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Research Article

Drinking Water Quality from Different Sources at Squatter Settlements of Bagmati River Corridors in Kathmandu, Nepal: An Assessment using Water Quality Index (WQI)

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Abstract

People living in squatter settlements are more vulnerable to health hazards due to a lack of potable drinking water. The key mission of this study was to evaluate the water quality from different sources at squatter settlements of Bagmati river corridors in Kathmandu. For this, a total of 131 water samples (24 KUKL pipelines, 29 wells, 35 tube wells, 9 stone spouts, 15 tankers, and 19 jars) were collected from different communities of the settlements from December 2021 to May 2022. The water quality of these sources was assessed using physicochemical and microbiological parameters. The water quality index (WQI) was also used to classify the suitability of different water sources. The results of all parameters were compared against the safe limits of the National Drinking Water Quality Standards (NDWQS, 2005). Out of 131 water samples, 11.5%, 24.4%, 11.5%, 16.0%, 28.2%, and 16.8% exceeded the NDWQS safe limits for total dissolved solids, total hardness, chloride, ammonia, iron, and manganese respectively. Likewise, 11.5% and 31.3% of the total water samples were contaminated with fecal and total coliform respectively. Tube well source was found highly contaminated both in physicochemical and microbiological form whereas jar water demonstrated more suitability for drinking purposes. Estimated WQI values also revealed well and tube well sources as poor, KUKL pipeline, stone spout, tanker sources as good, and jar as an excellent class of water. Since most of the water sources in this study were polluted, the implementation of appropriate water treatment processes as well as regular monitoring of water sources are strongly recommended.

Keywords: Kathmandu, NDWQS, Physicochemical and Microbiological parameters, Squatter settlement, Water quality

Introduction

All kinds of living beings on this planet depend on water not only for their existence but it is essential for maintaining the integrity and sustainability of the earth's ecosystems (Sharma *et al.*, 2005). Access to a safe drinking water supply is, therefore an essential prerequisite for improving public health as well as establishing a stable community of human beings. Safe drinking water is regarded as one whose physicochemical and microbiological parameters meet the permissible limits as per national standards or WHO guidelines (WHO, 2007). It is because safe water quality is greatly associated with public health importance and the well-being of the human race. However, the increasing anthropogenic activities may adversely affect not only the water quality but also in spreading of various waterborne transmissible diseases (Lerda & Prosperi, 1996). Water resources get contaminated through the direct disposal of domestic and industrial wastes that cause not only water pollution but also infections due to the presence of various sorts of microorganisms. Besides, nitrates, nitrites, sulphates, phosphates, ammonia, and organic matters including toxic heavy metals and radionuclides upon exceeding their threshold levels in water may adversely affect human health causing chronic illness, cancer, and many other human body malfunctions (Ikem *et al*., 2002). Globally, safe drinking water has not been accessible to over 884 million people and nearly two million children die every year due to diarrheal disease (Shrestha *et al*., 2009). Contaminated water is, therefore responsible for about 80% of all diseases in human beings (WHO, 2008).

A survey conducted by Kathmandu Upatyaka Khanepani Limited (KUKL) in 2008 identified 39 squatter settlements and 137 slums in the Kathmandu Valley, where a population of 40,237 live in 8,846 households. Of these, 22% were far out of reach to the pipeline water supply and suffered from poor sanitation. In another report, 45 squatter areas in Kathmandu Valley were identified out of which 29 are situated at the riverside and 16 at non-riverside (Shrestha, 2013). Deshar (2013) reported that there were only 17 squatter communities in Kathmandu in 1985 and the number has increased to 40 today. Eleven settlements out of 40 are situated along the Bagmati riverside whereas a majority of them (24) are situated along the river banks of Bishnumati, Manohara, Dhobikhola, Tukucha including Bagmati. In 1985, 11 settlements along the Bagmati riverside were inhabited by 3903 people. However, the extending trend of squatter households was found to be 37.9% in 2008, 39.2% in 2009, 24.8% in 2010, and 15.8% in 2011 (Deshar, 2013). A personal communication with a member of the Nepal Landless Democratic Union Party revealed that there are 73 settlements in Kathmandu Valley inhabited by more than 29,000 landless people in the squatters. Eighty percent of the total squatter population is living risky lives along the riverbanks. Moreover, 8000 families are living along the Bagmati riverbanks alone and only 1,082 families were registered as squatters in 2012.

Kathmandu Valley is facing rapid population growth and the size of many slum and squatter settlements is increasing with dwellers. Undoubtedly, the provision of basic requirements such as accessibility to clean drinking water and sanitation services are basic human needs and fundamental human rights. However, the supply of quality drinking water in most urban areas within Kathmandu Valley is still inadequate, demanding, and unsatisfactory due to increasing population growth, urbanization, and industrialization (MoUD, 2014). Squatter settlements and slums still have such a worse situation in the Valley, particularly in acquiring clean and safe drinking water despite continuous efforts from governmental and non-governmental organizations to improve the water quality situation (Deshar, 2013; Phuyal *et al*., 2019). The government of Nepal has also planned to improve the basic level of water supply and sanitation services by 2027 (MoUD, 2014). Unfortunately, squatters and slum dwellers, the poor, and marginalized groups are still so far out of reach for the basic needs of present time. They are facing acute problems with water both in terms of its quality and quantity (Acharya, 2010). Microbial hazards due to fecal contamination in water have continued to become the primary concern in both developed and developing countries including Nepal and hence, demanding the implementation of effective plans and programs for sustainable management of water sources in the affected areas (WHO, 2007).

