

Research Paper

Water quality status of groundwater and municipal water supply (tap water) from Bagmati river basin in Kathmandu valley, Nepal

Pabitra Bhandari, Megha Raj Banjara, Anjana Singh, Samikshya Kandel, Deepa Shree Rawal and Bhoj Raj Pant

ABSTRACT

Poor waste management in the Kathmandu valley has deteriorated the water quality of surface and groundwater sources. The objective of this study was to assess the status of water quality (WQ) in drinking water sources of groundwater and municipal supply (tap water) from the Bagmati river basin in Kathmandu valley. A total of 52 water samples from deep tube-well, tube-well, dug-well, and tap water were collected and analyzed for physical, chemical, and microbiological parameters using standard methods. The results revealed that chloride, total hardness (TH), copper, nitrate, sulfate, and turbidity were within the recommendations of the National Drinking Water Quality Standard (NDWQS). Total coliform (TC) bacteria in 84.6% of the samples exceeded drinking water guidelines. Similarly, the isolates of different enteric bacteria, namely *Escherichia coli* (21.5%), *Citrobacter* spp. (20.9%), *Klebsiella* spp. (19.8%), *Proteus* spp. (13.9%), *Enterobacter* spp. (8.72%), *Salmonella* spp. (5.8%), *Shigella* spp. (5.2%), and *Pseudomonas* (4.1%) were identified in the samples collected from the respective sources. Out of the 52 water samples, 7.7% of samples had fecal contamination of somatic coliphage. The groundwater and municipal water supply in the study area are not safe for drinking purposes. Treatment of water is required before its use for household applications.

Key words | coliphage, fecal pollution, microbial, total coliform, water contamination

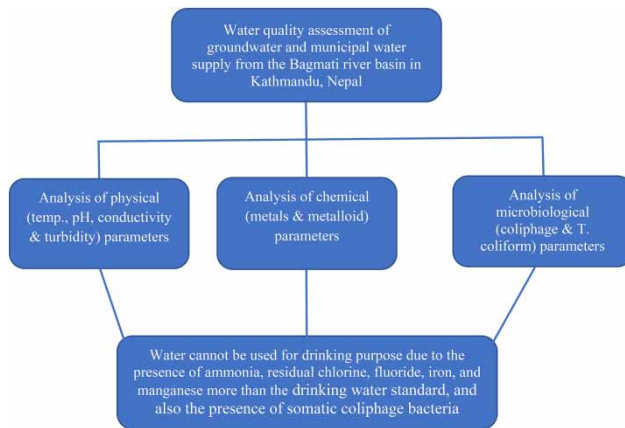
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GRAPHICAL ABSTRACT



INTRODUCTION

Water quality of the Bagmati river in the Kathmandu valley has swiftly deteriorated due to the discharge of untreated wastewater in the river and disposal of municipal solid waste in the open fields near the river bank (Regmi 2013). The state of the river and its tributaries are in degraded condition owing to indigent water quality. Such situations can negatively affect the groundwater quality along the riverside and can contaminate soil and air quality. This can consequently affect the availability of safe drinking water as groundwaters are largely been used for drinking purposes (Gurung *et al.* 2017).

The diarrheal disease remains a leading cause of illness and death in the developing world, which alone causes 2.2 million of the 3.4 million water-related deaths per year. About 90% of these deaths involve children less than 5 years of age. In the fiscal year 2015/2016, a total of 1,248,093 diarrheal cases among 2–59 months children were reported in Nepal, of which 0.2% suffered from severe dehydration (MoHP 2017). The World Health Organization (WHO) has estimated that about 80% of the waterborne diseases are due to inadequate sanitation and lack of safe drinking water. Unsafe drinking water is responsible for a large number of diseases, such as typhoid, cholera, dysentery, hepatitis, protozoan, and helminthic infections.

