^=$	−0.51	−0.23	−0.20	0.42
F⁻	0.08	0.11	0.25	0.83
Na⁺	−0.63	0.03	0.01	0.48
K⁺	−0.20	−0.65	0.12	0.04
Variance explained (%)	*43.3*	*13.5*	*10.9*	*7.3*
Eigen value	*7.36*	*2.28*	*1.84*	*1.24*

N.B.: Varimax normalized, Extraction: Principal components

1. Ca–Mg–HCO₃ type, 2. Na–Cl type, 3. Ca–Mg–Cl type, 4. Ca–Na–HCO₃ type, 5. Ca–Cl type, 6. Na–HCO₃ type (Fig. 4). The diagram reveals that most of the samples that were analysed for all required parameters belonged to Ca-Mg-HCO₃ class (67.9%) while a few were Ca–Mg–SO₄–Cl type (28.6%) and the rest 3.6% were in Ca–Mg–Cl class.

This implies that in the majority of samples, alkaline earths and weak acidic anions, respectively, exceeded alkali metals and strong acidic anions as indicated by dominance of Ca–Mg–HCO₃ type of water. The role of geogenic hydrochemical processes in causing high TDS is further strengthened by the distribution of hydrochemical facies in the Piper Diagram. High bicarbonate content depicted in Piper Diagram indicates to recharging water type and implies sufficiently long interaction of these groundwater samples with rocks, resulting in salt dissolution from rocks contributing to TDS. From the diamond field in the Piper Diagram, two main groundwater groups could be identified viz. Group 1 samples that are primarily the recharging ones having low salt concentration (average TDS 307 mg l⁻¹) and little contact with aquifer material and Group (3) samples that had more interaction with aquifer material leading to higher incorporation of ions (average TDS 712 mg l⁻¹). Therefore, Group (3) groundwater is relatively older than recharging water types in group (1). With respect to TDS, two primary groups of groundwater types were identified: (i) High TDS (> 500 mg l⁻¹), Ca–Mg–HCO₃ and Ca–Mg–Cl–HCO₃ types that ought to have undergone substantial interaction with subsurface geologic and aquifer materials (ii) Low to moderate TDS (< 500 mg l⁻¹) and Ca–HCO₃ and Ca–Na–HCO₃ types that are mainly recharging waters with lesser geological interaction.

In general, evaporative dissolution, ion exchange and rock-water interaction are the primary geochemical processes that influence prevalence of salts and groundwater chemistry (Roy et al. 2018). Keesari et al. (2013) reported salt incorporation in root zone, incongruent dissolution of

Fig. 4 Representation of hydrochemistry of water samples by Piper Diagram
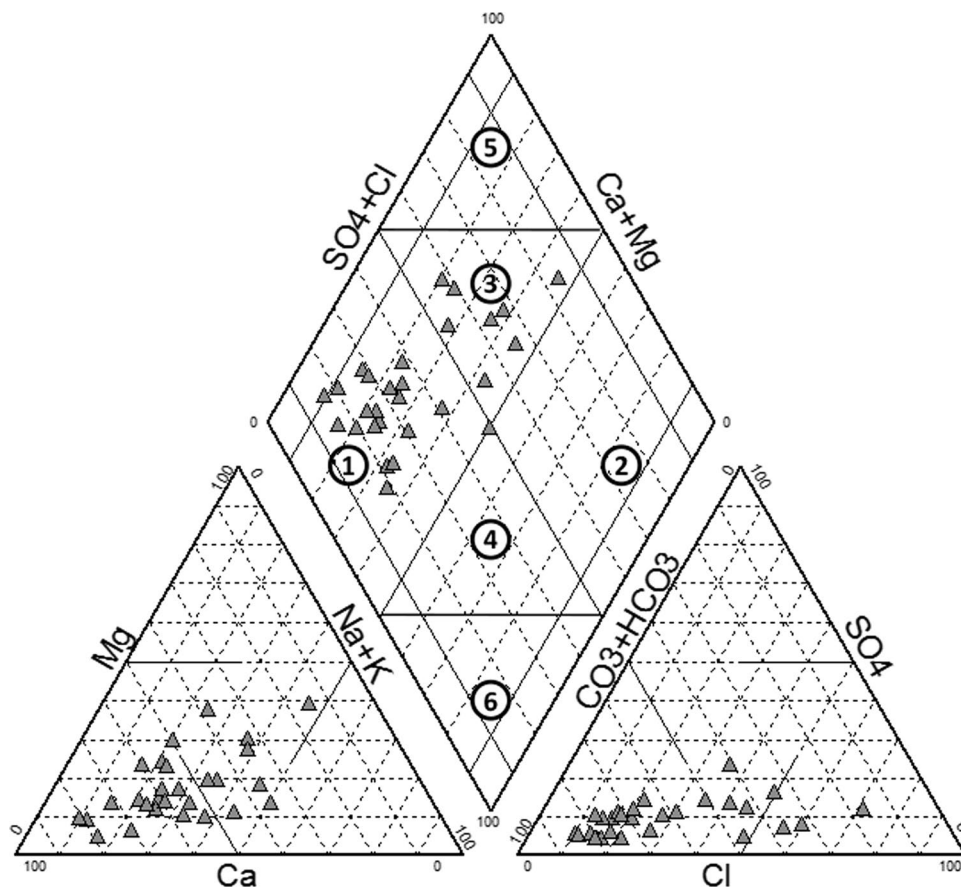
carbonate minerals and attributed high salt levels in shallow groundwater to its mixing with surface water. In a study in Bathinda of Punjab in India, groundwater was found to be affected by dissolution of minerals and ion exchange during pre-monsoon season while leaching of salts from vadose zone during post-monsoon contributed to the dissolved salts in groundwater (Sharma et al. 2017). Iqbal et al. (2021) suggested that high Ca^{2+} and Mg^{2+} in higher topographic regions might be a result of inverse ion exchange process, where Ca from aquifer is replaced by Na^+ present in groundwater. The hydrochemistry of samples were also evaluated in terms of concentrations of SO_4-HCO_3^- and Na–K-Ca (Fig. 5) that also indicated dominance of Ca^{2+} bicarbonate class of water. Further, the hydrochemical characteristics of water samples were plotted in Gibbs diagrams to show Gibbs ratio (cation or anion) against TDS (Fig. 6). All the groundwater samples belonged to the rock weathering region, implying incorporation of the geogenic salts in groundwater from rock-forming minerals during chemical weathering, eventually influencing groundwater TDS as also reported by Nagaraju et al. (2016).

