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Research Article

ASSESSMENT OF DRINKING WATER QUALITY IN GOVERNMENT SCHOOLS OF RAMDHUNI MUNICIPALITY, NEPAL

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ABSTRACT

Access to safe drinking water is essential to safeguarding human health, particularly among school-aged children who are highly vulnerable to waterborne diseases and chemical contaminants. In many government schools of eastern Nepal, groundwater extracted through tube wells serves as the primary source of drinking water. The quality of this water is therefore directly linked to the health and well-being of students, teachers, and school staff. This study assessed the physicochemical and microbial quality of tube-well water in eight government higher secondary schools of Ramdhuni Municipality, Sunsari District, Nepal. Total coliform contamination was detected in 25% of water samples, indicating potential microbial risk, although fecal coliform bacteria were absent in all samples. Significant positive correlations were found among electrical conductivity, total dissolved solids, and total hardness, as well as between selected metals and other water quality parameters. The Water Quality Index (WQI = 76.4) classified the water as category B, suggesting that it is suitable for domestic and agricultural use; however, the presence of heavy metals and microbial contamination raises concerns regarding its safety for drinking. These findings highlight the potential health risks associated with prolonged exposure to contaminated water and emphasize the need for routine monitoring, appropriate treatment systems, and stricter enforcement of water quality standards to ensure the provision of safe drinking water in school environments.

Keywords: Groundwater, Drinking water quality, Microbial parameters, Physicochemical parameters, Ramdhuni Municipality

INTRODUCTION

Water is one of the most precious natural resources after air, essential to the sustainability of life on Earth. Only about 2.5% of the Earth's water is fresh, with the remaining 97.5% being saline and largely found in lakes, seas, and oceans. About 70% of global freshwater is stored in wetlands, snow cover, soil moisture, and glaciers (Oksana & Dmytro, 2021). A little over thirty percent is groundwater, of which fifty percent is at a pumping depth of eight hundred meters, which is not cost-effective (du Plessis, 2017). Water supplies continue to decline due to pollution and depletion of available resources, while demand is rising rapidly because of urbanization, industrialization, and population growth (Mishra, 2023).

Nepal faces serious challenges regarding drinking-water quality and its management. Most of the water sources are contaminated by chemicals and microorganisms. The report by the Nepal Department of Water Supply and Sewage estimates that around 86% people have access to drinking water, though the water is questionable in terms of quality (DWSS, 2015). Moreover, only 21.9% in urban areas and 13.3% of the population in rural areas are provided with safe drinking water (WHO & UNICEF, 2013). In the present scenario, Nepal is facing a serious health issue regarding the quality of drinking water in schools. In different schools, different groundwater sources, such as a tube well, are highly used as a source of drinking water (Tripathi, 2018). However, the physicochemical and microbial state of the water is less commonly studied, despite its impact on the health of school-going children, teachers, and staff through various illnesses and waterborne diseases (Shrestha et al., 2017). In the context of Nepal, most of the population in the Terai region, including Sunsari District, depends on groundwater sources such as tube wells for drinking purposes for their drinking purposes but these sources are often contaminated with arsenic and other chemical pollutants. (Ogata & Suenaga, 2023), o Slight polish: "…had basic water service (improved and available), 24% had limited water service (unimproved or not reliably available), and 21% had no water service." (Acharya et al., 2025).

The evaluation of water quality has become crucial for maintaining the sustainability of health in the era of the growing global population and environmental hazards. Waterborne illnesses are largely caused by contaminated water, and they account for approximately 80% of all diseases and 33% of fatalities, and they are caused by anthropogenic activities (Khan & Ahmad, 2012). In South Asia, where over 0.5 million newborns die annually, the issue is made worse by extra health risks brought on by shoddy sanitation and water quality (WHO, 2013). Groundwater, which is the primary source of water for an increasing number of families, has been seriously contaminated by industrial pollution and human waste. The contaminated water not only harms aquatic life but also deteriorates its aesthetic qualities and harbors several waterborne illnesses, including cholera, typhoid, hepatitis A, and intestinal disorders (Archana et al., 2025). Each year, these diseases claim thousands of lives worldwide, particularly in developing countries (WHO & UNICEF, 2023). Fecal waste from sewage is the main source of drinking water pollution, while agricultural runoff and industrial effluents further contribute to chemical contamination of water resources. In some studies, arsenic levels have been reported to be high, exceeding permissible drinking water limits, revealing serious health risks (WHO, 1999). Unsafe drinking water is also a major global public health concern, with waterborne diseases contributing significantly to morbidity and mortality worldwide (WHO & UNICEF, 2013).