Organic matter has a direct relationship with coliform contamination in water (Seo *et al.* 2019). Coliform bacteria are considered an important water quality indicator related to human health (Seo *et al.* 2019). Fecal indicator organisms have largely been used as a measurement of drinking water quality as it is not feasible to test water for all known waterborne pathogens to assess its safety (Tallon *et al.* 2005). The WHO guidelines recommend *Escherichia coli* and/or thermotolerant fecal coliforms as indicator organisms for the potential presence of fecal contamination and waterborne pathogens (Tallon *et al.* 2005). However, bacteriophages that infect *E. coli*, *Enterococcus*, and various *Bacteroides* spp. are also considered as possible indicators of fecal contamination (WHO 2013). The most common indicator for fecal contamination is male-specific coliphage such as *E. coli* with an RNA genome or F+ RNA. These viruses fit with the criteria for an ideal indicator of microorganisms. The etiological study of waterborne diseases reveals that common agents are more likely to be viruses and parasitic protozoa than bacteria (Jofre *et al.* 2016).

The objective of this research was to assess the status of water quality (WQ) in drinking water sources of groundwaters and tap water from the Bagmati river basin in Kathmandu valley.

METHODS

Study area

The study area covers the Bagmati river corridor from Gothatar in the East to the Gaurighat in the West in the Kathmandu district of Kathmandu valley (Figure 1). The Kathmandu valley contains three major cities: Kathmandu, Lalitpur, and Bhaktapur, located in the midland of the Himalayas, lies in between 27°32' and 27°49' North and 85°12' and 85°32' East is almost round in shape with a diameter of approximately 30 km E–W and 25 km N–S (Dill et al. 2001). The valley has a central flat part at an elevation of 1,300–1,400 m above mean sea level and covers an area ~900 km² (Sharma 1997) with an average population density of 2,800 persons per km² (CBS 2017).

Sample collection

A total of 52 water samples in triplicates were randomly collected from the deep tube-well (>30 m depth, 31 samples), tube-well (11–30 m depth, 12 samples), dug-well (3–11 m depth, 7 samples), and tap water (municipal supply, 2 samples) in between July and September 2017, during the

rainy season. The sampling sites are located approximately 100 m to the north of the Bagmati river basin in the Kathmandu district. The deep tube-well, tube-well, and dug-well are the prime sources of water supply in Kathmandu valley. Of the groundwater sources, deep tube-well and tube-well are closed, except for an outlet at the top of the ground. But, in the dug-well, the opening is covered by a lid to avoid the entry of dirt. On the other hand, tap water is considered safe for household applications because the water is distributed only after treatment. However, the purity of the water is questioned due to the old pipes used in the water distribution system and the leakage from those pipes.

During the sample, collection samples were stored in a portable icebox and transported to the laboratory within 6 h and stored at ~4 °C in a refrigerator until physical, chemical, and microbiological analyses were carried out. The sample size was estimated according to the following equation:

$$N = \frac{(Z_{\alpha})^2 p(1-p)}{e^2} = \frac{(1.96)^2 \times 0.165 \times 0.835}{0.01^2} = 52.92$$

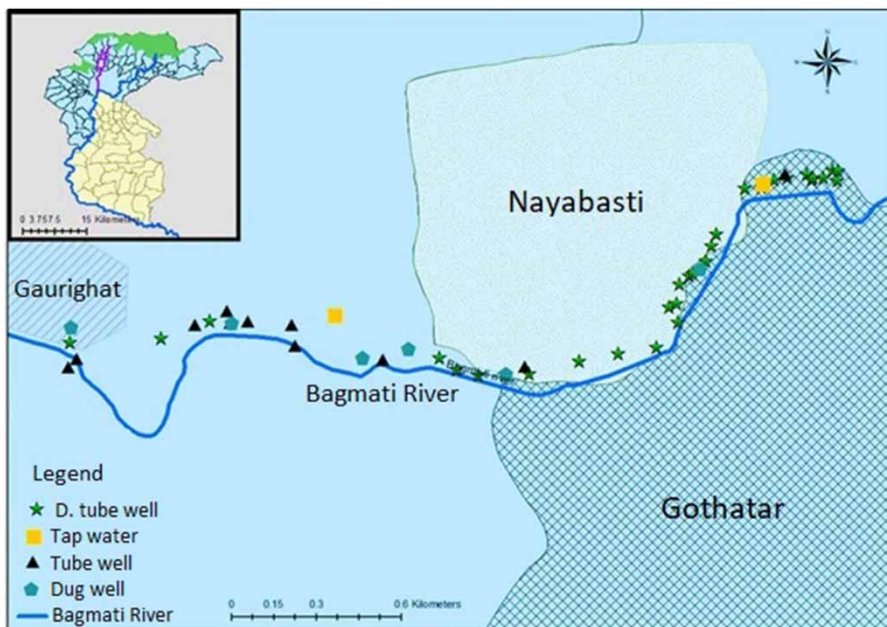


Figure 1 | Location of sampling sites in the Bagmati river basin of Kathmandu valley.

where N is the sample size, Z_{α} represents confidence interval (95%), p is the prevalence of waterborne diseases, and e indicates an allowable error.