Ionic ratios viz., HCO_3^-/Si and $Mg^{2+}/(Mg^{2+} + Ca^{2+})$ are assessed to evaluate the contribution of rock weathering processes on groundwater quality (Thakur et al. 2018). In the collected samples, HCO_3^-/Si ratio ranged from 1.4 to 31.4. In about 22% of samples the ratio was > 10, implying the role of carbonate weathering, while in 28%, the ratio was < 5, indicating silicate weathering. Further, ratio of $Mg^{2+}/(Mg^{2+} + Ca^{2+})$ ranged from 0.04 to 0.5, showing that both limestone and dolomite weathering influenced the hydrochemistry.

Water quality assessment for drinking and irrigation

TDS, Fe, F^- and As are the principal drinking water quality parameters that were assessed to evaluate groundwater samples for potability. Iron ranged from 0.02 to 6.64 mg l^{-1} (90th percentile: 1.7 mg l^{-1}) and 28.7% of samples exceeded the revised acceptable limit of 1.0 mg l^{-1} Fe prescribed for potable water in India by Bureau of Indian Standards (Amendment No. 1, June 2015 to IS: 10,500–2012). High turbidity in 15.4% groundwater samples (highest 59.4 NTU; 90th percentile 12.1 NTU) (Table 3) breached acceptable limit for potable water owing to the influence of Fe on the former. TDS concentration, the sum of all dissolved organic and inorganic substances (salts of Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, and Si), varied from

**Fig. 5** Representation of groundwater hydrochemistry
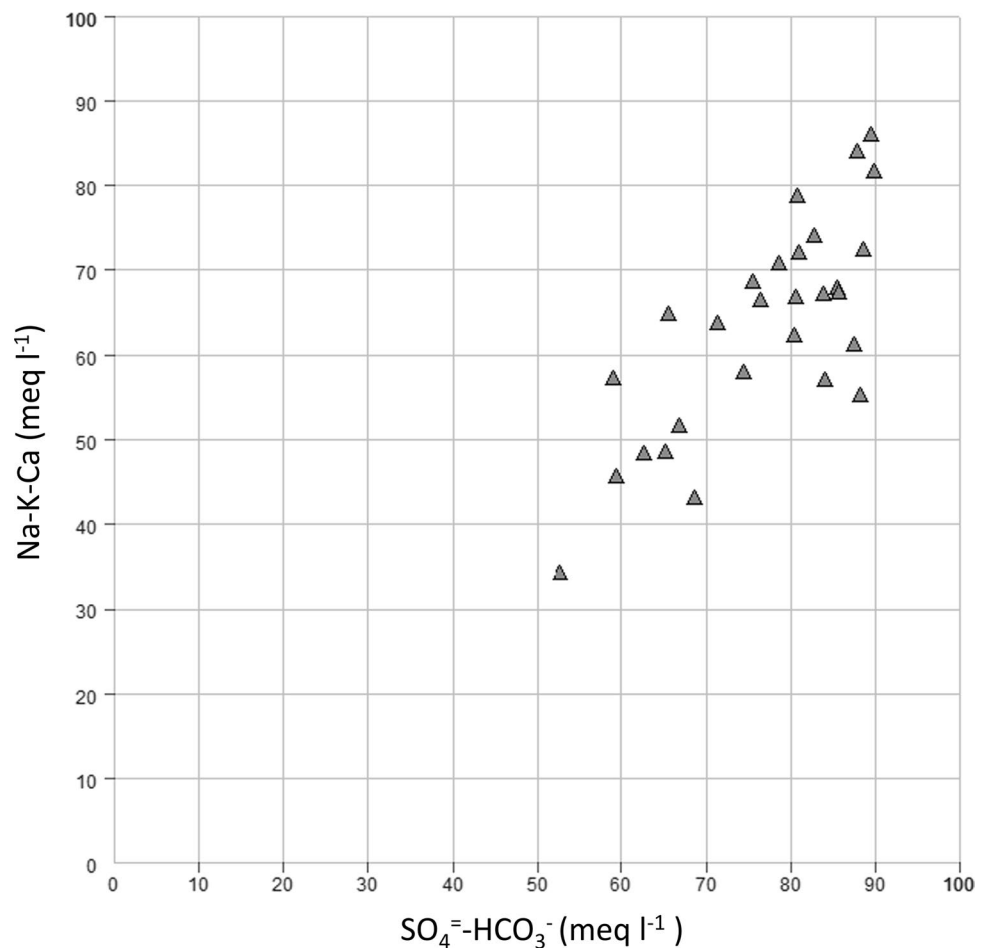
75.3 to 1272 mg l^{-1} and 36% exceeded acceptable limit of 500 mg l^{-1} for TDS (BIS Standard, IS 10500–2012) in potable water (Table 6). On the other hand, total hardness and Ca breached their respective acceptable limits in 39% and 58% of samples. Chloride was widely variable, ranging from 4.5 to 600 mg l^{-1}, breaching the acceptable limit in several samples. A crucial potable water quality parameter like F$^-$ ranged from 0.2 to 1.2 mg l^{-1}, never exceeding its acceptable limit of 1.5 mg l^{-1}. Other parameters like PO$_4^{3-}$, As, free residual chlorine (FRC), *E. Coli* and Cu were not detected in any sample, the LDL being < 0.03 mg l^{-1} (PO$_4^{3-}$), < 0.05 mg l^{-1} (As), 100 CFU ml^{-1} (*E. Coli*) and < 0.02 mg l^{-1} (Cu), respectively, in the deployed methods. Arsenic could be detected down to 50 μg l^{-1} only and was not found in any sample. The Bureau of Indian Standards (BIS) permissible limit for As in absence of any alternative potable water sources is 50 μg l^{-1} but the acceptable limit being 10 μg l^{-1} (both BIS and WHO), none of the samples could be assessed for acceptability in terms of As.

