Research Paper

Physical, chemical and microbiological characterization of processed drinking water in central Nepal: current state study

Niru Burlakoti, Jitendra Upadhyaya, Nandani Ghimire, Tirtha Raj Bajgai, Anup Basnet Chhetri, Deepa Shree Rawal, Niranjan Koirala and Bhoj Raj Pant

ABSTRACT

This study was undertaken to analyse processed bottled water for drinking water quality. Altogether 50 water samples of different brands were randomly collected from public places in Kathmandu valley. The samples were analysed for physical (turbidity, pH and electrical conductivity), chemical (iron, manganese, arsenic, cadmium, chromium, lead, ammonia, fluoride, chloride, sulphate, copper, total hardness, calcium, mercury and aluminum) and microbiological (fecal coliform and total coliform) parameters. The results revealed that >300 CFU/100 mL of Escherichia coli (E. coli) (fecal coliform) and total coliform (TC) bacteria were counted in 76 and 92% samples, respectively. The bacterial population was beyond the limit of the Department of Food Technology and Quality Control (DFTQC) (0 CFU/100 mL of water). Chemical parameters analysed for fluoride (0.5–1.5 mg/L) and ammonia (1.5 mg/L) exceeded the DFTQC values. The range of fluoride estimated was 0.001–2.37 mg/L and the maximum concentration of ammonia was 4.66 mg/L. Most of the processed water crossed the threshold standard of E. coli and TC bacteria and may pose a risk if used for drinking purposes. Therefore, to minimize the public health risk of contaminated water, scientific methods and standards of purification should be followed during the process, production, storage, and delivery of processed water.

Key words | ammonia, chemical parameter, fecal coliform, Kathmandu, public health, total coliform

INTRODUCTION

Water is one of the basic requirements of human daily consumption, yet much of the world’s population struggles to find consistent access to safe drinking water as recommended by the WHO drinking-water quality guidelines. Currently, about two billion people in the world live without access to safe drinking water (WHO 2017a, 2017b). In Nepal, 81% of households in the urban areas of the Terai region (flat region) and 32.9% in the urban hills have access to a piped water supply (Nicholson et al. 2017). Nevertheless, this supplied water is not reliably safe, as most of the
water supply systems across the country do not have access to basic water treatment facilities. This has resulted in frequent reports of faecal contamination in drinking water and outbreaks of waterborne diseases. Waterborne diseases such as diarrhoea, typhoid, dysentery, and cholera are still major public health threats to the people of Nepal because of contaminated water, poor sanitation, and unhygienic living conditions. According to the national demographic health survey, 8% of children below five years of age suffer from diarrheal diseases (MoHP 2007). Annually, about 3,500 children in Nepal (Aryal et al. 2012), and two million children throughout the world die due to waterborne diseases (UNICEF 2008).

Access to sufficient quantities of safe drinking water in Kathmandu valley is difficult (Gurung et al. 2017). According to Kathmandu Upatyaka Khanepani Limited (KUKL), drinking water demand in the valley in 2015 was 375 million litres per day (MLD), with supply limited to 90 MLD during the dry season and 150 MLD during the wet season (KUKL 2015). KUKL is a public company, responsible for the supply of safe drinking water in the valley. However, KUKL currently provides only one-third of the total drinking water demand required to meet the daily need of the population (Umale et al. 2016). The rest of the water demand (50 MLD) is fulfilled either from groundwater sources or water supplied by private suppliers, available as both raw and processed water (MoUD 2017). Processed water is available in 0.5–20 L polyethylene terephthalate (PET) jars and is popularly known as jar water. Due to an inadequate supply of treated water, most of the people in the valley are compelled to depend on processed water to meet their daily water requirements. Processed water has now gained commercial status and is available everywhere across the country. According to the Department of Food Technology and Quality Control (DFTQC), 125 water producing industries are currently registered in the valley and are producing processed drinking water (DFTQC 2016). However, there are more water processing industries than currently registered, and many water processing industries are operating without having formal registration. Due to the limited supply of treated water from municipalities, most of the people in the valley are compelled to use processed water for drinking and other household applications. From the public health perspective, water used for human consumption should be safe, but it is difficult to ensure the safety of the processed drinking water of Kathmandu valley.