The samples were collected according to the standard method (Greenberg *et al.* 2005). Samples to be analyzed for the microbiological parameter (Somatic coliphage and coliform) were collected in polyethylene bottles that were thoroughly cleaned by distilled water and sterilized in an autoclave at 121 °C and 15 LB pressure for 15 min. Samples for the analysis of chemical parameters (hardness, chloride, alkalinity, fluoride, iron, manganese, cadmium, chromium, lead, copper, zinc, and arsenic) were collected in polyethylene bottles cleaned by distilled water for several times. Before collecting the sample, the sample bottles were purged at least three times by the water to be collected from respective sources. A dip sampler was used in sample collection from the shallow wells, while the samples from the tube-well and deep tube-well were collected either by pumping through a hand pump or by using the electric motor. The sampling sites and the number of samples collected from different places are illustrated in Figure 1.

Sample analysis

Physical parameters were analyzed for pH, temperature (°C), turbidity (NTU), and Electrical Conductivity-EC ($\mu\text{S}/\text{cm}$). The pH was measured by using a digital pH meter (TOA HM-10P). The turbidity and EC were measured using the nephelometer (ELICO, India) and conductivity meter (WTW LF91), respectively.

Chemical parameters were analyzed for chloride, free residual chlorine, total hardness (TH), copper, arsenic, manganese, zinc, iron, ammonia nitrate, fluoride, and sulfate. The TH, chloride, and residual chlorine were determined volumetrically. Fluoride was measured by the SPADNS method using acid zirconyl SPADNS reagent. The nitrate, ammonia, and sulfate were determined using spectrophotometry. Metal ions, such as iron, manganese, cadmium, chromium, lead, copper, zinc, and arsenic, were analyzed in an atomic absorption spectrometer (Agilent Technologies, 240 FS). The chemical and solvents used in the analysis were of analytical grade (Fluka chemicals and reagents) and purchased from local suppliers in the Kathmandu valley.

Microbiological analysis was carried out for the enumeration of TC and fecal coliform using the standard method (Greenberg *et al.* 2005). The presence of enteric bacteria and coliphage bacteria were identified using the biochemical testing method. The samples were enriched in the selenite F-broth, followed by culture on Xylose Lysine Deoxycholate (XLD) agar to detect the *Salmonella* and *Shigella* spp. Similarly, the *Vibrio cholerae* was enriched in alkaline peptone water and cultured on TCBS agar. The isolates were further grown on nutrient agar to separate the pure colonies. Bacterial isolates were identified according to culture, morphology, and biochemical tests. The coliphage bacteria were isolated using a double-layer agar assay as described by Greenberg *et al.* (2005).

The statistical analysis of the data was carried out using Microsoft Excel 2010.

RESULTS AND DISCUSSION

Kathmandu valley is densely populated, and limited municipal water supply cannot fulfill the large demand for water. Most of the people in the valley depend on groundwater to fulfill their daily requirements; hence, groundwater is considered a crucial source of water for domestic and other applications.

The water temperatures vary widely between the sites and this variation in water temperature can be caused due to the variation in the weather at the time of sample collection (Table 1).

There are no standard guidelines for water temperature and the impact associated with public health. However, the temperature facilitates the growth of microorganisms in water and alters its quality (WHO 2013). The Canadian drinking water guidelines have recommended a maximum drinking water temperature of 15 °C (HC 2019). The average range of pH was 6.38–6.9 in the respective samples. The minimum pH of groundwater (deep tube-well, tube-well, and dug-well) was acidic and measured in the range of 6.0–6.1 pH. Nevertheless, the pH of tap water was within the recommendations of NDWQS. The variation in drinking water pH from normal pH (pH 6.8–8.5) to acidic (<7.0 pH) or alkaline pH (pH > 7.0) can affect public

