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Variation of iron in groundwater and its impact on human health in Dhangadhi area, Farwestern Nepal

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ABSTRACT

In April 2024, a study was conducted to assess the distribution of iron in the several types of groundwater resources in the Dhangadhi area. A total of 50 samples were collected, including 29 from shallow sources and 21 from deep sources. Iron was detected in 24 shallow and 8 deep sources. In shallow sources, iron concentrations ranged from 0.17 to 9.68 mg/l, with a mean of 2.46 mg/l and a standard deviation of 2.14 mg/l, while in deep sources, concentrations ranged from 0.17 to 7.14 mg/l, with a mean of 1.30 mg/l and a standard deviation of 2.24 mg/l. Except for samples SS5, SS7, DS10, and DS15 all other samples exceeded the permissible iron limit of 0.3 mg/l set by NDWQS 2022. The Water Quality Index (WQI), without considering iron, ranged from 2.10 to 122.22, classifying groundwater as 52% excellent, 34% good, 6% very poor, and 8% unsuitable for drinking. WQI ranged from 1.985 to 446.70, when iron was included, categorizing groundwater as 38% excellent, 20% good, 6% poor, 6% very poor, and 30% unsuitable for drinking, highlighting iron as the primary factor degrading water quality. The highest concentration was found in sample SS2 in the northern part of the area, with industrial and agricultural activities contributing to elevated levels. The reliance on shallow sources with high iron concentrations has led to public health issues, including liver and kidney diseases. Effective management and stringent quality control measures are essential to protect this critical water resource.

Keywords: Groundwater; Iron; Shallow sources; Deep sources; Water quality; Drinking water.

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INTRODUCTION

Groundwater serves as a vital source of drinking water, especially in regions where surface water is scarce or polluted. In areas like Dhangadhi, Nepal, groundwater quality is increasingly threatened by excessive iron levels, an issue driven by both natural geological conditions and human activities (Shrestha et al. 2016). While iron is an essential micronutrient, its elevated concentration can lead to health issues such as gastrointestinal distress, organ damage, and hemochromatosis (WHO 2017, Hassan et al. 2021, Sutradhar et al. 2020). Iron typically enters groundwater in its soluble ferrous (Fe^{2+}) form due to the dissolution of iron-bearing minerals, especially under reducing conditions found in forested or low-oxygen environments (Smedley and Kinniburgh 2002).

Shallow aquifers, typically found at depths less than 50 meters, are particularly susceptible to iron enrichment due to the reducing conditions prevalent in the floodplain alluvial sediments. In contrast, deeper aquifers (beyond 100 meters) tend to exhibit comparatively lower iron concentrations, although spatial heterogeneity remains significant. In Kailali district, a study by Gurung et al. (2015), highlight the broader issue of iron contamination in Nepal, underscoring the importance of continuous monitoring and intervention. Another groundwater quality study was conducted in eastern terai districts of Morang, Jhapa, and Sunsari revealed that iron concentrations in some samples exceeded safe thresholds, highlighting the broader issue of iron contamination in the region's groundwater (Mahato et al., 2018). The distribution and controlling mechanisms of iron in Dhangadhi's groundwater system is crucial for developing effective mitigation strategies and ensuring safe drinking water access for the local population.

STUDY AREA

The study area (Fig. 1) is in Kailali district, covering 45 km² of the Terai plains. It stretches from north of Godavari municipality (wards 1 and 5) to south of Dhangadhi sub-metropolitan city (wards 1, 2, 3, 4, and 13), between 28º41'N–28º48'N latitude and 80º32'E–80º35'E longitude. The geology ranges from Quaternary to recent deposits, consisting of boulders, gravel, sand, clay, and silt. Major rivers in the area include the Mohana River, Manahara Khola, Kailali Nala, and Namrada Gauriganga Khola. The region has a tropical to subtropical climate, with average monthly temperatures ranging from 14.68°C to 31.62°C and rainfall peaks in July (526.88 mm) and is lowest in November (1.68 mm).