There is a limited number of literature available on squatter settlements in Kathmandu. Some studies conducted by Acharya (2010), Toffin (2010), Little (2012), Deshar (2013), and Shrestha (2013) have provided basic information on the squatter settlements in Kathmandu Valley but the scope of their studies did not cover water quality of different water sources at squatter settlements. Phuyal *et al*. (2019) in their study provided information on water sources and drinking water quality at squatter settlements in Kathmandu Valley; however adequate studies related to water sources at the settlements are still lacking and need to be updated from time to time. Besides, there are very limited studies related to the assessment of water quality using WQI in the context of Nepal (Kayastha, 2015). Horton (1965) proposed WQI for the first time and many different indices for water quality assessment have been developed afterward. The simplicity of the WQI assessment is based on the fact that one can select water quality variables based on water quality measurements as per the study locations (CCME, 2006). In line with this, Singh *et al*. (2021) studied the water quality of Marshyangdi River, Nepal using WQI. Acharya *et al*. (2020) carried out the chemical characteristics of Karmanasha River, Lalitpur, and its appropriateness for irrigational usage by WQI assessment. Pant *et al*. (2021) used WQI for testing the water quality of the Ghodaghodi Lake, Sudurpaschim Province, Nepal for drinking purposes. Ram *et al*. (2021) estimated WQI of groundwater for suitability for human consumption in the hard rock terrain of Bundelkhand massif, Uttar Pradesh, India. Similarly, Atta *et al*. (2022) investigated the suitability of groundwater quality in the study area around Ismailia Canal, Egypt for drinking purposes using WQI. Based on these studies, it can be projected that most of the studies are focused on rivers and groundwater comparing their suitability with the drinking water standard of the respective country and/or the World Health Organization Guidelines (WHO, 2007; WHO, 2017). However, studies on the water quality status of locally available and consumed water sources using WQI are limited in the literature. Therefore, this study aims to present an assessment of the drinking water quality of different sources at squatter settlements of Bagmati river corridors in Kathmandu based on the water quality index (WQI) and in compliance with the National Drinking Water Quality Standards (NDWQS, 2005). It is expected that the findings of this study could be useful for local government and relevant stakeholders for the sustainable management of water sources at different squatter settlements in the Valley.

Materials and Methods

Identification of Squatter Settlements and Sample Selection

For this study, squatter settlements were identified and selected based on available literature (Phuyal *et al*., 2019; Lumanti, 2008). Table 1 shows the names of the rivers and nearby squatter settlements in Kathmandu Valley. Google Earth and Google Maps were also among the aids that helped in the identification of the squatter settlements.

Sufficient information regarding water sources available in different communities was also gathered through key informant interviews. Hence, the present study was based on primary as well as secondary sources from different published and unpublished sources. For testing drinking water quality, different water quality parameters were selected based on the National Drinking Water Quality Standards (NDWQS, 2005).

Collection of Water Samples

A total of 131 water samples were collected randomly from different communities of squatter settlements of Bagmati river corridors, Kathmandu for testing water quality. Table 1 depicts the name of rivers and nearby squatter settlements in Kathmandu. The types of water supply sources available at the study sites were found to be the KUKL pipeline, well, tube well, stone spout, tanker, and jar. For testing water quality, the number of water samples collected representing these water sources was 24, 29, 35, 9, 15, and 19 respectively. Whereas the pipeline, well, tube well, and stone spout water samples were received directly from the point of sources, tanker and jar water samples were collected from households dependent on the sources. Water samples from all these sources were collected (December 2021 to May 2022), in the early morning hours to avoid any kind of human disturbance. Sterilized bottles were used for the purpose of sample collection in order to avoid possible microbial contamination. Water samples were collected at different intervals of time during the study period with a view to observing possible variations in the concentration of water quality parameters. All the collected water samples were then transported to the laboratory and subjected immediately to chemical analyses. When immediate tests were not possible, they were preserved in a refrigerator at 4 °C. Moreover, the guidelines recommended by APHA (2005) were also followed while collecting and preserving water samples.

Table 1: Name of the river and nearby squatter settlements in Kathmandu Valley.

Nearby river		Name of squatter settlements
Bagmati River	:	Shanti Nagar, Bijaya Nagar, Jagriti Nagar, Gairigaun Tole, Pragati Tole, Kalimati Dole, Bansighat, Kuriyagaun and Shankhamul, Paurakhi Basti
Bishnumati River	:	Squatter settlements- Dhikure Chouki, Kumaristhan, Buddhajyoti Marg, Balaju Jagriti Tole, Sangam Tole, Ranibari Indigenous settlements- Inyatole, Ramghat, Hyumat, Dhaukhel and Bhimmukteshwor
Tukucha	:	Narayan Tole Maharajgung and Khadipakha Maharajgunj
Dhobikhola	:	Shanti Binayak, Devi Nagar, Bishal Nagar, Kalopul and Pathivara
Hanumante River	:	Manohara Bhaktapur
Other Locations	:	Palpakot, Anam Nagar, Maijubahal, Kumarigal, Radhakrishna Chowk, Mulpani, Kapan Dhungen, Subigaun, Ramhiti, Mahankal, Sukedhara and Mandikatar

Source: Phuyal *et al*. (2019); Lumanti (2008)

Analysis of Physicochemical Parameters

A total of ten physicochemical parameters *viz.*, hydrogen ion concentration (pH), electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), total hardness (TH), chloride (Cl^-), nitrate (NO_3^-), ammonia (NH_3), iron (Fe) and manganese (Mn) and two microbiological parameters (fecal coliform, and total coliform) were selected for testing water quality. The pH, EC, TDS, and DO were recorded in situ using the Hanna Combo pH/EC/TDS/DO/C tester HI98129. In the laboratory, TH and Cl^- ions were determined by EDTA and argentometric titrations respectively. Similarly, NO_3^- (stannous chloride reduction method), NH_3 (nesslerization method), Fe (1,10 phenanthroline method), and Mn (FAAS method) were determined by following the standard technique for the examination of water and wastewater (APHA, 2005). The results of each parameter obtained were also compared against the National Drinking Water Quality Standards (NDWQS, 2005).