Table 1 | Water quality status based on physical parameters

Parameter	Deep tube-well (31)			Tube-well (12)			Dug-well (07)			Tap water (02)			NDWQS
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	
Temperature (°C)	11.1	26.8	15.9	12.2	26.9	21.8	15.0	27.6	21.9	11.2	26.7	18.9	NA
pH	6.1	7.7	6.46	6.0	6.8	6.38	6.1	6.7	6.45	6.8	7.1	6.9	6.5–8.5
EC (µs/cm)	57.3	1,012.3	304.5	206.3	518.6	333.1	224.6	433.0	348.4	43.6	48.0	45.8	1,500
Turbidity (NTU)	0.78	320.6	34.9	6.57	120.6	24.97	0.78	22.7	40.6	8.07	26.7	17.4	5

NDWQS: National Drinking Water Quality Standard; NA: Not Available.

health. Out of the 52 water samples, 46.15% of samples comply with the NDWQS guideline.

The EC ranged from 43.6 to 1,012.3 µS/cm and the conductivity of the tested water complies with the NDWQS guidelines (Table 1). In general, groundwater tends to have high EC due to the presence of metallic ions and dissolved salts (Prakash & Somashekar 2006). Our findings also reveal that higher EC levels are higher in groundwaters than in tap water as tap water is treated before distribution. The turbidity in water showed a remarkable variation and ranged from 0.78 to 320.6 NTU. Out of 52 samples, 75% of samples have turbidity value above the NDWQS, and 25% of samples were within the guideline. The turbidity in water may be due to the mixing of suspended materials, colloidal particles, clay particles, asbestos minerals, leaching of organic matters, and domestic wastes from different sources. Besides, manuring activities and agricultural run-off also contribute to turbidity in water (Prakash & Somashekar 2006). The turbidity is an indicator of pollution in water.

Chemical parameters were analyzed to determine chloride, ammonia, nitrate, sulfate, TH, residual chlorine, fluoride, iron, copper, zinc, manganese, and arsenic (Tables 2 and 3). Of these parameters, the maximum values of chloride, TH, copper, nitrate, and sulfate, agreed with the standard guidelines. Residual chlorine and fluoride concentration exceeded the NDWQS values in deep tube-well, tube-well, dug-well, and tap water (Table 2). Whereas the ammonia was beyond the drinking water standard in deep tube-well, tube-well, and dug-well. The chloride, residual chlorine, and hardness are naturally present in the water sources. While nitrate is available from human and animal waste, industrial effluents, fertilizer, and chemicals applied in the agricultural fields, seeping and silage of drainage system.

The chloride concentration ranged between 3.8 and 76.82 mg/L, which was significantly lower than the maximum acceptable limit of 250 mg/L recommended by NDWQS (NDWQS 2005). Chloride is available in water sources due to agricultural activities, unprotected sewage systems, and also from natural sources. The health impact of chloride so far has not been reported. However, the chloride and sodium ions in water can interact with each other and form sodium chloride, which could impart a salty taste to water.

Table 2 | Water quality status based on chemical parameters

Parameter	Deep tube-well (31)			Tube-well (12)			Dug-well (07)			Tap water (02)			NDWQS
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	
Chloride (mg/L)	3.8	60.3	27.0	29.3	53.5	42.1	28.4	76.82	32.0	4.7	10.2	7.5	250
Ammonia (mg/L)	0.0	14.0	1.9	0.2	7.0	2.6	0.2	3.0	2.2	0.2	0.6	0.4	1.5
Nitrate (mg/L)	0.03	1.9	0.3	0.3	4.6	0.7	0.2	2.8	0.8	0.2	0.2	0.2	50
Sulfate (mg/L)	0.5	3.5	1.4	0.3	2.6	1.2	0.5	2.9	2.5	0.9	1.5	1.2	250
Total hardness (mg/L)	48.6	240.0	120.8	88.0	254.6	158.4	78.0	239.3	149.8	20.0	41.3	30.6	500
Res chlorine (mg/L)	0.0	18.8	1.5	0.0	13.0	4.44	0.0	6.5	2.3	0.0	1.8	0.89	0.2
Fluoride (mg/L)	0.15	7.8	2.4	0.8	9.2	2.3	1.1	5.3	2.5	1.3	2.6	1.9	1.5

NDWQS, National Drinking Water Quality Standard.