METHODOLOGY

This study is based on primary data collected through site observations and fieldwork conducted in January 2024. A questionnaire survey by locals gathered information on groundwater sources, including depth, usage, purpose, and associated health impacts. Groundwater were categorized as shallow sources (handpumps, borings) and deep sources (deep handpumps, artesian, borings) based on depth. In-situ analysis was conducted during the post-monsoon (February 2024) and pre-monsoon (April 2024) periods. Fifty water samples were collected during the dry season (April 2024) from various sources including shallow handpumps, deep handpumps, and artesian borings. Samples were collected in 1L bottles pre-washed and rinsed to ensure accuracy. In the lab, iron concentration was measured using a photo colorimeter, where iron reacts with ammonia and thioglycolic acid to form a stable pink to reddish complex. Water quality was evaluated using the Water Quality Index (WQI), comparing iron levels against NDWQS (2022) and WHO's guideline of 0.3 mg/L.

Horton (1965) introduced the Water Quality Index (WQI) using the Weighted Arithmetic Mean method. Reference values for interpreting WQI are provided in Table 1.

WQI Calculation: $WQI = \sum (qn \times Wn) / \sum Wn$ (1)

Quality Rating (qn): $qn = [(Vn - Vid) / (Sn - Vid)] \times 100$ (2)

Unit Weight (Wn): $Wn = K / Sn$ (3)

Where, qn = Quality rating of the nth parameter, Wn = Unit weight of the nth parameter, Vn = Measured value at the sampling site, Vid = Ideal value (0 for all except pH, where Vid = 7), Sn = Standard permissible limit, K = Proportionality constant, calculated as: $K = 1 / \sum(1/Sn)$