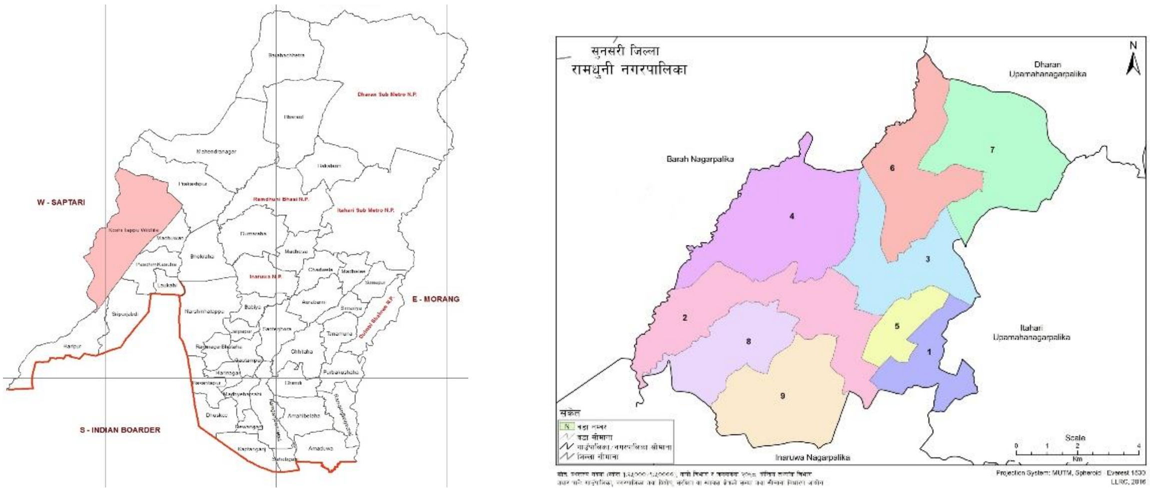
There is growing concern about groundwater quality and its health impacts. Many studies are reported in this regard in different regions of Nepal (Adhikari et al., 2023; Ghimire et al., 2023, 2025; Kandel et al., 2025; Pant et al., 2025; Ranabhat et al., 2025; Shrestha et al., 2023). These studies reflect the hydrochemistry of groundwater samples in Kathmandu, Bhaktapur, and Lalitpur. However, limited studies have been reported on the study of groundwater samples in eastern Nepal, including Sunsari district, especially in Ramdhuni Municipality. Studies by Bhandari & Aryal (2020) and Das (2017) have focused on surface water in Sunsari District, while Linkha et al. (2022) addressed probabilistic determination of groundwater potential in the district. However, the studies regarding health, sanitation, and water analysis of schools are also rare. The study on health, sanitation, and water has been conducted in different schools of Nepal (Acharya et al., 2025). In this study, physicochemical and microbial quality assessments of school tube wells in Ramdhuni Municipality are integrated, with implications for public health and WASH compliance.

The tube wells are the main source of drinking water in the government higher schools of Ramdhuni Municipality. The water quality of this tube well is directly linked with the health of students, school staff, and teachers. To date, no comprehensive study has been carried out to evaluate the physicochemical and microbial parameters of groundwater from school tube wells in Ramdhuni Municipality. The assessment of water quality is of great significance as there is a high reliance on groundwater for drinking purposes, and school children are vulnerable to waterborne contaminants. Moreover, the study is important to ensure safety and provide baseline information for developing effective management and monitoring strategies. However, there are few studies on the spatial distribution and exploitation of groundwater as well as the status of water resources and their impact on rural livelihood practices of Sunsari District (Pathak, 2017; Ghimire et al., 2022;). Similarly, the studies on groundwater quality assessment in Sunsari district are also limited (Mahato et al., 2018). Hence, this study aimed to evaluate the drinking-water quality status of government higher secondary schools in Ramdhuni Municipality by determining physicochemical and microbial parameters of the tube-well water."of government higher secondary schools of Ramdhuni Municipality by determining physicochemical and microbial parameters of the water samples. This study further aims to determine the relationship between the water quality parameters and WQI values to provide insightful information on the quality of drinking water in schools.

MATERIALS AND METHODS

Study area

Ramdhuni Municipality is located in Sunsari District, Koshi Province, Nepal, which is shown in Figure 1(a). The 9 administrative wards present in Ramdhuni Municipality are shown in Figure 1(b). It covers an area of 91.69 km² and lies near 87°10′ E and 26°42′ N. It has a population of 63,452 according to (CBS, 2021). It is bordered by Itahari Sub-metropolitan City to the west, Duhabi Municipality to the east, Inaruwa Municipality to the north, and Barju Municipality to the south. It experiences a subtropical climate with a temperature of 24°C and annual precipitation of approximately 1954 mm (Chaudhary et al., 2022). It is located at an altitude of 185 m above sea level.



(a) (b)

Figure 1. (a) Map of Sunsari district showing Ramdhuni Municipality (b) Map showing wards and sampling sites.

Sampling and water analysis

A total of eight water samples were collected, one from each government higher secondary school in Ramdhuni Municipality, with each school representing a different ward. Although the sample size is limited, this approach ensures coverage of all wards within the municipality, thereby providing a representative overview of spatial variations in physicochemical and microbial water quality across the study area. The water analysis was performed in February 2024, using a stratified purposive sampling design targeting higher secondary schools. The water samples were collected with prior permission and consent from the respective school authorities and local ward offices, following standard ethical practices. The sampling sites, along with their code, are as follows: Shree Chandra Higher Secondary School (HSS-1), Shree Sanischare Higher Secondary School (HSS-2), Shree Shivnagar Higher Secondary School (HSS-3), Shree Ramdhuni Higher Secondary School (HSS-4), Shree Janta Higher Secondary School (HSS-5), Shree Bhadghau Sinuwari Secondary School (HSS-6), Shree Panchyat Secondary School (HSS-7), and Shree Aadrasha Secondary School (HSS-8). High-density polyethylene (HDPE) bottles (1 L), treated with 5% HNO_3 and rinsed with double-distilled water, were used for physicochemical analyses, while sterile glass bottles were used for microbial analysis. Each sample was analyzed in triplicate to ensure reproducibility and minimize analytical variability. Standard American Public Health Association (APHA) guidelines (2017) were followed for sample collection and analysis of physicochemical and microbial parameters for sample collection as well as analysis of physicochemical and microbial parameters. The parameters, such as conductivity, pH, and temperature, were measured at the site. The samples were preserved at 4°C in a refrigerator when immediate analysis was not possible. For each parameter, the mean value, standard error of the mean (SE) and standard deviation (SD) were calculated from the triplicate measurements. All measurements were evaluated at a 95% confidence level to ensure statistical reliability. The material and method used for analysis of the water quality parameters, along with their World Health Organization (WHO, 2011) and National Drinking Water Quality Standard (NDWQS, 2022) guidelines, have been presented in Table 1.