Table 3 | Status of metal and metalloid in the water sample

Parameter	Deep tube-well (31)			Tube-well (12)			Dug-well (07)			Tap water (02)			NDWQS
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	
Iron (mg/L)	0.18	3.88	2.32	0.16	3.78	2.11	1.95	4.56	2.89	0.01	3.8	1.91	0.3
Copper (mg/L)	0.01	0.29	0.16	0.07	0.2	0.16	0.05	0.18	0.08	0.18	0.29	0.34	1.0
Zinc (mg/L)	0.01	0.13	0.03	0.01	0.13	0.03	0.01	0.02	0.02	0.03	0.11	0.07	3.0
Manganese (mg/L)	0.01	0.94	0.11	0.01	0.16	0.04	0.01	0.15	0.03	0.01	0.41	0.21	0.2
Arsenic (mg/L)	0.01	0.07	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.05

NDWQS, National Drinking Water Quality Standard.

The average value of ammonia in deep tube-well, tube-well, dug-well, and tap water ranged from 0.4 to 2.6 mg/L, and 50% of samples were within the guideline value recommended by NDWQS (1.5 mg/L). The presence of ammonia in water is due to the heavy use of fertilizers in the agricultural fields, the presence of bacteria, and the sewage infiltration to the groundwater table through soil pores (Ganesh *et al.* 2018). Ammonia has a toxic effect on humans only if the intake becomes higher than the detoxification capacity of the body (NHMRC 2018).

The average concentration of nitrate in the samples collected from deep tube-well, tube-well, dug-well, and tap water ranged from 0.2 to 0.8 mg/L. The value of nitrate was within the permissible limit of 50 mg/L, as recommended by the NDWQS. Nitrate is found naturally in groundwaters, but the increased level of nitrate in water is due to fertilizer application in the field, animal farming, percolation from the septic tank, and wastewater discharges in the open field.

Sulfate in the water sample was within a range of 0.3–3.5 mg/L. These values comply with the NDWQS guideline (250 mg/L). Sulfate is accessed to the groundwater mostly due to natural phenomena under the Earth's crust (Prakash & Somashekar 2006) and also as an anthropogenic activity, such as discharge of untreated industrial effluent in the open places and poor management of municipal garbage.

The hardness in the water varied from 20 to 254.6 mg/L. These values are within the recommendations of NDWQS (500 mg/L). Hard water is not considered harmful for public health, but it can cause problems in industrial applications, such as laundering and water circulation pipes in the boilers. The TH in water is due to the presence of metallic ions, particularly the bicarbonates of calcium and magnesium ions (Annapoorna & Janardhana 2015).

Free residual chlorine formation in water is pH-dependent (Pal 2017). The hypochlorous acid, a major component of residual chlorine is formed when chlorine reacts with water at a pH ranged between 5 and 10 pH. Within this pH, the chlorine exists as hypochlorous acid and hypochlorite. The variation in the pH dissociates these products into separate components, resulting in the reduction of water disinfection efficiency. Similarly, the chemical reaction between chlorine with organic matter, inorganic substances, and microorganisms present in water

can also produce the reaction byproducts, which are hazardous to public health. In this study, the average free residual chlorine in the water ranged from 0.89 to 4.44 mg/L, and 84.6% of samples were within the range specified in the NDWQS, but 15.4% of samples exceeded the guideline value for residual chlorine. The amount of residual chlorine in tap water is comparatively less than in groundwaters. The reason for low residual chlorine in tap water may be due to pre-treatment of water before distribution. The fluoride in the water sample was between 0.15 and 9.2 mg/L, and 59.62% of samples were above the drinking water standard value for fluoride, and 40.38% of samples comply with the guidelines for drinking water quality. Fluoride is an essential mineral of public health concern. The use of the water containing the maximum concentration of fluoride is susceptible to dental fluorosis and bone demineralization (Burlakoti *et al.* 2020).

The estimated range of maximum iron level was between 3.8 and 4.56 mg/L in deep tube-well, tube-well, dug-well, and tap water (Table 3).