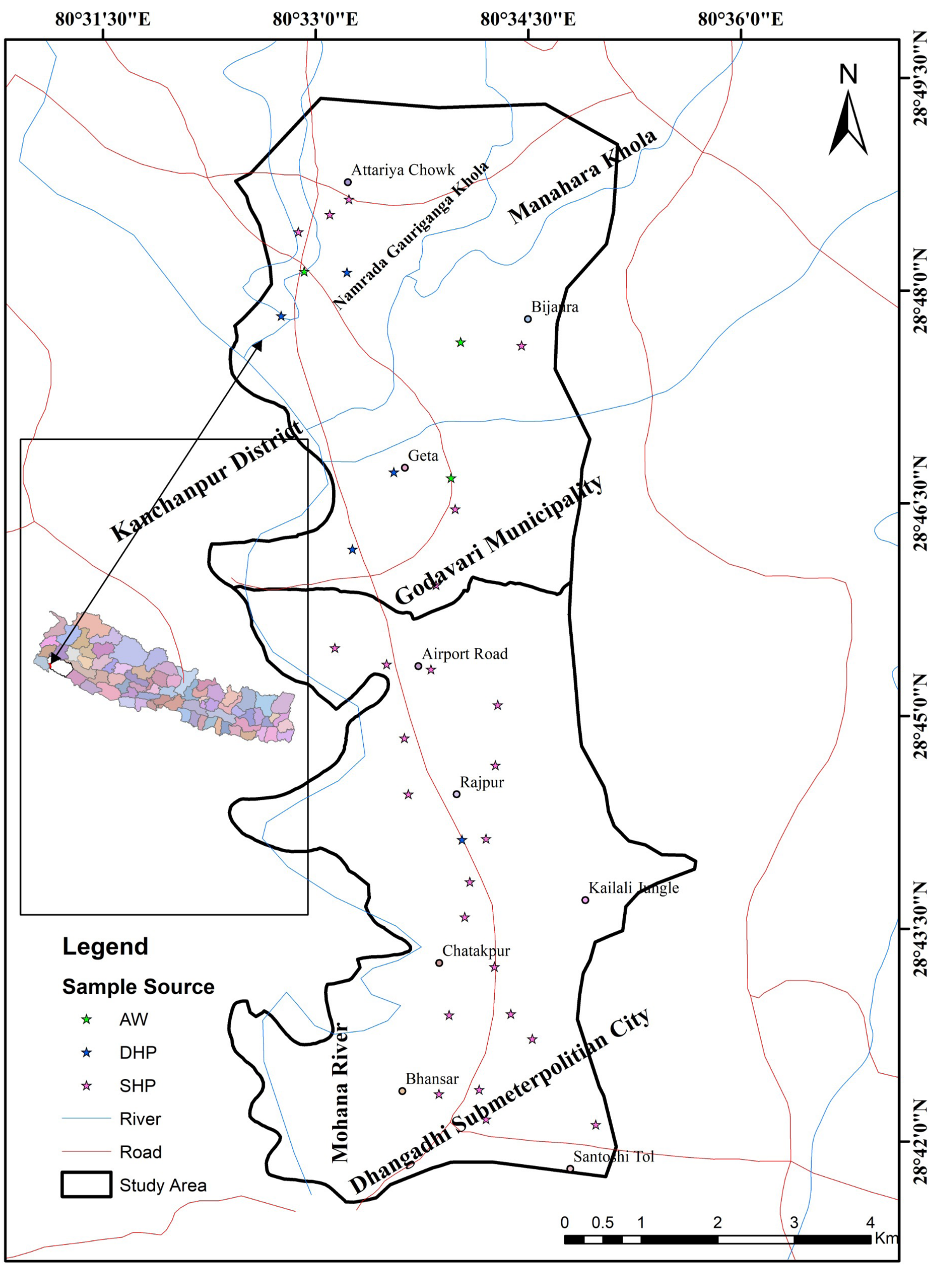

Fig. 1: Location map of the study area.

Table 1 Ratings of water quality as per the weighted arithmetic water quality index method (Tyagi et al. 2013)

WQI Value	Water Quality Rating	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-90	Very Poor water quality	D
91-100	Unsuitable for drinking	E

RESULTS

Iron concentration

The April 2024 study in Dhangadhi revealed notable variation in iron concentrations among groundwater sources. Out of 50 samples, 29 were from shallow and 21 from deep sources. Iron was detected in 24 shallow and 8 deep sources including 3 from artesian samples (DD11, DD12, DD15) and 5 from deep handpumps samples (DD6, DD8, DD9, DD10, DD18, DD21) highlighting widespread iron contamination across both well types (Table 2).

Table 2 Iron Concentration in shallow and deep sources in the research area

Parameter	Sources	Sample no.	Concentration (mg/l)	Sources	Sample no.	Concentration (mg/l)	Permissible limit (mg/l) NDWQS (2022)
Iron (mg/l)	Shallow Sources	SS1	0.85	Deep Sources	DD1	0	0.3
		SS2	9.86		DD2	0	
		SS3	0		DD3	0	
		SS4	0.34		DD4	0	
		SS5	0.17		DD5	0	
		SS6	1.87		DD6	7.14	
		SS7	0.17		DD7	0	
		SS8	0.34		DD8	1.62	
		SS9	0.17		DD9	0.51	
		SS10	0		DD10	0.34	
		SS11	0		DD11	0.17	
		SS12	3.06		DD12	0.68	
		SS13	4.59		DD13	0	
		SS14	4.93		DD14	0	
		SS15	3.23		DD15	0.17	
		SS16	0.51		DD16	0	
		SS17	1.12		DD17	0	
		SS18	2.04		DD18	0.34	
		SS19	2.72		DD19	0	
		SS20	0		DD20	0	
		SS21	4.25		DD21	4.25	
		SS22	3.91				
		SS23	3.51				
		SS24	2.55				
		SS25	2.55				
		SS26	3.23				
		SS27	0.51				
		SS28	0				
		SS29	0.68				

In shallow sources, iron levels (Figure 2) ranged from 0.17 mg/L to 9.86 mg/L, with a mean of 2.46 mg/L and a standard deviation of 2.14 mg/L. The highest concentration was found in sample SS2 (9.86 mg/L). Out of iron detected samples, only SS5, SS7, and SS9 sample had lower concentrations of (0.17 mg/L), remains within permissible limits.