Table 1. Materials and methods used for water quality parameters

Parameters	**WHO, 2011**	**NDWQS, 2022**	**Material/methods**
Physical			
Temperature (°C)	-	-	Mercuric thermometer
pH	6.5–8.5	6.5–8.5	pH meter (HI98107)
Conductivity (µS/cm)	800-1000	1500	Digital conductivity meter (HI5521)
Colour (TCU)	15	5	Spectrometric (LT-291)
Turbidity (NTU)	5	5	Nephelometer (HI98703 HANNA)
TDS (mg/L)	500	1000	Gravimetric method

Chemical			
Chloride (mg/L)	250	250	Argentometric method
TA (mg/L)	-	-	Acid-base titration
TH (mg/L)	80-120	500	EDTA titration
Ca-hardness (mg/L)	-	-	EDTA titration
Nitrate (mg/L)	50	50	Spectrophotometer (LT-291)
Ammonia (mg/L)	1.5	1.5	Phenate method (LT-291)
Iron (mg/L)	0.3	0.3	AAS (Thermo scientific/ icE 3000)
Manganese (mg/L)	0.4	0.2	AAS (Thermo scientific/ icE 3000)
Arsenic (mg/L)	0.01	0.05	Arsine generator method
Fluoride (mg/L)	1.5	0.5-1.5	Colorimetric method (LT-291)
Microbial			
Total coliform (CFU/100 mL)	0	0	Membrane filtration method
Fecal coliform (CFU/100 mL)	0	0	Membrane filtration method

TA = Total Alkalinity, TH = Total Hardness, AAS = Atomic Absorption Spectrophotometer

Quality control and assurance

The pH meter was calibrated with buffer solutions of pH 4.0, 7.0, and 10.0 before its use. Similarly, the conductivity meter was calibrated with a standard reference solution containing potassium chloride (KCl) with a specific conductivity of 1413 µS/cm. All glassware was soaked in 14% HNO_3 overnight and then thoroughly rinsed with distilled water. The measurement of the parameters was performed using well-calibrated instruments and complete cleaning of glassware and equipment. For heavy metal analysis, the water samples were collected in acid-washed polyethylene bottles and preserved with nitric acid ($pH < 2$). Before analysis, samples were acid-digested using the standard procedures of APHA. Similarly, the concentration of heavy metals was determined from external calibration with certified standard solutions and reagent blanks. Quality control was further ensured by triplicate analysis and spike recovery tests, with acceptable recoveries within standard limits, ensuring the accuracy and reliability of the results.

Water Quality Assessment (WQI)

In order to determine the quality of water in the sampling sites, the WQI was calculated for the water quality parameters. In the present study, physical parameters such as pH, electrical conductivity (EC), total hardness (TH), and turbidity were considered, along with colour, major ions (Cl^-, NO_3^-, NH_3, F^-) and heavy metals (Fe, Mn, As) for WQI deterfor determining WQI as they significantly influence the quality of water. The assessment of WQI was based on the standards of NDWQS, 2022. However, the parameters like temperature, total alkalinity, and calcium hardness were not considered as their permissible limit or standards have not been specified in the NDWQS. The WQI is calculated as follows:

$$WQI = \sum_{i=1}^{n} W_i q_i \qquad \text{…(i)}$$

Where, Wi = weight factor and qi = quality rating

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad \text{... (ii)}$$

where, $w_i th\ the\ unit\ weight$ of the ith parameter and $\sum_{i=1}^{n} w_i$ is the sum of all the weights of all parameters (1 to n). The weight (wi) of 1, 2, 3, 4, and 5 is provided to water quality parameters if 81-100 %, 61-80%, 41-60%, 21-40%, and 0-20 % of samples are within the permissible limit(Singh et al., 2021).

Similarly, qi is calculated as follows:

$$q_i = \frac{c_i}{s_i} \times 100 \qquad \text{...(iii)}$$

Statistical analysis

The statistical analysis was performed using IBM SPSS Statistics (version 19, IBM Corp., Armonk, NY, USA). The descriptive parameters such as mean, standard deviation, and standard error of the mean) were determined for different water quality parameters. Similarly, the normality test was carried out using the Shapiro-Wilk (S-W) test at 5% significance since Given the small sample size ($n < 30$), the Shapiro–Wilk test was applied, as it is appropriate for sample sizes of approximately 3–50 and is widely used in environmental studies and is widely used in environmental studies. The degree of association between the different water quality parameters in different sampling sites was determined using a correlation matrix.

RESULTS AND DISCUSSION

The different physicochemical and microbial parameters of the water samples from 8 sampling sites are represented in Table 2. All the results are presented as mean ±standard deviation (SD) to describe the variability among samples, while the standard error of the mean (SEM) was used to indicate the precision of the estimated mean. For testing the normality of the distribution, the Shapiro-Wilk (S-W) test was used. Among the 17 water quality parameters in the present study, the p-value of temperature, nitrate, ammonia, iron, manganese, arsenic, and total coliform was less than 0.05, which indicated these parameters did not follow normal distribution, whereas the remaining parameters showed normal distribution. Hence, the investigated data showed approximately normal distribution. Hence, a parametric test or Pearson correlation coefficient was calculated to determine the relationship between the water quality parameters.

Analysis of physical parameters of water samples

The temperature of the studied tube-well water samples from different higher secondary schools in the present study varied from (21.7⁰C –23.4⁰C) with a mean temperature of (22.24 ± 0.695) ⁰C. In the previous study of Shrestha et al. (2023) and Mahato et al. (2018), the maximum temperature was higher than the upper limit of temperature in the present study, possibly due to surface water mixing or climatic variation (Taylor & Stefan, 2009).