The average concentration of iron in the water (1.91–2.89 mg/L) exceeded the maximum limit as recommended by the NDWQS. Iron is an essential mineral required in the recommended amount by living organisms (Crichton 1991). However, excess iron intake causes toxicological problems of acute exposure and chronic iron overload. Ingestion of iron in exceeding amount (>0.5 g) can cause liver, heart, and lung diseases, as well as diabetes mellitus, hormonal abnormalities, and dysfunctional immune system (Gurzau *et al.* 2003). Similarly, the maximum concentration of iron makes the water esthetically unacceptable due to discoloration, metallic taste, metallic odor, turbidity, staining of laundry, and plumbing fixtures (Kontari 1998). Our finding shows that iron is rich in the groundwater and tap water sources available in the Bagmati river basin in Kathmandu valley, indicating that the groundwater is rich in iron-bearing minerals. Iron is accessed to water by natural sources due to the demineralization of iron-bearing ores under the Earth's crust and as a result of anthropogenic activities. A similar work carried out for the estimation of iron in the groundwater of Kathmandu valley supports our findings as the study demonstrated that iron level was 5.2, 4.9, and 5.5 mg/L in deep tube-well, tube-well, and shallow well, respectively (Pant 2011).

The concentration of copper and zinc in the water samples comply with the NDWQS values of 1.0 and 3.0 mg/L, respectively (Table 3). Our results on copper and zinc concentration are as per the findings of Shradha et al. (2018) and Raut et al. (2015), respectively. But the concentration of manganese exceeded the drinking water guidelines for deep tube-well and tap water (Table 3). For tube-well and dug-well, the metal ion is within the recommendations of NDWQS values (0.2 mg/L). Similarly, arsenic levels in water sources other than deep tube-wells follow the drinking water standard (0.05 mg/mL). In deep tube-wells, arsenic was detected to 0.07 mg/mL. These results indicate that the source of manganese near to the aquifers of tube-well and dug-well are absent. The maximum concentration of metal ion present in deep tube-well and tap water may be due to the availability of the manganese in deep sources. Similarly, the result also suggests that arsenic is present in the deep groundwater table of the Bagmati river basin.

The coliform was present in all the water samples tested (Table 4), and these values exceed the drinking water guideline recommended by NDWQS (0 CFU/mL).

The thermotolerant coliform was positive in 67.3% of samples (Table 4). Of these isolates, *E. coli* was maximum in the deep tube-well. Our findings for the presence of *E. coli* in groundwater source is as per the results of Kolawole et al. (2013), where >95% thermotolerant *E. coli* isolated in the groundwaters. This is an indication of fecal contamination in water and can be a source of pathogenic viruses, protozoa, and helminths. The presence of *E. coli* in drinking water indicates the risk of intestinal disease-causing pathogens (Obire et al. 2007). We have detected the viruses only in *E. coli* positive samples, confirming that the *E. coli* may

be an indicator of pathogenic contamination in groundwaters. Our findings have been supported by Haramoto et al. (2011), who has studied the prevalence of protozoa, viruses, and coliphages in water samples.

The enteric bacteria isolated from the groundwater samples comprise 21.51% *E. coli* spp., 20.93% *Citrobacter* spp., 19.77% *Klebsiella* spp., 13.95% *Proteus* spp., 8.72% *Enterobacter* spp., 5.81% *Salmonella* spp., 5.23% *Shigella* spp., and 4.07% *P. aeruginosa*. Our findings on bacterial isolate comply with the results of Halage et al. (2015). Out of the 52 water samples, 7.7% of samples were fecal contaminated by somatic coliphage. Meanwhile, none of the water samples showed positive with F-RNA coliphage and male-specific coliphage. The presence of somatic or F-RNA coliphage indicates fecal contamination in water. Nevertheless, it is difficult to point out the source of contamination, whether it is due to human or animal feces.

Our results on chemical analysis across four groundwater types generally exhibit that deep tube-well, tube-well, and dug-well waters have a higher level of chemicals like residual chlorine, fluoride, ammonia, iron, and arsenic in some of the samples (deep tube-well). Exceeding the standard specified by NDWQS for such chemicals in water that are used for drinking purposes may pose different types of health risk. Similarly, for microbiological analysis, the highest number of coliphage were present again in the water of deep tube-well, tube-well, and dug-well. Thus, the study demonstrates that considering the analysis of chemical and microbiological parameters, water from all three groundwater sources is hazardous compared with the tap water source.