Analysis of Microbiological Parameters

Analysis of microbiological parameters in water samples was performed by the Pour Plate Technique (Van Soestbergen & Lee, 1969). This technique was used for the enumeration and identification of total coliform and fecal coliform counts using Violet Red Bile Agar (VRBA, Hi-Media). For this, 1.0 mL of the sample was taken in two separate sterile petri plates followed by pouring the media aseptically over the plates. The petri plates were swirled well to mix the inoculum evenly. Then, the plates were poured with a thin layer of media again to maintain a semi-anaerobic condition. After solidifying the media, the plates were incubated at 37 and 44.5 °C for 24 h respectively for total and fecal coliform. Finally, the number of colonies (CFU/mL) was counted after incubation.

The same technique was also employed for total plate count using Plate Count Agar (PCA, Hi-Media). For this purpose, 1.0 mL of the sample was placed on the sterile plate. The autoclaved media was then poured over the same plate containing the sample. It was gently shaken in an aseptic condition. After solidifying the media, it was incubated at 37 °C for 24 h.

Drinking Water Quality Index (DWQI)

In this study, the DWQI was determined using the drinking water quality standard recommended by the National Drinking Water Quality Standards (NDWQS, 2005). The DWQI was used to evaluate the suitability of different water sources available in the study areas for drinking purposes. For this, ten physicochemical parameters namely pH, EC, TDS, TH, DO, Cl^-, NO_3^-, NH_3, Fe, and Mn were used as reported in the literature (Said *et al.*, 2004; Regmi *et al.*, 2017; Ram *et al.*, 2021). The assignment of these water quality parameters was based on their relative importance in the overall quality of water for drinking purposes. In the first step, the relative weight (Wi) for each parameter was calculated using Eqn. 1.

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \qquad \text{(Eqn. 1)}$$

Where, Wi and wi are the relative weight and weight for each physico-chemical parameter respectively, ∑wi is the sum of all parameters and n is the number of parameters. In the above equation, if a range of 0-20, 21-40, 41-60, 61-80, and 81-100 % of samples are within the permissible limit, weights (wi) of 5,4,3,2 and 1 are assigned to the water quality parameters respectively (Singh *et al.*, 2021; Raychaudhuri *et al.*, 2014). In the second step, the quality rating for each parameter was calculated by dividing the mean concentration in each category of water sample by the respective standard and then multiplying the result by 100 as per Eqn. 2.

$$qi = \left(\frac{Ci}{Si}\right) x\, 100 \qquad \text{(Eqn. 2)}$$

Where, qi is the quality rating, Ci is the mean concentration of each chemical parameter in each category of water sample (mg/L) and Si refers to the standard limit for each chemical parameter (mg/L).

Finally, the drinking water quality index (DWQI) was estimated by assigning the sub-index of water quality (SIi) for each parameter using Eqn. 3 and then summing up all the values of SIi to calculate the final DWQI using Eqn. 4.

$$SIi = Wi\,.\,qi \qquad \text{(Eqn. 3)}$$

$$DWQI = \sum_{i=1}^{n} SIi \qquad \text{(Eqn. 4)}$$

Where, SIi is the sub-index of water quality, Wi is the relative weighting, qi is the quality rating scale, and DWQI refers to the drinking water quality index. Based on the DWQI range (Table 2), the water quality is classified into five categories: Excellent, Good, Poor, Very Poor, and Unfit for Drinking (Raychaudhuri *et al.*, 2014).

Table 2. Classification of computed Drinking Water Quality Index (DWQI) values.

DWQI Range	Type of water
< 50	Excellent water
50.1 – 100	Good water
100.1 – 200	Poor water
200.1– 300	Very poor water
>300.1	Unfit for drinking

The Statistics

Descriptive statistics such as frequency, percentage, range, mean, and standard deviation were used wherever applicable. The correlation analysis was performed among the physicochemical parameters using Pearson's correlation coefficient and the significance level was tested at $p<0.05$. For the statistical analysis, the software package (SPSS 26) was used.

Results and Discussion

Physicochemical Characteristics of Water

Water samples collected from different sources at squatter settlements were subjected to analyses of ten physicochemical parameters. The mean concentrations of the studied parameters are enumerated in Table 3. The number and percentage of water samples from different sources exceeding NDWQS safe limits are presented in Table 4.

Table 3. Physico-chemical parameters of water samples during pre-monsoon.