In Jharkhand, groundwater in some areas of Sahibganj and Ranchi district have substantial As (Nayek et al. 2008; Tirkey et al. 2017) while some areas in Deoghar, Dhanbad and Bokaro districts are affected with high Fe in groundwater (Banerjee

and Mukherjee, 2013; Singh et al. 2017). Singh et al. (2012) has reported high salinity and Mg hazard at a few districts of Jharkhand state. On the other hand, F$^-$ is reported to have been found beyond the safe limit in some parts of Palamu, Garhwa, Koderma and Pakur Districts in the state (Central Ground Water Board, 2016). As per Singh et al. (2012), F$^-$ levels were < 1.0 mg l^{-1} in most of the samples collected from Dumka and Jamtara Districts in Jharkhand state. Some other districts also in the state have areas where groundwater F$^-$ is above the permissible level of BIS (2012) (Kumari and Pathak, 2014; Avishek et al. 2010; Patolia and Sinha, 2017).

The groundwater samples could be classified into low, medium and high salinity (classes 1, 2 and 3) (Fig. 7) and those in 'high' salinity hazard category are considered detrimental to soils and crops in the long run and are suitable for applying to medium and highly salt-tolerant crops only. Further, Class 4 (very highly saline) water is suitable for only highly salt-tolerant crops but none of the tested water samples belonged to this category. The potential salinity (PS) in the water samples ranged from 0.24 to 17.08 me l^{-1} that is indicative of their suitability for irrigation. About 46% of samples had low PS (< 3 me l^{-1}) that are considered suitable for irrigating fine, medium and coarse