CONCLUSIONS

The study suggests that the water from the sources cannot be used for drinking purposes due to the presence of ammonia, residual chlorine, fluoride, iron, and manganese that exceeded the recommendations of NDWQS, and also the existence of somatic coliphage bacteria. We recommend incorporating a suitable scientific method for water treatment to make the water potable. In general, groundwaters are contaminated due to the practices like untreated disposal of solid waste and waste waters. Disposal of wastewater and solid wastes in the open field can be seen

Table 4 | Microbiological analysis

Parameter	Deep tube-well (31)	Tube-well (12)	Dug-well (7)	Tap water (2)	NDWQS
Somatic coliphage (PFU/mL)	1.0	2.0	1.0	0.0	NA
Male-specific coliphage (PFU/mL)	0.0	0.0	0.0	0.0	NA
Total coliform (CFU/mL)	22.0	6.0	5.0	2.0	0

NDWQS, National Drinking Water Quality Standard; NA, Not Available.

in most of the places in the study area, which can leach to groundwater sources by contaminating the water. Therefore, to protect the groundwaters from bacterial contamination, environmental protection practices should be introduced, mainly focusing on the safe disposal of solid waste and wastewaters in the case of the Kathmandu valley.

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DISCLOSURE STATEMENT

There are no competing interests for the present study.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

- Annapoorna, H. & Janardhana, M. R. 2015 *Assessment of groundwater quality for drinking purpose in rural areas surrounding a defunct copper mine*. *Aquatic Procedia* **4**, 685–692.
- Burlakoti, N., Ghimire, N., Chhetri, A. B., Rawal, D. S., Pant, B. R., Upadhyaya, J. & Koirala, N. 2020 *Physical, chemical, and microbiological characterization of processed drinking water in central Nepal: current state study*. *Journal of Water, Sanitation & Hygiene for Development* **10** (1), 157–165.
- CBS (Central Bureau of Statistics) 2017 *Statistical Year Book-Nepal*. Available from: <https://nepalindata.com/resource/statistical-year-book-nepal-2017/> (accessed 18 November 2020).
- Crichton, R. R. 1991 *Inorganic Biochemistry of Iron Metabolism*. Ellis Horwood, Ltd., Chichester, UK.
- Dill, H. G., Kharel, B. D., Singh, V. K., Piya, B., Busch, K. & Geyh, M. 2001 *Sedimentology and paleogeographic evolution of the intermontane Kathmandu basin, Nepal, during the Pliocene and quaternary*. *Journal of Asian Earth Science* **19** (6), 777–804.
- Ganesh, R., Koju, R. & Prajapati, R. R. 2018 *Assessment of groundwater quality and water table mapping of Bhaktapur municipality*. *Journal of Science & Engineering* **5** (18), 43–50.
- Greenberg, A. F., Clescerl, L. S. & Eaton, A. D. 2005 *Standard Methods for the Examination of Water and Wastewaters*. American Public Health Association (APHA), Washington, DC.
- Gurung, Y., Zhao, J., Bal Kumar, K. C., Wu, X., Suwal, B. & Whittington, D. 2017 *The costs of delay in infrastructure investments: a comparison of 2001 and 2014 household water supply coping costs in the Kathmandu Valley, Nepal*. *Water Resources Research* **53** (8), 7078–7102.
- Gurzau, E. S., Neagu, C. & Gurzau, A. E. 2003 *Essential metals – case study on iron*. *Ecotoxicology and Environmental Safety* **56** (1), 190–200.
- Halage, A. A., Ssemugabo, C., Ssemwanga, D. K., Musoke, D., Mugambe, R. K., Guwatudde, D. & Ssempebwa, J. C. 2015 *Bacteriological and physical quality of locally packaged drinking water in Kampala, Uganda*. *Journal of Environmental & Public Health* **215**, 1–6.
- Haramoto, E., Yamada, K. & Nishida, K. 2011 *Prevalence of protozoa, viruses, coliphages, and indicator bacteria in groundwater and river water in the Kathmandu valley, Nepal*. *Tropical Medicine & Hygiene* **105** (12), 711–716.
- HC (Health Canada) 2019 *Guidelines for Canadian Drinking Water Quality Summary Table*. Available from: https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/water-eau/sum_guide-res_recom/sum_guide-res_recom-eng.pdf (accessed 3 September 2020).
- Jofre, J., Lucena, F., Blanch, A. R. & Muniesa, M. 2016 *Coliphages as model organisms in the characterization and management of water resources*. *Water* **8** (5), 1–21.
- Kolawole, O. M., Alamu, F. B., Olayemi, A. B. & Adetitun, D. O. 2013 *Bacteriological analysis and effect of water consumption on the hematological parameters in rats*. *International Journal of Plant, Animal & Environmental Sciences* **3** (2), 125–131.
- Kontari, N. 1998 *Groundwater, iron and manganese: an Unwelcome Trio*. *Water Engineering & Management* **135** (2), 25–26.
- MoHP (Ministry of Health & Population) 2017 *Nepal Demographic and Health Survey*. Available from: <https://www.dhsprogram.com/pubs/pdf/fr336/fr336.pdf> (accessed 17 September 2020).
- NDWQS (National Drinking Water Quality Standard) 2005 *Ministry of Physical Planning and Works (MoPPW)*. Government of Nepal. Available from: <file:///C:/Users/Dell/Downloads/National%20Drinking%20Water%20Quality%20Standards,%202005%20IMPLEMENTATION%20DIRECTIVES%20FOR%20NATIONAL%20DRINKING%20WATER%20QUALITY%20STANDARDS,%202005.pdf> (accessed 15 September 2020).