Water source → Parameter ↓	Statistical parameter	Pipeline (n = 24)	Well (n = 29)	Tube well (n = 35)	Stone spout (n = 9)	Tanker (n = 15)	Jar (n = 19)	NDWQS (2005)
pH	Range	6.6 –7.8	6.8 –8.2	7.2 -8.3	7.1 –7.9	7.5 - 8.4	6.6 –8.0	6.5 -8.5
	Mean	6.9	7.7	7.9	7.4	7.8	7.2	
EC (μS/cm)	Range	282 -589	736 -1202	610 -987	458 -877	196 -575	542 -887	1500
	Mean	378	956	813	658	243	768	
TDS (mg/L)	Range	680 -1105	768 -1227	729 -1405	572 -766	718 -1143	188 -357	1000
	Mean	782	851	902	664	881	241	
DO (mg/L)	Range	6.8 –7.9	6.6 –7.4	6.4 –7.3	6.5 –7.0	6.9–8.0	6.8 –7.8	6.5 -8.0
	Mean	7.6	6.9	6.6	6.7	7.4	7.2	
T. hardness (mg/L)	Range	178 -617	342 -790	305 -817	390 -578	202-597	58 -115	500
	Mean	282	475	495	417	451	78	
Chloride (mg/L)	Range	187 -305	80 -170	92 -207	77 -159	112-288	52 -79	250
	Mean	224	104	157	125	181	58	
Nitrate (mg/L)	Range	2-7	17 -29	23 –40	8-19	3-8	0.5 –3.0	50
	Mean	3.5	24	28	10	5.7	1.7	
Ammonia (mg/L)	Range	0.68 –2.10	0.75 -3.17	0.83 –4.71	0.38 -1.25	0.77 -1.13	0.13– 0.68	1.5
	Mean	1.16	1.67	3.02	0.87	1.02	0.32	
Iron (mg/L)	Range	0.07 -0.40	0.10 - 2.04	0.14 – 2.57	0.17 - 0.35	0.21 - 0.36	0.07 - 0.21	0.3
	Mean	0.25	1.03	1.21	0.20	0.27	0.18	
Manganese (mg/L)	Range	0.07 – 0.25	0.12 – 0.25	0.05 – 0.37	0.08 – 0.15	0.10– 0.24	0.05– 0.11	0.2
	Mean	0.12	0.19	0.26	0.10	0.17	0.08	

Table 4. Number and percentage (in parentheses) of water samples exceeding NDWQS values.

Water source → Parameter ↓	Pipeline (n = 24)	Well (n = 29)	Tube well (n = 35)	Stone spout (n = 9)	Tanker (n = 15)	Jar (n = 19)	Total (n = 131)
pH	0	0	0	0	0	0	0
EC	0	0	0	0	0	0	0
TDS	2 (8.3)	4 (13.8)	7 (20.0)	0	2 (13.3)	0	15 (11.5)
DO	0	0	0	0	0	0	0
Total hardness	7 (29.2)	5 (17.2)	12 (34.3)	2 (22.2)	6 (40.0)	0	32 (24.4)
Chloride	11 (45.8)	0	0	0	4 (26.7)	0	15 (11.5)
Nitrate	0	0	0	0	0	0	0
Ammonia	2 (8.3)	5 (17.2))	14 (40.0)	0	0	0	21 (16.0)
Iron	5 (20.8)	9 (31.0)	17 (48.6)	2 (22.2)	4 (26.7)	0	37 (28.2)
Manganese	3 (12.5)	7 (24.1)	9 (25.7)	0	3 (20.0)	0	22 (16.8)

pH

pH is one of the important water quality parameters which has a vital role in an aquatic ecosystem and also directly influences the biotic composition of the system. It is the parameter on which all the biochemical functions and other biotic activities depend (Tadesse *et al*., 2018). Besides, the level of pH may also be influenced by different biological activities in water bodies such as respiration and photosynthesis. In this study, the highest pH value of 7.9 was found in tube well water while KUKL pipeline water measured the lowest pH value of 6.9 (Table 3). However, the mean values and pH ranges of all water sources were found within the NDWQS guideline range of 6.5 – 8.5. It was also found that none of the water samples from different sources exceeded the NDWQS safe limit (Table 4). pH can be toxic to aquatic life if the permissible limit is exceeded as it influences some chemical contents such as ammonia, hydrogen sulfide, and heavy metals in water bodies (Klontz, 1993). The findings of the present study are also in good agreement with Shakya *et al*. (2019) and Bajracharya *et al*. (2022) who also reported pH values of different water sources within the permissible limit. Besides, the observed values of pH in this study (Table 3) also indicate the alkaline nature of the well, tube well, stone spout, and tanker water. This may be attributed to the presence of sufficient carbonates in the respective water sources that may adversely affect the disinfection process (Tadesse *et al*., 2018; Shakya *et al*., 2019).

Electrical Conductivity (EC)

Inorganic materials and certain ions in the form of dissolved solids carry electrical currents in water (Kayastha, 2015; Shakya *et al*., 2019). Electrical conductivity (EC) is, therefore a measure of ions or salinity of water. A higher mean value of EC (956 µS/cm) was measured in well water while a lower value of EC (243 µS/cm) was in tanker water under the present investigation. However, none of the mean EC values of all water sources and their ranges exceeded the NDWQS permissible limit of 1500 µS/cm (Table 3) in line with the previous studies (Tamrakar & Shakya, 2013; Bajracharya *et al*., 2022). Gaihre *et al*. (2022) in their study, however, reported some percentage samples of well water and boring water exceeding NDWQS guidelines. The concentration of EC if exceeding the maximum permissible limit may induce corrosive nature in water (Tadesse *et al*., 2018). Besides, high EC may also give a mineral taste to the water by lowering its value aesthetically (WHO, 2007).