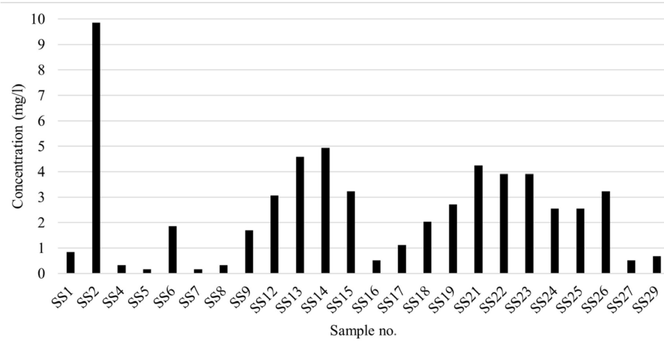

Fig. 2: Iron level in shallow sources in the area.

It highlights the uneven distribution of iron contamination, suggesting localized geogenic or anthropogenic influences. In deep sources, iron concentrations (Figure 3) ranged from 0.17 mg/L to 7.14 mg/L, with a mean of 1.30 mg/L and a standard deviation of 2.24 mg/L. The highest concentration was observed in sample DD6 (7.14 mg/L), significantly exceeding the NDWQS 2022 limit. On comparing iron concentrations were lower in deep sources compared to shallow ones and among artesian samples, DD12 exceeded.

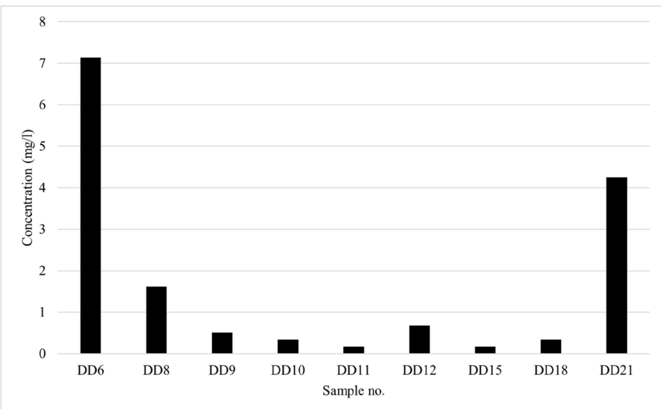

Fig. 3: Iron level in the deep sources in the area.

Figure 4 shows the highest concentration in SS2 sample collected near the forested areas around Attariya chowk. Iron contamination is present across a wide range of depths, with shallow aquifers being more affected and highlights critical hotspots where concentrations exceed safe limits for drinking water.

Hydrogeology and water quality

The area's hydrogeology consists of silt, clay, gravel, and fine to coarse sand, with iron bearing gravel sediments in the northern part influencing groundwater movement and iron presence. Fig.5 shows the lithological profile, a surface layer of clay extending up to 5 m underlain by a thick sequence of sand layers that continue down to a depth of 50 meters. Groundwater is primarily extracted from these sandy layers. Handpumps are commonly used for water withdrawal within a depth range of 4.88 to 50.292 meters in the area. Additionally, artesian wells are deeper and are used at depths ranging from 45.72 to 152.4 meters, indicating the presence of a pressurized groundwater zone at greater depths. The depth preferences for water extraction were determined through local surveys, highlighting the community's reliance on various groundwater sources based on accessibility and aquifer characteristics.

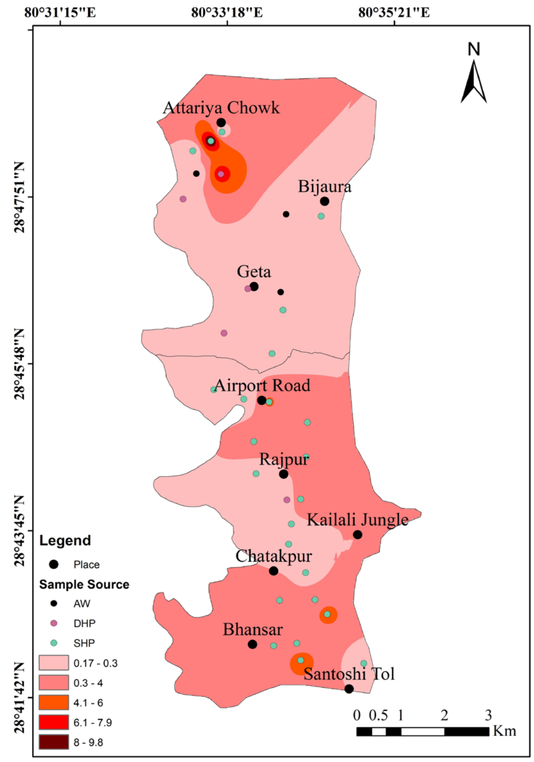

Fig. 4: Spatial distribution of iron and the sample having the highest concentration of iron in the area.