Fig. 6 Representation of groundwater hydrochemistry by Gibbs diagrams
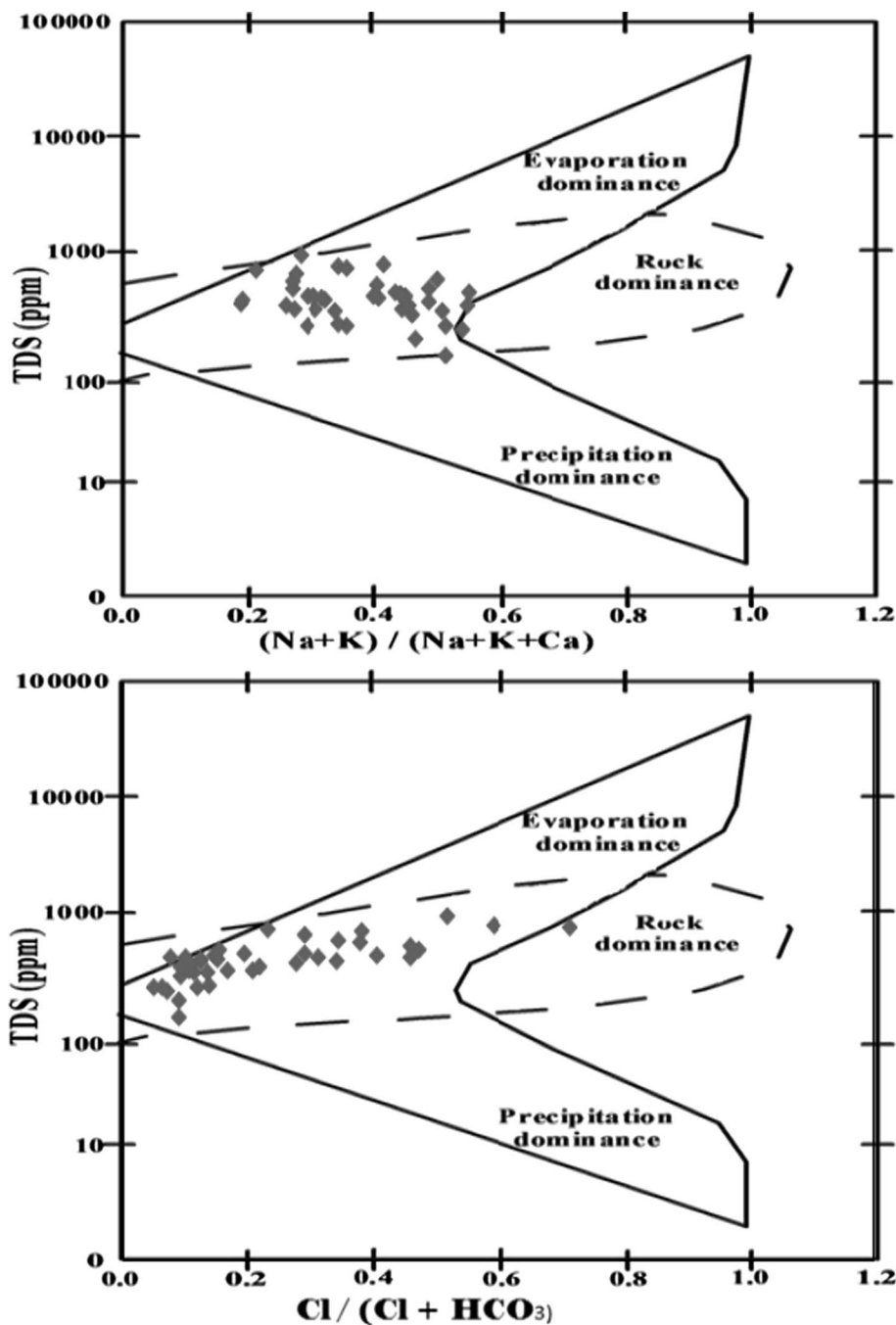
textured soils. On the other hand, about 52% of samples had PS of 3−15 me l^{-1}, implying their suitability for medium and coarse textured soils. Rest can be used only in coarse textured soils. Sodium percent is another important indicator of irrigation water. Dissolution of alkali feldspar minerals, ion exchange processes, sewage contamination and infiltration from agricultural run-off may impart Na in groundwater. Repeated use of Na contaminated water for irrigation areas also contributes to Na in groundwater (Keesari et al. 2016, 2019). As per Na% assessment, about

29% samples could be categorized under the class 'good' (20–40) while 71% samples could be categorized under the 'permissible' range (40–60). Further, as per Sodium Absorption Ratio (SAR) which is a standard indicator for suitability of irrigation water, about 12% samples were categorized under excellent class (i.e. 0–10) while 88% were in good class (i.e. 10–18).

The mean water quality index (WQI) of water samples was calculated to be 208.7, that renders water unfit for drinking in general. But, when the index is calculated without Fe,

Table 6 Groundwater samples exceeding the permissible limits for potable water prescribed by Bureau of Indian Standards (BIS) and WHO

Parameters	Unit	BIS Standard* (IS: 10,500, 2012)		No. of samples exceeding acceptable limit	% Samples exceeding acceptable limit	WHO Standard*		No. of samples exceeding acceptable limit	% Samples exceeding acceptable limit
		Acceptable Limit (mg l^{-1})	Permissible Limit (ppm)			Acceptable Limit	Permissible Limit		
pH	–	6.5—8.5	–	1	0.7	7.0—8.5	–	1	0.7
Electrical conductivity	µs cm^{-1}	300	–	129	90.2	300	–	129	90.2
TDS	mg l^{-1}	500	–	52	36.3	500	–	52	36.4
Turbidity	NTU	10	25	22	15.4	10	25	22	15.4
Total Hardness	mg l^{-1}	300	600	56	39.2	500	–	18	12.6
Calcium	mg l^{-1}	75	200	83	58.0	–	–	–	–
Magnesium	mg l^{-1}	30	–	18	12.6	–	–	–	–
Alkalinity	mg l^{-1}	200	600	67	46.9	100	–	118	82.5
Chloride	mg l^{-1}	250	1000	12	8.4	200	600	19	13.3
Sulphate	mg l^{-1}	200	400	None	None	200	400	None	None
Fluoride	mg l^{-1}	1.5	1.9	None	None	1.0–1.5	–	None	None
Phosphate	mg l^{-1}		–	None	None	–	–	None	None
Copper	mg l^{-1}	0.05	–	None	None	1	–	None	None
Iron	mg l^{-1}	1.0	No relaxation	97	67.8	–	–	NA	NA
Arsenic	mg l^{-1}	0.01	No relaxation	NA	0	0.01	–	None	None

*Bureau of Indian Standards (IS: 10,500: 2012)