Total Dissolved Solids (TDS)

Total dissolved solids (TDS) are one of the most important water quality parameters and are directly correlated with electrical conductivity (Kayastha, 2015). The mean TDS value was measured highest (902 mg/L) in tube well water and lower (241 mg/L) in jar water. Besides, mean TDS values for the pipeline, well, stone spout and tanker water were 782, 851, 664, and 881 mg/L respectively. It was observed that none of the mean TDS values of the water sources violated the permissible limit of 1000 mg/L prescribed by the NDWQS. However, 2 (8.3%), 4 (13.8%), 7 (20%), and 2 (13.3%) water samples respectively for the pipeline, well, tube well and tanker sources were above the NDWQS (Table 3). In all, 15 (11.5%) of the total water samples exceeded the NDWQS guideline value. High TDS concentration reduces the transparency as well as the solubility of gases like oxygen in water (Parihar *et al*., 2012). Besides, it also decreases photosynthetic activity, affects the physicochemical properties of water, and its aesthetic value limiting thereby the utility of water for domestic, agricultural, and industrial purposes (Tadesse *et al*., 2018; Gurung *et al*., 2019).

Dissolved Oxygen (DO)

Dissolved oxygen (DO) is an important chemical parameter that indicates the bio-physical processes occurring in a water body. DO level is often considered an indicator of a healthy aquatic ecosystem and its saturation level in water is a measure of life existence (Trivedy & Goel, 1984). Besides, the DO level in water is often influenced by two factors namely water temperature and salinity (WHO, 2007). In this study, the mean value of DO in the water samples ranged from 7.6 mg/L (pipeline) to 6.6 mg/L (tube well). Water samples from all sources were found to have their mean values and ranges within the permissible range (6.5 -8.0) of NDWQS indicating an optimum value of suitability for drinking purposes.

Total Hardness (TH)

Total hardness (TH) is due to the presence of dissolved calcium and magnesium in the water. Water flowing through soil and rock contributes naturally occurring minerals to groundwater (Ram *et al*., 2021). Bicarbonates are the predominant ions in most natural waters that are associated mainly with calcium than magnesium (Khan *et al*., 2012). In this study, mean values of TH in the water ranged from 495 mg/L (tube well) to 78 mg/L (jar) including all sources within the maximum permissible limit (500 mg/L) of NDWQS. Similar to the findings of this study, Tamrakar and Shakya (2013), Shakya *et al*. (2019), and Bajracharya *et al*. (2022) also obtained the total hardness of water from different sources in Kathmandu within the NDWQS limit. However, 7 (29.2%) pipeline, 5 (17.2%) well, 12 (34.3%) tube well, 2 (22.2%) stone spout and 6 (40.0%) tanker water samples in this study crossed the NDWQS limit for the same parameter. Gaihre *et al*. (2022) also found TH values of some well water and boring water samples above the NDWQS limit while treated and tap water samples were within the limit. Health issues such as cardiovascular disease, kidney stones, growth retardation, and reproductive failure in humans are associated with the high concentration of TH in the water (Fulvio & Olori, 1965).

Chloride (Cl^-)

All types of freshwaters naturally contain low concentrations of chloride. The use of sodium chloride by humans for various purposes may be attributed to the increasing concentration of chloride in freshwater as well as its impacts on aquatic life (Klee & Graedel, 2004). Besides, sources of chloride in drinking water also originate from natural sources, sewage and industrial effluents, wastewater, urban and agricultural runoff, waste incineration, and precipitation (Purandara & Varadarajan, 2003; Müller & Gächter, 2012). In this study, the highest mean concentration of Cl^- was found in KUKL pipeline water (224 mg/L) and the lowest concentration in jar water (58 mg/L). Water samples from all types of studied sources revealed their mean Cl^- concentration within the safe limit (250 mg/L) as per the guideline of the NDWQS. The findings of the present study are also consistent with Paudel and Basi-Chipalu (2022) and Karki *et al*. (2022) who also reported a safe limit of chloride in water samples from different sources, Kathmandu. Among the water sources, all except 11 (45.8%) pipeline and 4 (26.7%) tanker water samples under the present study did not exceed the permissible limit. Additionally, 15 (11.5%) of the total water samples of all studied sources violated the NDWQS safe limit. Although chloride at low concentrations in drinking water does not pose a health risk, intake of a high chloride can cause hyperchloremia i.e., high chloride in the blood.

Nitrate (NO_3^-)

Nitrate is the highest oxidized form of nitrogen. The biological oxidation of organic substances containing nitrogen reveals the most important source of nitrate. Surface and groundwater also get contaminated with nitrate directly from agricultural runoff containing nitrate in fertilizers (Nolan *et al*., 1998). Besides, urban drainage and sewage disposal systems, septic tanks, municipal and industrial wastewater, animal feeds, refuse dumps, animal feeds, decaying plant debris, etc., also contain substantial quantities of nitrate. In this study, tube well water revealed the highest mean concentration of nitrate (28 mg/L) followed by well (24 mg/L), stone spout (10 mg/L), tanker (8.7 mg/L), pipeline (3.5 mg/L), and jar (1.7 mg/L) respectively. All studied water sources did not exceed the NDWQS safe limit of 50 mg/L for nitrate. Similarly, none of the water samples were above the safe limit which is consistent with the findings of Bajracharya *et al*. (2022), Paudel and Basi-Chipalu (2022), Shakya *et al*. (2019) and Diwakar *et al*. (2008). Nitrate contamination in drinking water causes harmful biological effects. Children particularly suffer from methemoglobinemia (also known as blue baby syndrome) through the consumption of water containing too much nitrate (NAS, 1981).