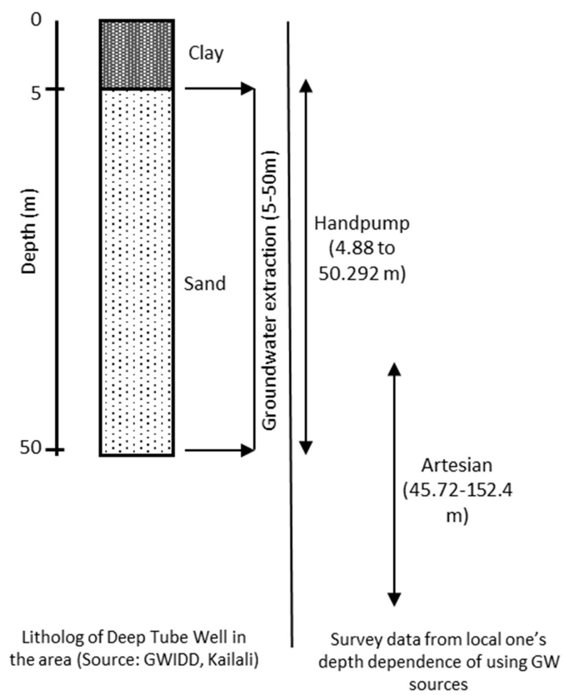

Fig. 5: Litholog of deep tube well in the area (source: GWIDD, Dhangadhi, Kailali).

The Water Quality Index (WQI), when iron was included (Fig. 6 a), quality declined notably, 38% of the samples are excellent, 20% good, 6% both poor and very poor, 30% are unsuitable for drinking purposes, reflecting serious water quality issues. Figure 6 b demonstrates WQI without considering iron and gives the results 52% of groundwater as excellent, 34% good, 6% very poor, and 8% unsuitable drinking purpose, showing a slight increase in poor water quality due to elevated iron content.

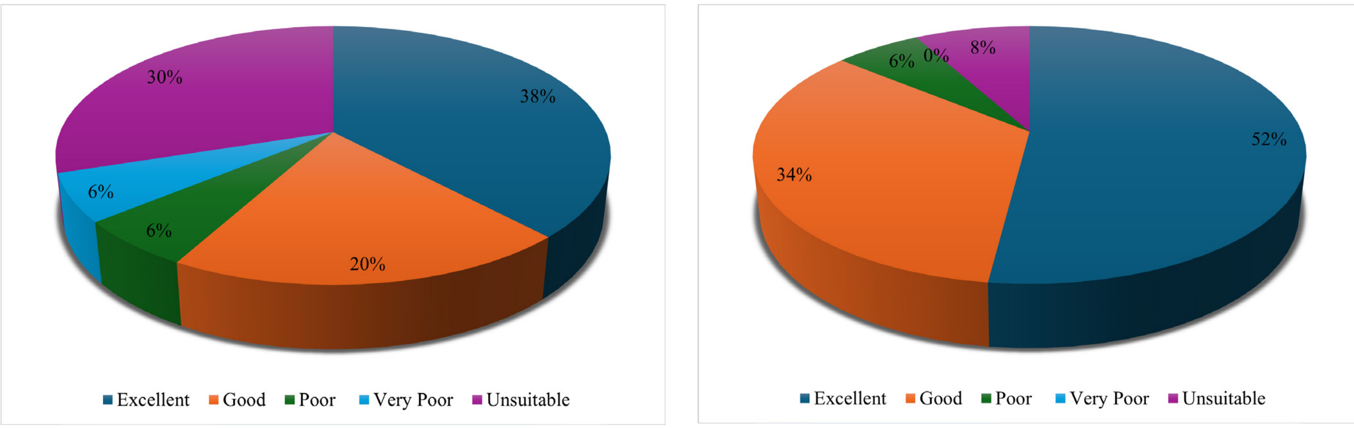

Fig. 6: WQI, a) with considering iron, and b) without iron as the measuring.