*World Health Organization (2017)

mean WQI sharply declined to 8.57, putting the same under 'excellent' class, suitable for drinking, irrigation and industrial purposes. On the other hand, mean Pollution Index (PI) was calculated to be 3.92 making the water 'lightly polluted' in general while without Fe, mean PI came down to 2.74, keeping water quality in the same category. Mean Comprehensive Pollution Index (CPI) was calculated to be 1.004, categorizing general water quality into 'polluted' class that is of very poor quality and requires restriction for irrigation. But, without taking Fe into consideration, CPI was 0.81 that came under 'Basically Qualified' class meant for irrigation only. On the other hand, Puri's Salt Index (PSI)values ranged from − 2236.1 to 95.78 and about 90% samples belonged to 'good class' while the rest were categorized under poor quality. Index of Magnesium Hazard (MH) also determines suitability of groundwater for irrigation. Generally in water, equilibrium is established between Ca and Mg but with increasing concentration of Mg, salinity of water increases and soil is affected by such water, affecting crop yield. Water with MH < 50 is suitable for irrigation while > 50 makes soil alkaline on continuous application. In our study area, MH ranged from 4.2 to 49.5, making all samples suitable for irrigation. Also, Kelly's Ratio (KR) in all the samples were < 1, making them suitable for irrigation.

Water consumption patterns *vis a vis* socio-economic conditions

Groundwater is the principal source of potable water in this region and it is mostly drawn from tube- and dug-wells. The dug-wells are mostly private properties that are mostly dug during house construction and accessed by only family members while tube-wells are mostly put up by Gram Panchayats for public access. About 49% of interviewees perceived that there was at least one problem with potable water while another 49% agreed that water quality was either satisfactory or good. High Fe content is the principal water quality problem in this block and visible reddening of water and red scale formation in storage vessels on standing are common in some areas. The study area being a part of laterite soil belt, high Fe content in water can be expected as reported from many other parts of India (Girish and Seralathan, 2006; SubbaRao, 2008; Achary, 2014). Central Groundwater Board (CGWB) of India lists Fe as one of the prominent groundwater pollutant in India and mentioned Jharkhand as one of the affected states (http://cgwb.gov.in/WQ/GROUND%20WATER%20QUALITY%20SCENARIO%20IN%20INDIA.pdf). As household water purification systems were not found in the surveyed households, Fe and taste imparted by it in potable water remains largely unaddressed.

Fig. 7 Evaluation of ground-water for irrigation through Salinity Diagram
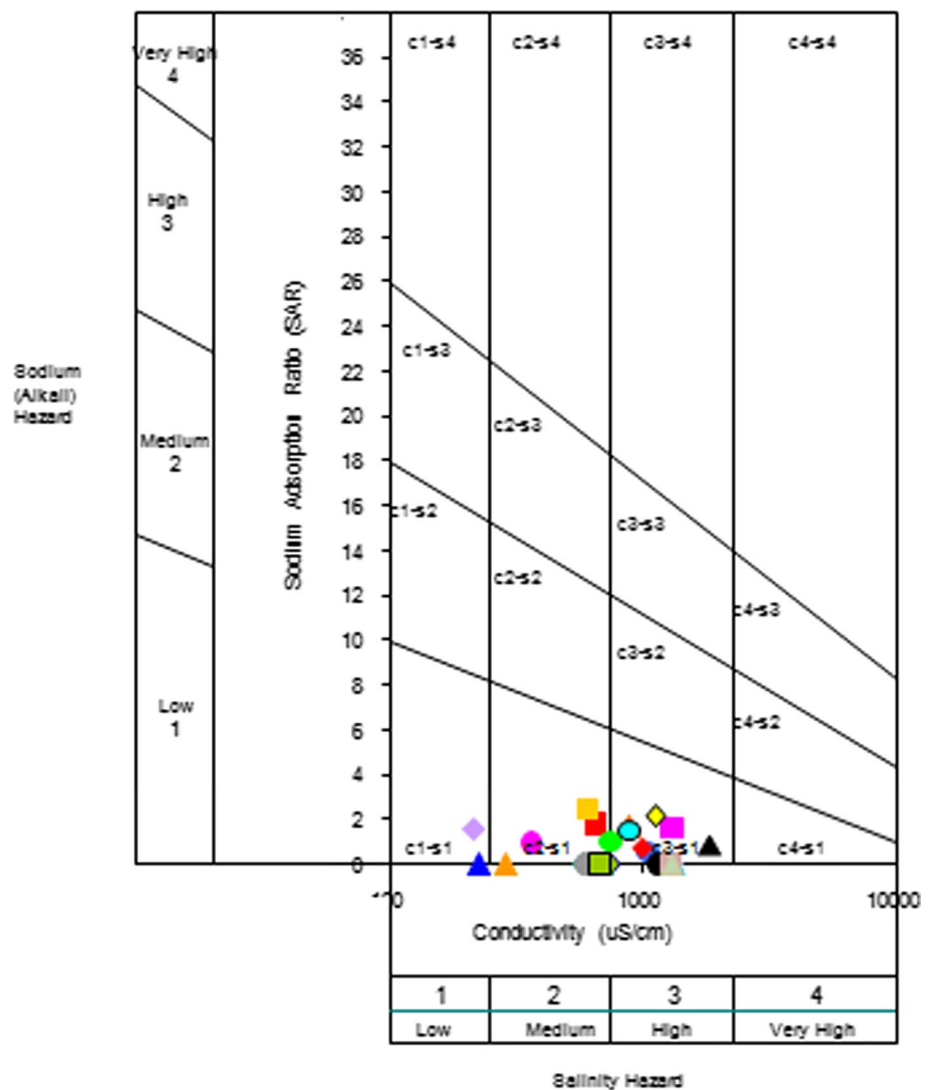
Most of the families in the region are involved in crop cultivation while some work as agricultural labourers or workers in shops or businesses. Some have their own businesses while very few are in government jobs. Mean family size ranged from 7 to 17, indicating presence of a joint family system where kin stay together in a house. Mean water usage per family and per capita ranged from about 200 to 517 L per day and 19.7 to 47 L per day, respectively, that included water for drinking and other uses. Per capita potable water consumption was 1.2−4.37 L per day. A few Indian cities have shown similar water consumption viz. 20–40 L per capita per day (lpcd) in Jaipur (Jethoo and Poonia, 2011) and about 55 lpcd in Chennai (Dhanapal, 2019) while Bangalore reportedly consumed higher e.g. 100–125 lpcd (Ramachandra et al. 2016). Ministry of Housing and Urban Affairs (MoHUA), Government of India has set a benchmark of 135 lpcd for Indian cities (WaterAid India, 2018) and therefore, water consumption in this region is lower than this benchmark set for cities. Mean monthly family income ranged from 6800 to 18,727 Indian rupees (95.7 to 263.6 US $ as per exchange rates on 18.1.2020), indicating that the villages represented lower to lower-middle class Indian population (Table 7). Expectedly, mean family water consumption increased with increasing number of mean family members while the former increased at a lower rate with increasing family income (Fig. 8) which sometimes is aligned with higher water usage in improved toilets. Family income also heavily influences affordability to own household water purifiers that were not found to be popular in this region due to lack of affordability to own and maintain such purifiers in the long-run for large families consisting of 7−18 members. Family income that can be linked to profession and formal education, has significant influence on development of required perception on importance of water quality on human health while family income would go on to