Ammonia (NH_3)

Natural sources of ammonia include animal and human excreta, and nitrogen fixation processes (Ryer-Powder, 1991). Agriculture runoff containing ammonia-rich fertilizers is the major artificial source of ammonia in waters. In this study, the highest ammonia content was found in tube well water (3.02 mg/L) and the lowest level in jar water (0.32 mg/L). It was also observed that only mean values of the well and tube well water exceeded the NDWQS safe limit of 1.5 mg/L for ammonia. Besides, 2 (8.3%) pipeline, 9 (31.0%) well, and 14 (40.0%) tube well water samples under the present analysis crossed the safe limit. Moreover, 21 (16.0%) of the total water samples violated the NDWQS limit. Previous studies indicated variable concentrations of ammonia in different sources of drinking water in Kathmandu Valley. Bajracharya *et al.* (2022) reported high ammonia content in traditional dug well water of Lalitpur metropolitan city while Karki *et al.* (2022) found concentrations of the parameter in Kathmandu municipal water supply within the NDWQS safe limit. Besides, previous studies conducted by JICA/ENPHO/MPPW (2005) and NGO FORUM (2006) also showed high ammonia content in various drinking water sources in Kathmandu Valley. A high concentration of ammonia may be attributed to sewage contamination and ammonification of organic matter in water. High ammonia content in drinking water may cause shaking of arms or hands, drowsiness, agitation, sluggish movement, personality changes etc., (Ryer-Powder, 1991).

Iron (Fe)

In the present study, it was observed that 37 (28.2%) of the total water samples collected from different water sources exceeded the NDWQS guideline for iron (0.3 mg/L). Among these were 5 (20.8%) pipeline, 9 (31.0%) well, 17 (48.6%) tube well, 2 (22.2%) stone spout, and 4 (26.7%) tanker water samples. Jar water did not, however, exceed the safe limit. As for the mean concentration of Fe, only well (1.03 mg/L) and tube well (1.21 mg/L) water samples were found exceeding the safe limit. Similar findings were also reported in groundwater samples of Kathmandu Valley by Pant (2011) and Tamrakar and Shakya (2013) while Bajracharya *et al.* (2022) and Paudel and Basi-Chipalu (2022) reported a safe limit of iron in similar sources of water. Iron occurs in different natural sources like lakes, rivers, and groundwater including soil, sediments, and rocks. Undesirable growth of bacteria can be promoted in iron-containing water in the presence of dissolved carbon dioxide (Purandara & Varadarajan, 2003). Iron has almost no associated health risks but its higher concentration is still considered a nuisance.

Manganese (Mn)

Manganese is a naturally occurring element in all freshwater as well as groundwater, especially in an anaerobic environment. The sources of Mn contamination in groundwater are mainly through leaching of the overlying soils and minerals in underlying rocks. The minerals of the aquifer itself can contaminate the groundwater. However, Mn levels in the water may vary significantly depending on the geological environment, rainfall chemistry, groundwater flow paths, residence time, aquifer lithology etc., according to time and space (Honeyman & Santschi, 1988). In the present study, tube well water measured the highest mean concentration of Mn (0.26 mg/L) while jar water (0.08 mg/L) measured the lowest level of all sources. Results revealed only tube well water exceeding the NDWQS limit (0.2 mg/L) while the rest was within the safe limit. The findings of the present study are consistent with Ram *et al.* (2021) who also published similar results in groundwater. However, 3 (12.5%) pipeline, 7 (24.0%) well, 9 (25.7%) tube well, and 3 (20.0%) tanker were among the water samples violating the NDWQS safe limit. Of the total water samples, 22 (16.8%) water samples crossed the safe limit. A small amount of Mn is essential for proper metabolism in the human body but it is toxic in high concentrations. High levels of Mn in drinking water may harm both infants and young children in their brain development (Mahmoud *et al*., 1990).

Correlation Matrix

The correlation matrix is an important statistical tool that is widely used to show a degree of inter-relationship among physicochemical parameters (Bradford *et al*., 1996). A strong and positive correlation among the parameters may be attributed to common sources of origin and similar pathways in the environment (Puth *et al*., 2014; Rodriguez *et al*., 2008)). Table 5 shows the inter-relationship among various physicochemical parameters of drinking water quality, using the Pearson correlation coefficient.

It was observed that various physicochemical parameters showed strong and moderate positive and negative correlations at p<0.05. Results showed significant and positive correlations between EC and TDS (r = 0.885), TDS and NH$_3$ (r = 0.609), and Fe and Mn (r = 0.785) at p < 0.05, suggesting the possibility of contamination from a common source. TDS is a good indicator of EC since the concentration of EC in water increases with increasing concentration of TDS (Paudel *et al*., 2022). Ammonia in the form of NH$_4^+$ ions helps increase TDS in water. Similarly, Fe and Mn always co-exist in a variety of surface and near-surface environments (e.g., waters, soils, and sediments) and have strong mutual interactions (Bhandari & Nayal, 2008). Similarly, a moderate positive correlation was also observed between other parameters such as pH-EC, pH-TDS, pH-DO, pH-Cl$^-$, EC-DO, EC- NO$_3^-$ and TDS-NO$_3^-$ at (p<0.05). The present correlation study is consistent with several previously conducted studies on the physicochemical characteristics of water (Mohamed *et al*., 2013; Sharma *et al*., 2015; Bajracharya *et al*., 2022).

Drinking Water Quality Index (DWQI)

The DWQI of water sources available for drinking purposes at different communities of the study area was computed from the mean values of selected physicochemical parameters. The calculation of DWQI and the corresponding water quality status are shown in Tables 6 and 7 respectively.