- NHMRC (National Health and Medical Research Council) 2018 *Australian Drinking Water Guidelines*. Available from: [file:///C:/Users/Dell/Downloads/australian-drinking-water-guidelines-may19%20\(1\).pdf](file:///C:/Users/Dell/Downloads/australian-drinking-water-guidelines-may19%20(1).pdf) (accessed 17 September 2020).
- Obire, O., Ogan, A. & Okigbo, R. N. 2007 *Impact of fertilizer plant effluent on water quality*. *International Journal of Environmental Science & Technology* **5** (1), 107–118.
- Pal, P. 2017 *Chemical Treatment Technology*. Available from: <https://www.sciencedirect.com/science/article/pii/B9780128103913000023> (accessed 1 November 2020).
- Pant, B. R. 2011 *Groundwater quality in the Kathmandu valley of Nepal*. *Environmental Monitoring & Assessment* **178** (1–4), 477–485.
- Prakash, K. L. & Somashekar, R. K. 2006 Groundwater quality assessment on Anekal Taluk, Bangalore urban district, India. *Journal of Environmental Biology* **27** (4), 633–637.
- Raut, R., Bajracharya, R. M., Sharma, S., Sharma, C. M. & Dongol, B. S. 2015 Seasonal variation of water chemistry of Panchpokhari: a case study of an alpine lake series in the central Himalayas. *Jacobs Journal of Hydrology* **1** (1), 1–9.
- Regmi, S. 2013 *Wastewater Treatment in Kathmandu: Management, Treatment and Alternative*. Bachelor's Thesis, Mikkeli University of Applied Sciences, Finland.
- Seo, M., Lee, H. & Kim, Y. 2019 Relationship between coliform bacteria and water quality factors at weir stations in the Nakdong river, South Korea. *Water* **11** (1171), 1–16.
- Sharma, C. K. 1997 *Urban air quality of Kathmandu Valley 'Kingdom of Nepal'*. *Atmospheric Environment* **31** (17), 2877–2883.
- Shraddha, K. C., Gurung, A., Chaulagain, L., Amagain, S., Ghimire, S. & Amatya, J. 2018 *Physicochemical and bacteriological analysis of Bagmati river in Kathmandu valley*. *Annals of Applied Bio-Sciences* **5** (3), 64–69.
- Tallon, P., Magajna, B., Lofranco, C. & Leung, K. T. 2005 *Microbial indicators of faecal contamination in water: a current perspective*. *Water, Air, and Soil Pollution* **166**, 139–166.
- WHO (World Health Organization) 2013 *Emergency Treatment of Drinking-Water at the Point of Use*. Available from: https://www.who.int/water_sanitation_health/publications/tech_note5/en/ (accessed 3 September 2020).

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