Table 7 Socioeconomic status of sample population *vis a vis* water usage

Village	Sample Number (=household or family)	Family Profession (with number)	Mean no. of family members	Mean family income (Rs/month)	*Mean family consumption (L/day)	Per capita use (L/day)	Source	Problems in water quality (Colour or Odour)
Aaragaro	19	Ag-10, Busi-3, Lab-3, Pvt.-3, Gov.-0	12	10,263	300	25.0	TW-19, W-0	H. Red.-11, S. Red.-2, Odour-0
Bajpur	4	Ag-4, Busi-0, Lab-0, Pvt.-0, Gov.-0	12	15,750	283	23.6	TW-4, W-0	H. Red.-1, S. Red.-1, Odour-0
Bandhachok	23	Ag-11, Busi-5, Lab-5, Pvt.-2, Gov.-0	9	12,615	239	26.6	TW-23, W-0	H. Red.-0, S. Red.-9, Odour-0
Baradih	6	Ag-3, Busi-0, Lab-2, Pvt.-1, Gov.-0	12	10,000	308	25.7	TW-3, W-3	H. Red.-0, S. Red.-1, Odour-0
Barki Dhamrai	13	Ag-7, Busi-2, Lab-3, Pvt.-1, Gov.-1	9	12,462	296	32.9	TW-2, W-3, S-8	H. Red.-0, S. Red.-0, Odour-0
Bendi	5	Ag-2, Busi-0, Lab-3, Pvt.-0, Gov.-0	13	6800	330	25.4	TW-5, W-0	H. Red.-4, S. Red.-0, Odour-0
Bhondo	16	Ag-6, Busi-2, Lab-6, Pvt.-1, Gov.-1	12	11,285	271	22.6	TW-12, W-4	H. Red.-3, S. Red.-2, Odour-0
Bisodhi	7	Ag-3, Busi-2, Lab-1, Pvt.-1, Gov.-0	14	16,200	321	22.9	TW-7, W-1	H. Red.-3, S. Red.-0, Odour-0
Chamgo do Kalan	18	Ag-15, Busi-0, Lab-0, Pvt.-1, Gov.-1	10	16,588	314	31.4	TW-18, W-0	H. Red.-5, S. Red.-3, Odour-0
Chandwara	11	Ag-0, Busi-7, Lab-3, Pvt.-0, Gov.-1	13	10,272	355	27.3	TW-11, W-0	H. Red.-5, S. Red.-2, Odour-0
Charki Phari	15	Ag-5, Busi-2, Lab-4, Pvt.-2, Gov.-2	11	12,500	517	47.0	TW-15, W-0	H. Red.-0, S. Red.-0, Odour-0
Chorahi	2	Ag-0, Busi-2, Lab-0, Pvt.-0, Gov.-0	9	13,500	300	33.3	TW-2, W-0	H. Red.-0, S. Red.-0, Odour-0
Chotti Dhamrai	5	Ag-5, Busi-0, Lab-0, Pvt.-0, Gov.-0	12	6600	308	25.7	TW-0, W-5	H. Red.-1, S. Red.-0, Odour-0
Dhob	6	Ag-2, Busi-2, Lab-1, Pvt.-0, Gov.-1	15	9500	375	25.0	TW-6, W-0	H. Red.-3, S. Red.-1, Odour-2
Dhigthu	6	Ag-4, Busi-1, Lab-1, Pvt.-0., Gov0	9	9333	241	26.8	TW-5, W-1	H. Red.-2, S. Red.-0, Odour-0
Gainra	6	Ag-5, Busi-0, Lab-1, Pvt.-0, Gov.-0	8	16,400	280	35.0	TW-6, W-0	H. Red.-2, S. Red.-2, Odour-0
Gajure	4	Ag-4, Busi-0, Lab-0, Pvt.-0, Gov.-0	18	10,500	375	20.8	TW-4, W-0	H. Red.-1, S. Red.-2, Odour-0
Gawanpur	11	Ag-10, Busi-1, Lab-0, Pvt.-0, Gov.-0	12	14,636	300	25.0	TW-9, W-2	H. Red.-6, S. Red.-0, Odour-0