Table 5. Pearson's Correlation Coefficient (r) among physicochemical parameters of water sample.

	pH	EC	TDS	DO	TH	Cl$^-$	NO$_3^-$	NH$_3$	Fe	Mn
pH	1.000									
EC	***0.367**	1.000								
TDS	***0.326**	***0.885**	1.000							
DO	***0.448**	***0.401**	0.191	1.000						
TH	0.299	0.256	0.277	0.412	1.000					
Cl$^-$	***0.399**	0.222	0.201	0.020	0.154	1.000				
NO$_3^-$	-0.231	***0.344**	**0.312**	-0.296	0.118	0.042	1.000			
NH$_3$	0.225	0.272	***0.609**	0.262	-0.112	0.171	0.185	1.000		
Fe	0.131	0.245	0.112	-0.076	0.067	0.059	0.031	0.287	1.000	
Mn	0.118	0.215	0.102	-0.047	0.081	0.032	0.063	0.213	***0.785**	1.000

*****Correlation is significant at p<05.

Table 6: Water sources, water quality parameters, weight (wi), calculated relative weight (Wi), and quality rating (qi) for each parameter.

KUKL Pipeline											
Parameter →	pH	EC	TDS	DO	TH	Cl^-	NO_3^-	NH_3	Fe	Mn	∑wi
Weight (wi)	1	1	1	1	2	3	1	1	2	1	14
Relative weight (Wi)	0.071	0.071	0.071	0.071	0.143	0.214	0.071	0.071	0.143	0.071	-
Quality rating (qi)	81.2	25.2	78.2	95.0	56.4	89.6	7.0	77.3	83.3	60.0	-
Well											
Parameter →	pH	EC	TDS	DO	TH	Cl^-	NO_3^-	NH_3	Fe	Mn	∑wi
Weight (wi)	1	1	1	1	1	1	1	1	2	2	12
Relative weight (Wi)	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.167	0.167	-
Quality rating (qi)	90.6	63.7	85.1	86.3	95.0	41.6	48.0	111.3	343.3	95.0	-
Tube well											
Parameter →	pH	EC	TDS	DO	TH	Cl^-	NO_3^-	NH_3	Fe	Mn	∑wi
Weight (wi)	1	1	2	1	2	1	1	3	3	2	17
Relative weight (Wi)	0.059	0.059	0.118	0.059	0.118	0.059	0.059	0.177	0.177	0.118	-
Quality rating (qi)	92.9	54.2	90.2	82.5	99.0	62.8	56.0	201.3	403.3	130.0	-
Stone spout											
Parameter →	pH	EC	TDS	DO	TH	Cl^-	NO_3^-	NH_3	Fe	Mn	∑wi
Weight (wi)	1	1	1	1	2	1	1	1	2	1	12
Relative weight (Wi)	0.083	0.083	0.083	0.083	0.167	0.083	0.083	0.083	0.167	0.083	-
Quality rating (qi)	87.1	43.9	66.4	83.8	83.4	50.0	20.0	58.0	66.7	50.0	-
Tanker											
Parameter →	pH	EC	TDS	DO	TH	Cl^-	NO_3^-	NH_3	Fe	Mn	∑wi
Weight (wi)	1	1	1	1	3	2	1	1	2	2	15
Relative weight (Wi)	0.067	0.067	0.067	0.067	0.200	0.133	0.067	0.067	0.133	0.133	-
Quality rating (qi)	91.8	16.2	88.1	92.5	90.2	72.4	11.4	68.0	90.0	85.0	-
Jar											
Parameter →	pH	EC	TDS	DO	TH	Cl^-	NO_3^-	NH_3	Fe	Mn	∑wi
Weight (wi)	1	1	1	1	1	1	1	1	1	1	10
Relative weight (Wi)	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	-
Quality rating (qi)	84.7	51.2	24.1	90.0	15.6	23.2	3.4	21.3	60.0	40.0	-

Results revealed that the water quality status ranged from poor to excellent conditions on the basis of the calculated DWQI values (Table 7). The DWQI for jar water was observed to be 41.35 which belonged to the excellent category (DWQI < 50). It indicates that the jar water is potable and could be used for drinking purposes from the perspective of measured parameters. Similarly, the DWQI values for pipeline, stone spout, and tanker water supplies were 69.26, 63.18, and 75.61 respectively. Accordingly, these water sources can be categorized as good water as per the classification of DWQI values (50.1 – 100). Well water (124.79) and tube well water (165.23), however, belonged to the poor category (100.1 – 200) indicating that the quality of these groundwater sources is not safe for human consumption. While observing the site conditions during field visits at different water sources, dumping of domestic waste was found near the wells, and tube wells including unmanaged private and public latrines. Besides, some well and tube wells were also located near the riverside of Bagmati corridors which might have polluted groundwater. The high value of DWQI can be attributed to the higher concentrations of chloride, nitrate, manganese, iron, and nickel in the groundwater (Ram *et al*., 2021). The findings of this study are in contradiction with the previous studies that reported excellent to a good class of groundwater (Ram *et al*., 2021; Embaby *et al*., 2017).

Microbiological Characteristics of Water

Fecal coliform and total coliform counts in different water sources and their numbers exceeding the NDWQS safe limit are depicted in Table 8 (a & b). In this study, pipeline, tanker, and jar water sources did not show any fecal contamination. However, tube well water showed a comparatively wider range of fecal coliform (0 – 67) followed by well (0 – 45) and stone spout (0 – 15) water. It was also observed that 5 (17.2%) well, 8 (22.9%) tube well, and 2 (22.2%) jar water samples contained fecal coliform and crossed the NDWQS safe limit. This indicates that these sources of water are unfit for drinking purposes without any proper procedure for water treatment. Of the total water samples, 15 (11.5%) water samples exceeded the safe limit in this study.