The mean turbidity of tube well water samples in the present study was (0.861 ± 0.802) NTU. The turbidity of all the tested water samples was low and within the threshold limit of NDWQS and WHO. Low turbidity indicates minimal suspended particulate matter, likely due to natural filtration through soil layers in tube wells. However, slight variations among samples may be attributed to localized soil disturbance or minor infiltration of fine particles. The turbidity reported in the study of Mahato et al. (2018) was higher than that of the present study, in which (44.57%) of groundwater samples surpassed the safe limit of NDWQS and WHO, which deviates from the present study. High turbidity in groundwater is due to the presence of sewage organic wastes, clay, sand, and silt, which seriously affect public health (WHO, 1999).

Water colour ranged from 2.1 to 8.29 TCU, with a mean of 6.31 ±2.60 TCU. While most samples were within WHO limits, some exceeded NDWQS standards, indicating the presence of dissolved organic matter or mineral content. Such variation may result from interaction between groundwater and surrounding geological materials, particularly iron-rich formations or organic-rich soil layers. Higher values compared to the earlier study of Mahato et al. (2018) suggest localized geochemical influence in the study area (Xia et al., 2022).

The pH of the samples ranged from 6.44 to 6.90, with a mean of 6.64 ± 0.165, indicating slightly acidic conditions. Although all samples were within permissible limits, the acidic nature may be attributed to dissolved carbon dioxide and weak organic acids in groundwater, whereas higher carbonate content in aquifer geology contributes to alkaline conditions. The slightly acidic pH suggests limited buffering capacity of the aquifer system. The present study was in alignment with the previous study (Acharya et al., 2025), in which the pH of groundwater samples was within the range of 6.5-8.5. Similarly, the basic nature of ground water samples were reported in the studies of Adhikari et al. (2023), Shrestha et al. (2023), and Kandel et al. (2025), Mahato et al. (2018) and Ghimire et al. (2023). , the acidic nature may be attributed to dissolved carbon dioxide and weak organic acids in groundwater whereas higher carbonate content in aquifer geology contributed to alkaline conditions of ground water (Hanshaw & Back, 1979; Langmuir, 1997)

Electrical conductivity (EC) ranged from 161.3 to 818 µS/cm, with a mean of 435.01 ± 247.81 µS/cm, indicating moderate mineralization of groundwater. The variation in EC suggests differences in ionic composition across sampling locations. In the studies of Adhikari et al. (2023), Mahato et al. (2018), and Kandel et al. (2025), EC of the water samples were within the permissible limit of WHO and NDWQS, which was in good agreement with the present study. Similarly, Ghimire et al. (2023) and Shrestha et al. (2023) reported EC values higher than the upper limit of EC in the present study. The high EC of groundwater is caused by the presence of high concentrations of metals and ions such as ammonium, chloride, and nitrate dissolved in water (Dzwairo et al., 2006).

In the present study, Total Dissolved Solids (TDS) were in a range (116.7 – 409) mg/L with a mean value (217.54 ±123.99) mg/L. The present study was in good alignment with the study of Mahato et al. (2018), in which all the studied water samples had TDS values within the permissible limit of WHO and NDWQS. In the study of Adhikari et al. (2023), TDS values were reported in the range were reported in a range (137–1063) mg/L and (243-956) mg/L, respectively, which is higher than the present study. Low TDS values suggest limited mineral dissolution and low anthropogenic contamination. The variation among samples may be influenced by differences in soil composition and water–rock interaction processes (Xun et al., 2007).

Analysis of chemical parameters

The total hardness (TH) of water samples ranged from 7.4 mg/L to 350 mg/L, with a mean value of (199.75 ±128.57) mg/L. Mahato et al. (2018) reported the TH values of tube well water samples in a range (35.00–349.0) mg/L, in which the lower limit was higher than the present study; however, the upper limit was similar to the present study. In the present study, 50% of the water samples were moderately hard, 12.5% were hard, and 37.5% of the water samples were very hard according to the classification of hardness of water (WHO, 2011). This hardness is primarily attributed to the presence of calcium and magnesium ions, which are naturally released through weathering of carbonate and silicate minerals in aquifer rocks. Similar findings have been widely reported in groundwater systems where rock–water interaction dominates water chemistry (Thomas et al., 2015).

The mean value of calcium hardness in the tested water samples was (122.74 ± 83.76) mg/L, and all samples were within permissible limits of WHO and NDWQS, which aligned with the value of calcium hardness reported by Mahato et al (2018). The high value of hardness in water was reported in the previous studies by Ghimire et al. (2023) and Adhikari et al. (2023), which exceeded the present result. The high calcium hardness in water is due to a high concentration of Ca^{2+} ions in water from the dissolution of calcium-bearing minerals such as limestone and gypsum (Bhandari et al., 2021).

The mean concentration of nitrate (NO3–) in the water samples was (0.297 ± 0.326) mg/L, and all samples complied with drinking water standards of NDWQS and WHO. The maximum concentration of nitrate in groundwater samples reported by Mahato et al (2018) was higher than that in the present study. The study by Adhikari et al. (2023) and Ghimire et al. (2023) reported the high value of the nitrate in the groundwater samples, which were 24 mg/L and 6.58 mg/L, respectively. The high content of nitrogen in groundwater is mainly from the sewage, industrial waste, agricultural waste, as well as organic nitrogenous substances (Basi-Chipalu & Paudel, 2022). The low nitrate observed in the present study reveals that there is limited anthropogenic impact, including leaching of septic tanks in the groundwater of the studied school (Shakya et al., 2019).