Table 7 (continued)

Village	Sample Number (=household or family)	Family Profession (with number)	Mean no. of family members	Mean family income (Rs/month)	*Mean family consumption (L/day)	Per capita use (L/day)	Source	Problems in water quality (Colour or Odour)
Greaindih	16	Ag-9, Busi-2, Lab-3, Pvt.-1, Gov.-1	11	15,077	316	30.56	TW-14, W-2	H. Red.-5, S. Red.-0, Odour-0
Harino	10	Ag-3, Busi-1, Lab-3, Pvt.-1, Gov.-2	7	9857	257	36.7	TW-10, W-0	H. Red.-1, S. Red.-1, Odour-0
Harli	10	Ag-8, Busi-1, Lab-1, Pvt.-0, Gov.-0	13	13,400	330	25.4	TW-9, W-1	H. Red.-0, S. Red.-4, Odour-0
Jalahkarma	6	Ag-2, Busi-0, Lab-4, Pvt.-0, Gov.-0	11	9333	400	36.4	TW-0, W-0, S-6	H. Red.-0, S. Red.-2, Odour-0
Jamkatti	13	Ag-7, Busi-1, Lab-3, Pvt.-2, Gov.-0	8	11,615	238	29.7	TW-7, W-6	H. Red.-5, S. Red.-2, Odour-0
Jongi	8	Ag-5, Busi-0, Lab-1, Pvt.-2, Gov.-0	11	8500	275	25.0	TW-8, W-0	H. Red.-5, S. Red.-1, Odour-0
Kanko	29	Ag-21, Busi-2, Lab-1, Pvt.-3, Gov.-2	13	17,000	291	22.4	TW-24, W-5	H. Red.-16, S. Red.-1, Odour-2
Kanti	15	Ag-6, Busi-4, Lab-4, Pvt.-1, Gov.-0	14	12,500	328	23.4	TW-7, W-3, S-5	H. Red.-5, S. Red.-5, Odour-0
Kurmidih	9	Ag-1, Busi-4, Lab-0, Pvt.-3, Gov.-1	7	10,888	233	33.3	TW-9, W-0	H. Red.-5, S. Red.-2, Odour-0
Madangundi	7	Ag-4, Busi-2, Lab-1, Pvt.-0, Gov.-0	11	8000	400	36.4	TW-5, W-0, S-2	H. Red.-1, S. Red.-1, Odour-0
Nawardi	6	Ag-2, Busi-2, Lab-2, Pvt.-0, Gov.-0	11	9833	258	23.5	TW-4, W-2	H. Red.-0, S. Red.-4, Odour-0
Pipradih	11	Ag-6, Busi-2, Lab-1, Pvt.-2, Gov.-0	17	18,727	336	19.7	TW-9, W-2	H. Red.-6, S. Red.-2, Odour-1
Piprahi	6	Ag-3, Busi-, Lab-0, Pvt.-2, Gov.-1	12	15,666	283	23.6	TW-6, W-0	H. Red.-0, S. Red.-1, Odour-0
Porsatola	7	Ag-0, Busi-0, Lab-0, Pvt.-0, Gov.-1	12	16,000	500	41.7	TW-1, W-0	H. Red.-0, S. Red.-0, Odour-0
Puto	7	Ag-2, Busi-2, Lab-0, Pvt.-1, Gov.-2	15	17,000	440	29.3	TW-7, W-0	H. Red.-5, S. Red.-0, Odour-0
Sardardih	5	Ag-2, Busi-0, Lab-1, Pvt.-1, Gov.-1	8	9400	200	25.0	TW-4, W-1	H. Red.-0, S. Red.-1, Odour-0
Tham	6	Ag-6, Busi-0, Lab-0, Pvt.-0, Gov.-0	10	12,166	400	40.0	TW-6, W-0	H. Red.-0, S. Red.-0, Odour-0
Titirchanch	12	Ag-8, Busi-1, Lab-1, Pvt.-1, Gov.-1	14	14,636	504	36.0	TW-11, W-1	H. Red.-7, S. Red.-0, Odour-0

Table 7 (continued)

Village	Sample Number (=household or family)	Family Profession (with number)	Mean no. of family members	Mean family income (Rs/month)	*Mean family consumption (L/day)	Per capita use (L/day)	Source	Problems in water quality (Colour or Odour)
Urwan	10	Ag-3, Busi-4, Lab-1, Pvt.-1, Gov.-1	13	13,500	325	25.0	TW-8, W-0, S-2	H. Red.-3, S. Red.-0, Odour-0

*Mean potable water consumption ranged from 1.2–4.27 lit/day/person

Ag- Agriculture, Lab-Labourer, Busi- Business, Pvt.- Private Job, Gov. – Government job