As for the total coliform count, all sources of water samples except the jar showed a variable range of coliform counts. Accordingly, a comparatively wide range of total coliform counts was observed in tube well water (0 – 218) followed by well (0 – 115), pipeline (0 – 87), tanker (0 – 54), and stone spout (0 – 45) water. Moreover, 7 (29.2%) pipeline, 7 (24.1%) well, 15 (42.9%) tube well, 4 (44.4%) stone spout, and 8 (53.3%) tanker water samples exceeded the NDWQS permissible limit indicating unsuitability for drinking purposes. Moreover, 41 (31.3%) of the total water samples violated the safe limit in this study which is consistent with the previous studies (Shakya *et al*., 2019; Bajracharya *et al*., 2022, Paudel & Basi-Chipalu 2022; Gaihre *et al*., 2022). In drinking water, bacterial contamination is a major issue in many developing countries and Nepal is no exception. Children under five years suffer from the most common waterborne disease called diarrhea (Shrestha *et al*., 2021). Bacteria belonging to the coliform group are often used as an indicator of fecal contamination in water. These microorganisms show the possibility of other pathogenic organisms of fecal origin in drinking water (WHO, 2019). Water sources like dug well, tube well, springs, stone spouts, etc., get contaminated with fecal matter polluting the aquatic environment. Besides, humans suffer from waterborne diseases like cholera, dysentery, hepatitis A, typhoid, dysentery, gastroenteritis, polio etc., (WHO, 2007).

Table 7: Sub-index of each chemical parameter (Sli), DWQI, and water classification of each water source.

	SIi										DWQI = ∑SIi	*WCL
Water source	pH	EC	TDS	DO	TH	Cl^-	NO_3^-	NH_3	Fe	Mn		
Pipeline	5.77	1.79	5.55	6.75	8.07	19.17	0.50	5.49	11.91	4.26	69.26	Good
Well	7.52	5.29	7.06	7.16	7.89	3.45	3.98	9.24	57.33	15.87	124.79	Poor
Tube well	5.48	3.20	10.64	4.87	11.68	3.71	3.30	35.63	71.38	15.34	165.23	Poor
Stone spout	7.23	3.64	5.51	6.96	13.93	4.15	1.66	4.81	11.14	4.15	63.18	Good
Tanker	6.15	1.09	5.90	6.20	18.04	9.63	0.76	4.56	11.97	11.31	75.61	Good
Jar	8.47	5.12	2.41	9.00	1.56	2.32	0.34	2.13	6.00	4.00	41.35	Excellent

*WCL: Water classification

Table 8(a): Fecal coliform and total coliform counts (CFU/100mL) with respect to water sources.

Water source → Parameter ↓	Pipeline (n = 24)	Well (n = 29)	Tube well (n = 35)	Stone spout (n = 9)	Tanker (n =15)	Jar (n = 19)	NDWQS (2005)
Fecal coliform	Nil	0 - 45	0 - 67	0 - 15	Nil	Nil	0 in 95% samples
Total coliform	0 - 87	0 - 115	0 - 218	0 - 45	0 - 54	Nil	

Table 8(b): Number and percentage of water samples exceeding NDWQS values.

Water source → Parameter ↓	Pipeline (n = 24)	Well (n = 29)	Tube well (n = 35)	Stone spout (n = 9)	Tanker (n =15)	Jar (n = 19)	Total (n =131)
Fecal coliform	0	5 (17.2%)	8 (22.9%)	2 (22.2%)	0	0	15 (11.5%)
Total coliform	7 (29.2%)	7 (24.1%)	15 (42.9%)	4 (44.4%)	8 (53.3%)	0	41 (31.3%)

Conclusions

The key objective of this study was to evaluate drinking water quality from different sources at squatter settlements of Bagmati river corridors in Kathmandu. Altogether ten physicochemical and two microbiological parameters were used to assess the water quality and the water quality index (WQI), based on the mean concentration of the parameters, was used to classify the water supply sources. Physicochemical parameters revealed all sources except jar water, unhygienic for drinking purposes since they did not meet the NDWQS safe limits. Besides, the assessment of water supply sources using WQI also indicated jar water as an excellent class of water, KUKL pipeline, stone spout, and tanker water as a good class, and well and tube well water as a poor class. Microbiological parameters revealed fecal coliform contamination in 11.5% of the total water samples that included well, tube well, and stone spout sources. Similarly, total coliform was also detected in 31.3% of the total water samples including all water sources except the jar suggesting that only the jar water supply is suitable for drinking purposes. In this study, the tube well was found the most contaminated one among the studied water sources in both physicochemical and microbiological forms. The major problem in the tube well source was the presence of high levels of TDS, TH, NH_3, Fe, Mn, and fecal and total coliform exceeding the maximum permissible limits. Based on the overall findings, it may be concluded that a majority of people inhabiting the study area are vulnerable to health issues. Therefore, it is recommended to the concerned authority for the implementation of appropriate water treatment processes in the affected squatter settlements. Besides, a similar study on seasonal variation is also suggested to figure out the water quality status for the whole year as water quality may change accordingly.

Authors' Contribution

All authors have made equal contributions at every phase of the present work, including manuscript preparation, critical revision of the manuscript for important intellectual content, and final approval of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest pertinent to this work.

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