In the present study, ammonia (NH_3) concentration was reported to range from (0.005–0.05) mg/L. The present study was in contradiction with the study of Mahato et al. (2018), in which 3.43% of water samples crossed the safe limit of NDWQS and WHO. Similarly, Adhikari et al. (2023) also reported 31% samples exceeding the NDWQS limit, indicating high ammonia in water samples. The study by Ghimire et al. (2023) was consistent with the present study, in which a low content of ammonia was reported in the water samples. The low ammonia concentration suggests minimal organic pollution and limited infiltration from sewage or waste decomposition (Kurwadkar, 2019). The high content of ammonia in groundwater causes unpleasant taste and odor as well as seriously affects aquatic life and human health (Bajracharya et al., 2022).

The chloride content of the water samples ranged from 2.00 to 42.98 mg/L, with a mean value of 20.74 ± 15.01 mg/L, and all samples were within safe limits. The Cl^- level in the present study was in alignment with the value reported by Adhikari et al. (2023) and Ghimire et al. (2023). The observed levels indicate limited salinity intrusion in the study area. However, high Cl^- content was reported in the previous studies (Ghimire et al., 2023; Mahato et al., 2018), which is due to the leakage of leachates, fertilizers, landfill, and industrial effluents (Sameer, 2011).

Fluoride (F^-) content in tested water samples was under the safe limit of NDWQS and WHO, which ranged from (0.47–1.06) mg/L. The fluoride reported in the present study was in good alignment with the study of Mahato et al. (2018). Fluoride levels in groundwater are controlled by geological composition, particularly fluorine-bearing minerals. The observed values suggest balanced geochemical conditions without risk of fluorosis (Ayoob & Gupta, 2006; WHO, 2004).

The total alkalinity (TA) of the water samples was in a range of 8.5-28.9 mg/L, which indicates the low buffering capacity of the water. Low alkalinity suggests limited carbonate content in the aquifer system, which may influence pH stability. Although no guideline value for alkalinity has been specified by NDWQS or WHO, high alkalinity may cause a bitter taste and high corrosive nature of water (WHO, 2011).

Table 2. Physicochemical and microbial parameters from different sampling sites under the present study

Water Quality Parameters	**Sampling sites**								**Mean ± SD**	**SEM**	***S-W Test (P value)**
	HSS-1	**HSS-2**	**HSS-3**	**HSS-4**	**HSS-5**	**HSS-6**	**HSS-7**	**HSS-8**			
pH	6.49	6.44	6.56	6.77	6.50	6.70	6.76	6.90	6.64 ± 0.165	0.058	.472
Temp	23.40	23.30	21.7	21.9	21.8	21.8	22.0	22.0	22.24 ± 0.695	0.246	.003
EC	233.4	349	161.3	274.9	579.2	314.3	750	818	435.01 ± 247.81	87.64	.200

Turbidity	0.76	1.17	0.09	0.09	1.65	2.28	0.73	0.12	0.861 ± 0.802	0.284	.250
Colour	8.29	9.72	2.10	4.95	5.98	4.26	9.13	6.08	6.31 ± 2.60	0.92	.791
TDS	116.7	174.5	80.66	137.4	289.5	157.1	375.5	409	217.54 ± 123.99	43.83	.198
Cl–	12	30	2.00	4	33.98	13	42.98	28	20.74 ± 15.01	5.31	.513
TA	28.9	34	18.7	15.3	17	8.5	10.2	15.3	18.49 ± 8.78	3.10	.283
TH	108	106	74	118	282	150	350	410	199.75 ± 128.57	45.47	.085
Calcium Hardness	90.18	52.1	54.11	70.14	154.3	70.14	216.42	274.54	122.74 ± 83.76	29.62	.058
NO3–	0.34	1.00	0.16	0.06	0.09	0.10	0.10	0.53	0.297 ± 0.326	0.115	.011
NH3	0.05	0.05	0.05	0.05	0.05	0.005	0.05	0.05	0.044 ± 0.016	0.006	.000
F–	0.47	0.61	0.58	1.03	1.06	0.87	0.76	0.99	0.796 ± 0.226	0.080	.416
Fe	0.05	1.40	0.05	0.42	0.05	0.05	0.12	0.05	0.27 ± 0.473	0.167	.000
Mn	0.20	0.48	0.09	0.15	1.49	1.49	0.092	0.14	0.52 ± 0.614	0.217	.002
As	0.005	0.005	0.005	0.005	0.1	0.005	0.05	0.005	0.023 ± 0.035	0.012	.000
Total Coliform	0	0	0	35	16	0	0	0	6.37 ± 12.85	4.54	.000
Fecal Coliform	0	0	0	0	0	0	0	0	0	0.00	.000

*Temp = Temperature, EC = Electrical Conductivity, Cl- = Chloride, TDS = Total Dissolved Solid, NO3- = Nitrate, NH3 = ammonia, F- = Fluoride, Fe = Iron, Mn= Manganese, As = Arsenic, TH = Total Hardness SEM = Standard Error of the Mean, *S-W Test = Shapiro-Wilk test*

Analysis of heavy metals

In the present study, arsenic (As) was in a range of (0.005 – 0.1) mg/L, with a mean value of 0.023 ± 0.035 mg/L, with one sample exceeding the permissible limit, whereas 87.5% of the examined water samples contained arsenic within the safe limit for consumption. The mean value of As in groundwater samples was reported as 0.013 mg/L and 0.005 mg/L in earlier studies (Mahato et al., 2018; Shrestha et al., 2016), which was lower than the present study. The principal source of contamination of arsenic in water samples is due to the release of arsenic-containing rocks and soil erosion into water sources, as well as different anthropogenic causes like mining, industrial effluents, pesticides, burning of fossil fuels, etc. (Patel et al., 2023). The presence of arsenic above safe limits in one location highlights potential health risks and spatial variability in groundwater quality.