TW- Tube well, W-Well, S- supply water by State Government

H. Red-Highly Red, S. Red-Slightly Red

Fig. 8 Variation in water consumption with number of mean family member and mean family income
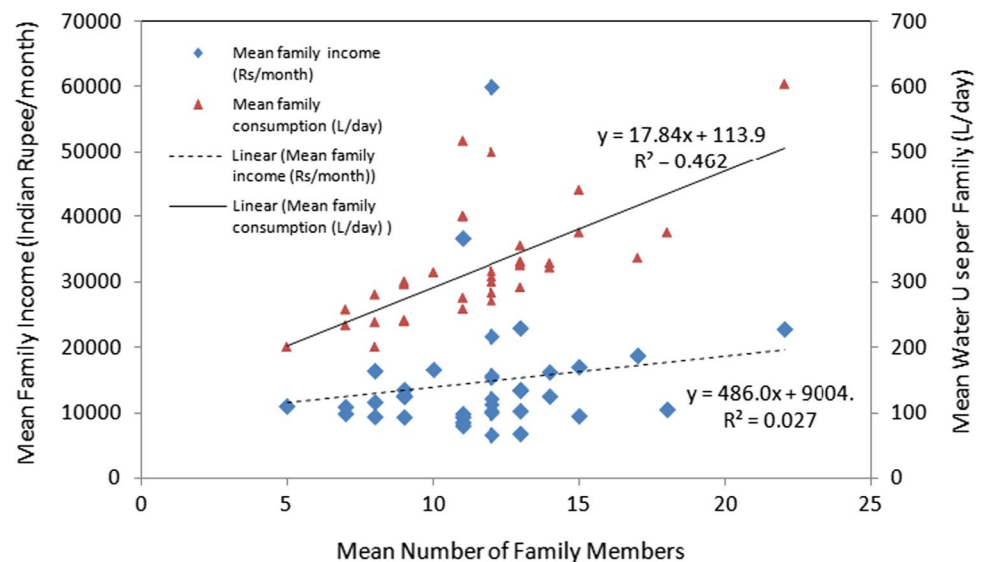
influence the affordability to own household water purifiers or participation in contributing to the procurement and management of community level water treatment plants. As per WHO, increased national income and proportion of population with access to improved water supply are correlated. In Africa, people spend about a third of income on treatment of water-related diseases (WHO, https://www.who.int/water_sanitation_health/watandmacr2.pdf), signifying the importance of affordability and willingness to combat water-borne diseases. Installation of community RO plants may be one of the possible solutions to ensure quality potable water for all in this region. The past experience on the operation and economics of community RO plants from Indian villages (Shah et al. 2004; Sharma and Joshi, 2014; APMAS, http://apmas.org/gagi/A%20Case%20Study%20on%20RO%20Water%20Plant-Mission%20Gagillapur.pdf) could be of great assistance in planning for such endeavour in this region.

Conclusion

This study assessed groundwater quality over a large area in 39 villages in Koderma District in India along with micro-level baseline information on water consumption *vis a vis* economic classes of consumers. Spatial variation in groundwater quality (TDS, Fe) was analysed by kriging method and mapped along with assessment of anthropogenic and geological sources of contamination by statistical methods. The study provides valuable clues in understanding water management issues and policy implications with respect to groundwater quality, availability and consumption. In terms of water consumption for domestic purposes, the families in Chandwara Block are placed on the same pedestal with a few prominent Indian cities but have lower consumption than a consumption benchmark of 135 lpcd set for Indian cities by Housing and Urban Affairs (MoHUA), Government of India. Most of the groundwater samples in Chandwara CD Block can be deemed unsafe

for drinking primarily due to high Fe and TDS, both of which are considered critical potable water parameters. In the southern and central areas of the block, groundwater is affected by Fe (> 1 mg l^{-1}) while in the northern part, it is mostly affected by TDS of > 500 mg l^{-1}. High TDS at some places is due to long interaction of groundwater with rocks and eventual dissolution of minerals in water. On the other hand, Fe is incorporated in groundwater and held in solution in varying amounts through the release of Fe from ferruginous lateritic soil present in study region. As Fe-rich groundwater is exposed to air upon withdrawal, Fe would get oxidized to less water-soluble forms, becomes visible in water and forms white, yellow and finally red-brown particles. Further, high Fe in water would promote growth of non-pathogenic bacteria that feed on iron, forming red-brown iron slime that can foul and clog water systems, often producing a foul odour. Therefore, Fe in groundwater may be a potential problem for drinking and domestic water supply networks in affected regions that needs to be redressed through conscious decision making and using either Point of Use (PoI) or Point of Entry (PoE) water purification before consumption. Groundwater in study region may need to be treated by household reverse osmosis units (PoI) for TDS and Fe removal before consumption, but economic condition of families having mean monthly income of INR 6800 to 18,727 (95.72 to 263.6 US $ as per exchange rates on 18.1.2020), is not conductive for spending towards individual household water purification units that could cost anything around INR (Indian rupees) 15,000–25,000 each (US $ 202.8–338.0, as per exchange rates on 12.1.22), apart from costly maintenance of recommended iron removal pre-units and RO membranes that would need about 20−25% of capital cost of equipment per year. In terms of irrigation, groundwater withdrawn in some villages are suitable for only salt tolerant crops and hence, needs judicious decision making in terms of their continuous use in regional agriculture. This study would serve as a useful guide in regional groundwater management, livelihood, water carrying capacity analysis and policy-making.

Declarations

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