Human health

A survey covering 26 artesian wells and 142 handpumps; including from shallow and deep depth, showed that artesian wells serve around 4,500, while handpumps are used by 861 people. For iron analysis, 2,000 artesian well users and 250 handpump users were sampled. Iron contamination was found in 3 artesian wells, affecting 200 people (4.44%), and in handpumps used by 182 people (30%). Overall, 34.44% of the surveyed population consumes iron-contaminated water. Shallow source users reported issues like reddish discoloration, utensil staining, turbidity, and salty taste. Survey data also indicated a high prevalence of kidney stone cases. Comparing WQI results with usage data, it was revealed that 115 people were consuming water classified as unfit for drinking purposes.

DISCUSSION

Iron concentration

The elevated iron concentrations in both shallow and deep aquifers suggest that iron contamination is a widespread issue in the study area. The higher maximum iron level in shallow sources SS2 (9.86 mg/L) reflects more active geochemical processes such as iron reduction (Stumm and Morgan, 1996; Appelo and Postma, 2005) which are common in organic-rich alluvial sediments in shallow depths especially in the northern gravel-rich zones. This aligns with previous findings that shallow aquifers are more vulnerable due to surface interactions such as organic matter from agricultural runoff or septic leakage, which can enhance microbial activity and promote the mobilization of iron. In contrast, deep aquifers, although considered more protected, still show significant iron concentrations in DD6 (7.14 mg/L), suggesting that iron-bearing strata may extend to greater depths (Shrestha et al., 2016). The presence of iron in deep sources might also be linked to longer residence times. Iron in artesian wells, typically near forested areas, may result from natural processes such as organic acid-driven leaching and weathering of iron-rich soils and rocks (Zhang et al. 2017; Bogner et al. 2013). The area's industrial and agricultural activities may further contribute to contamination (Hassan et al. 2021). The spatial variation in iron levels emphasizes the influence of lithology and aquifer characteristics on groundwater quality.

Human health

The social survey revealed critical public health concerns linked to iron contaminated groundwater. While around 4,500 people using artesian wells are safe, only 3 wells showed iron presence at non-harmful levels. In contrast, 30% of handpump users consume iron-contaminated water, posing both aesthetic (discoloration, staining, salty taste) and health risks, including a high prevalence of kidney stones (Singh et al. 2020). Water Quality Index (WQI) data showed that 115 individuals consume water unsuitable for drinking. Initially, 52% of groundwater sources were classified as excellent and 8% as unfit; however, with iron included, only 38% remained excellent while 30% became unfit, highlighting the importance of including trace metals in routine water monitoring (Tiwari et al. 2017; WHO 2017). This disparity, 30% of handpump users vs. 4.44% of artesian well users exposed to high iron, suggests differences in aquifer vulnerability and construction quality. The situation in Dhangadhi mirrors findings from other regions, where high iron levels degrade water quality and impact health (Sutradhar et al. 2020). A regional approach for Kailali District is essential, involving iron removal technologies, public education, stricter source protection, and sustainable groundwater management (Gurung et al. 2015; Mukherjee 2018).

CONCLUSIONS

The study confirms widespread iron contamination in groundwater, especially in shallow aquifers, due to local geology. Iron levels reached up to 9.86 mg/l, far above permissible limits. Around 30% of the population consumes water with high iron, posing risks such as kidney stones and other health issues. WQI analysis, when factoring iron, showed a clear decline in water quality. Approximately 34.44% of the community drinks water not fit for consumption per WQI standards. Reported issues like discoloration and taste changes suggest the presence of other contaminants as well. These findings emphasize the importance of depth-specific water treatment solutions, such as iron removal systems, and the need for targeted water quality monitoring, stricter control of industrial and agricultural pollution are crucial to safeguard water quality and public health in the region.

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