The mean concentration of iron (Fe) in tube-well samples from the higher secondary schools was 0.27 ± 0.473 mg/L, with values ranging from 0.05 to 1.4 mg/L. Two samples (25%) exceeded the NDWQS and WHO threshold limits under the present study surpassed the threshold limit of NDWQS and WHO. Higher concentrations of iron were reported in the study of Adhikari et al (2023), Ghimire et al (2023), and Kandel et al (2025), in which 33 %, 31 %, and 77% of water samples surpassed the NDWQS threshold limit. The main leading factor for increasing the content of iron in water samples is the weathering of iron-bearing minerals and rocks, industrial waste, mining, and metal corrosion (Basi-Chipalu & Paudel, 2022; Samantara et al., 2017). The occurrence of iron contamination in some samples suggests localized geochemical conditions favoring iron mobilization.

The concentration of manganese (Mn) in the tested tube well samples ranged from (0.09 – 1.49) mg/L, with a mean value (0.52 ± 0.614) mg/L, with 62.5% contained Mn concentrations above the NDWQS and WHO permissible limits, which aligns with the previous literature (Mahato et al., 2018; Shrestha et al., 2016)· Elevated manganese is typically associated with reducing groundwater conditions and leaching from soil and rock matrices (Adhikari et al., 2023; Kandel et al., 2025). The high exceedance rate suggests that manganese contamination is a significant concern in the study area.

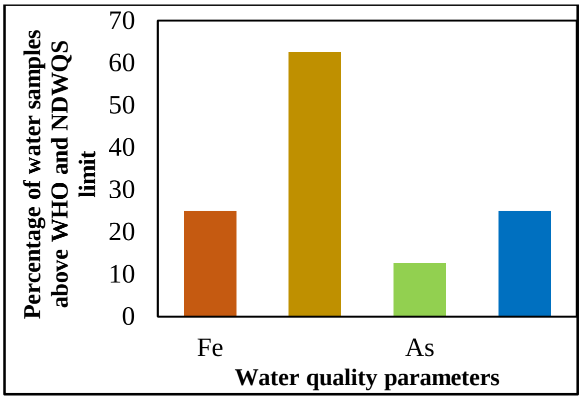


Figure 2. Water samples above the NDWQS and the WHO limit

Microbial analysis

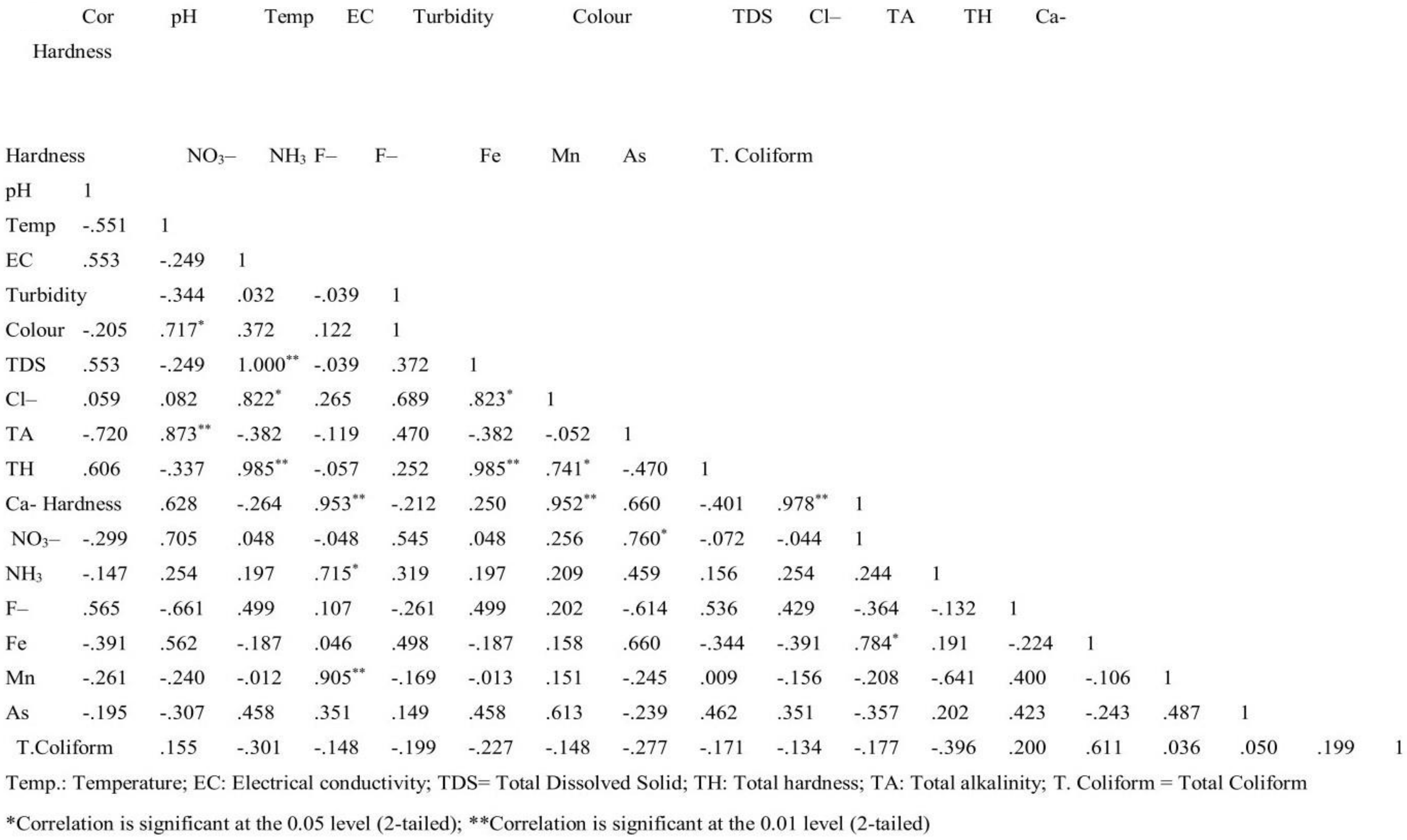
In the tested tube-well water samples, total coliform ranged from 0 to 35 CFU/100 mL. The water samples from schools HSS-4 and HSS-5 were highly contaminated with total coliform, indicating 25% water samples were contaminated with total coliform, as shown in Figure 2. (Bajracharya et al., 2022) reported 44.3% water samples with total coliform and 12.69% of samples with fecal coliform, which was in contrast with the present study, where none of the studied water samples had fecal coliform. Similarly, Adhikari et al. (2023) reported 22.9% water samples from tube wells to be contaminated with fecal coliform, with 42.9 % with total coliform. In the studies of Inoue et al. (2015), Bhandari et al. (2021), and Sarkar et al. (2022), total coliform, fecal coliform, and other pathogenic bacteria and viruses were observed in the groundwater of the Kathmandu Valley. The total coliform in groundwater samples is mainly from contamination from seepage through infiltration of contaminated sewage and agricultural waste (WHO, 2011).

Correlation analysis

The association of different water quality parameters was determined using the Pearson correlation coefficient (r) (Table 3). The strong significant positive correlation was obtained at 5% significance between color and temperature (r = 0.717), EC and Cl^- (r = 0.822), Cl^- and TDS (r = 0.823), TH and Cl^-(r = 0.741), NH_3 and turbidity (r = 0.715), Fe and NO_3^- (r = 0.784). Similarly, strong positive correlation at 1% significance is observed for TDS and EC (r = 1.00), Temperature and TA (r = 0.873), TH and EC (r = 0.985), TH and TDS (r = 0.985), EC and Ca- Hardness (r = 0.953), Ca- Hardness and TDS (r = 0.952), TH and Ca- Hardness (r = 0.978), Mn and Turbidity (r = 0.905). The correlation analysis between the water quality parameters in the present study is in good agreement with the previous studies (Ganiyu, 2017; Manyal et al., 2025; Sameer, 2011; Shrestha et al., 2016). The strong correlation between temperature and color is due to the fact that an increase in temperature increases the decomposition of organic materials as well as the growth of microorganisms, which release pigment and give a yellow tint to water. In the study of Bajracharya et al. (2022), ammonia was positively correlated with turbidity in alignment with the present study. The EC, as well as TDS, exhibited significant positive correlation, which is consistent with previous literature (Adhikari et al., 2023; Basi-Chipalu & Paudel, 2022; Kandel et al., 2025), as EC depends on the dissolved ions present in water, EC increases with the increase in TDS, and is positively correlated(Ganiyu, 2017). Total hardness is due to Ca^{2+}, $Mg^{2+,}$ and Cl^- ions; however, calcium hardness is contributed mainly by Ca^{2+} ions. On increasing hardness, concentration of ions Ca^{2+} and Cl^- also increases, which increases EC as well as TDS (Nnorom et al., 2019). The significant positive correlation between Fe and NO_3^- reveals a common source of origin of iron and nitrate, such as anthropogenic sources like agricultural run-off of fertilizers, sewage, or industrial waste. Mn oxides to solid MnO_2, which increases suspended particles in water; as a result, the turbidity of water increases. Similarly, an increase in suspended organic particles increases turbidity, which gives rise to an increase in ammonia concentration. The positive correlation between ammonia and Turbidity also indicates that both parameters are influenced by similar sources of contamination (Manyal et al., 2025).

Strong correlations observed among certain water quality parameters, such as electrical conductivity with total dissolved solids, indicate co-variation across sampling sites. These relationships highlight patterns in how environmental and anthropogenic factors may influence multiple water quality parameters simultaneously. However, it is important to emphasize that correlation does not imply causation. Observed associations suggest potential links but do not establish direct cause-and-effect relationships. These patterns should therefore be interpreted as indicative of co-occurring trends rather than definitive mechanistic relationships, and further targeted studies are needed to confirm causal pathways.

Table 3. Correlation matrix among different water quality parameters from different sampling sites.



Cor pH Temp EC Turbidity Colour TDS Cl– TA TH Ca-
Hardness

Hardness NO_3– NH_3 F– F– Fe Mn As T. Coliform

pH	1																	
Temp	-.551	1																
EC	.553	-.249	1															
Turbidity		-.344	.032	-.039	1													
Colour	-.205	.717*	.372	.122	1													
TDS	.553	-.249	1.000**	-.039	.372	1												
Cl–	.059	.082	.822*	.265	.689	.823*	1											
TA	-.720	.873**	-.382	-.119	.470	-.382	-.052	1										
TH	.606	-.337	.985**	-.057	.252	.985**	.741*	-.470	1									
Ca- Hardness		.628	-.264	.953**	-.212	.250	.952**	.660	-.401	.978**	1							
NO_3–	-.299	.705	.048	-.048	.545	.048	.256	.760*	-.072	-.044	1							
NH_3	-.147	.254	.197	.715*	.319	.197	.209	.459	.156	.254	.244	1						
F–	.565	-.661	.499	.107	-.261	.499	.202	-.614	.536	.429	-.364	-.132	1					
Fe	-.391	.562	-.187	.046	.498	-.187	.158	.660	-.344	-.391	.784*	.191	-.224	1				
Mn	-.261	-.240	-.012	.905**	-.169	-.013	.151	-.245	.009	-.156	-.208	-.641	.400	-.106	1			
As	-.195	-.307	.458	.351	.149	.458	.613	-.239	.462	.351	-.357	.202	.423	-.243	.487	1		
T.Coliform		.155	-.301	-.148	-.199	-.227	-.148	-.277	-.171	-.134	-.177	-.396	.200	.611	.036	.050	.199	1

Temp.: Temperature; EC: Electrical conductivity; TDS= Total Dissolved Solid; TH: Total hardness; TA: Total alkalinity; T. Coliform = Total Coliform

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Water quality assessment

The water quality was assessed from the mean values (Ci) of the selected physicochemical parameters. The calculated weight (wi), relative weight (Wi), and quality rating (qi) for each parameter used in the determination of the Water Quality Index (WQI) are presented in Table 4.

Table 4. Weight (wi), relative weight (Wi), and quality rating (qi) of selected parameters used for the calculation of the Water Quality Index (WQI) of the studied water samples

Parameters	NDWQS, 2022 standard (Si)	Mean Concentration (Ci)	Weight (wi)	Wi	qi	Wiqi
pH	8.5	6.64	1	0.05	78.12	3.906
EC	1500	435.01	1	0.05	29.00	1.450
Turbidity	5	0.861	1	0.05	17.22	0.861
Colour	5	6.31	4	0.2	126.2	25.24
TDS	1000	217.54	1	0.05	21.754	1.088
Cl-	250	20.74	1	0.05	8.296	0.415
TH	500	199.75	1	0.05	39.95	1.997
NO3–	50	0.297	1	0.05	0.594	0.03
NH3	1.5	0.044	1	0.05	29.33	1.466
F–	1.5	0.796	1	0.05	53.07	2.65
Fe	0.3	0.27	2	0.1	90.00	9.00
Mn	0.2	0.52	2	0.1	260.00	26.00
As	0.05	0.023	1	0.05	46.00	2.30
			$\sum$wi =18			WQI = $\sum$Wi qi = 76.4

The WQI value for the groundwater samples in Ramdhuni Municipality was observed as 76.4, which belonged to group B under the good category within the range of (50.1 – 100) according to the classification based on WQI values (Raychaudhuri et al., 2014). The WQI values in the present finding were in alignment with the previous studies in which the quality of ground water samples in accordance with WQI values was reported as excellent to good category (Ram et al., 2021). The WQI of dug well water in the study area was found to be 59.74, classifying it as good water quality (WQI: 50-100; Table 1), thereby placing it in grade B. The dug well water classified as grade B quality is appropriate for agricultural, commercial, and domestic uses, but not for consumption. Shrestha et al (2023) found the WQI index ranging from 5 to 581. Similarly, Adhikari et al (2023) reported low water quality in dug wells (WQI =124.8) while examining water samples from certain squatter settlements along the Bagmati River corridors in Kathmandu. Moreover, Mandal et al. (2023) indicated that the majority of well water samples from Bhaktapur municipality were unsuitable for drinking based on the WQI. Poor groundwater quality may be linked to anthropogenic activities such as excessive use of chemical fertilizers and groundwater, agricultural runoff, sewage system and septic tank leakages, inadequate cleanliness of groundwater sources and nearby areas, organic matter effluent, etc. (Thakur et al., 2015).

This study has several limitations, including a small sample size and single-season assessment. However, the results from the current study have significant implications for maintaining good health and water safety in schools. The quality of water affects the health of children. Though most of the physicochemical parameters are within the standards of WHO and NDWQS, microbial contamination was observed in some water samples, indicating a risk of waterborne diseases. Similarly, iron and manganese exceeded the safe limit. The calculated WQI indicated the water should not be used for drinking purposes; hence, regular monitoring, routine analysis, treatment of water, and safe water management techniques are highly recommended in schools. Similarly, national water quality standards and WASH (Water, Sanitation, and Hygiene) guidelines should be strictly implemented to ensure safe drinking water and maintain the good health of school communities.

CONCLUSION

The water quality of tube wells used for drinking in government higher secondary schools in Ramdhuni Municipality, Sunsari, was evaluated. Most physicochemical parameters were within the permissible limits of NDWQS and WHO; however, elevated concentrations of Fe, Mn, and as were detected, posing potential health risks. Microbial analysis further revealed the presence of total coliforms, indicating that the water is unsafe for direct consumption. Although the Water Quality Index (WQI) classified the samples as “good,” the coexistence of heavy metals and microbial contamination raises significant concerns regarding water safety. Despite limitations such as a small sample size, single-season sampling, and limited microbial assessment, this study provides valuable baseline information on groundwater quality in school settings. To improve water safety, it is recommended that local authorities and school management implement regular multi-seasonal monitoring, install appropriate treatment systems such as iron removal and disinfection units, and conduct routine microbial testing alongside improved sanitation practices. These measures will help ensure safe drinking water and support progress toward Sustainable Development Goal 6 (Clean Water and Sanitation), while further comprehensive studies are needed to better understand seasonal variations and contamination sources.

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AUTHORS CONTRIBUTION

Conceptualization: HS, AB; Methodology: HS, JM, SKS; Validation: AB; Investigation: HS, JM; Data analysis: HS, JM, SKS; Writing-original draft: SKS; Writing-review & editing: HS, JM, SKS, AB; Supervision: AB

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

ETHICAL STATEMENT

There was no ethical approval needed for this work. However, verbal consent of the Principal of the respective schools was taken so far.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

SUPPLEMENTARY INFORMATION

None

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