In this article, ‘processed water’ means the water which is sold in water bottles and jars (containers) commercially by the water processing and filtering companies in Nepal. These bottled and processed waters are claimed to be safe for human consumption by the bottling companies. Therefore, the main objective of this study was to analyse processed water (jar water) of different brands to monitor the quality of drinking water in Kathmandu valley, Nepal.

**STUDY AREA**

The study area covers mostly the urban regions of Kathmandu and Lalitpur districts of Kathmandu valley (Figure 1). Kathmandu valley contains three major cities: Kathmandu, Lalitpur, and Bhaktapur, with an approximate population of 2.5 million (CBS 2011). The valley is located in the midland of the Himalayas, and lies between 27°32’ and 27°49’ north and 85°12’ and 85°32’ east, and 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 with an elevation of 1,300–1,400 m above mean sea level, covering an area ~900 km² (Sharma 1997) with an average population density of 1,900 people per square km (CBS 2011). It is difficult to determine the exact number of people who have been using processed water in the study area. Nevertheless, the number of processed water producing industries registered in the valley clearly indicates that most of the population use processed water to fulfil their daily water requirements.

**MATERIALS AND METHODS**

**Sampling sites**

A total of 50 processed water samples of different brands were randomly collected from grocery stores, restaurants, college cafeterias, and hotels in the Kathmandu and Lalitpur districts in Kathmandu valley during April and May of 2018 for quality analysis. Sample collection was carried out
according to the standard method (Greenberg et al. 2005). For ethical reasons, the brand names of the different brands of processed water have not been disclosed. The sampling sites and the number of samples collected from different places are illustrated in Figure 1. Sterilized polyethylene bottles of ~250 mL capacity were used for sample collection. Bottles were sterilized in an autoclave at 121 °C and 15 LB pressure for 15 min. Samples for the analysis of chemical parameters (iron, manganese, arsenic, cadmium, chromium, fluoride, lead, copper, zinc, Escherichia coli (E. coli), and total coliform bacteria) were collected in polyethylene bottles, cleaned by distilled water several times. Before collecting the samples, the sample bottles were purged by the water to be collected from the respective jar water. The 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 characterization was performed.

The sample code (SC) and sampling locations are presented in Table 1.

Sample analysis

The samples were characterized for pH, electrical conductivity (EC), turbidity, hardness, chloride, ammonia, sulphate, nitrate, residual chlorine, fluoride, iron, manganese, arsenic, cadmium, chromium, lead, copper, zinc, Escherichia coli (E. coli), and total coliform bacteria. The pH and EC were measured by using a pH meter (TOA HM-10P) and conductivity meter (WTW LF 91), respectively. Turbidity was measured using a nephelometer (ELICO, CL 52). The hardness, chloride and residual chlorine was determined volumetrically. Fluoride was measured by the SPADNS method using acid zirconyl SPADNS reagent. The ammonia, sulphate, and nitrate were determined using a spectrophotometer. Iron, manganese, cadmium, chromium, lead, copper, zinc, and arsenic were analysed in an atomic absorption spectrometer (Agilent Technologies, 240 FS).

Microbiological parameters for E. coli and total coliform (TC) bacteria were quantified by the membrane filtration method (Greenberg et al. 2005). The samples (100 mL each)
were filtered using sterile filter paper with a pore size of 0.45 μm by applying vacuum suction and incubated in an incubator at 37 °C for 24–48 h in M-endo agar media. After incubation, total coliform bacteria were enumerated by counting the colonies. The colonies showing pink colour with or without green metallic luster were enumerated as total coliform, whereas the colonies with green metallic shine were sub-cultured on nutrient agar plates and incubated at 37 °C for 24 h. Gram staining and biochemical tests for all the subculture isolates were performed for the identification of E. coli.

Hydrochloric acid, sulphuric acid, acetic acid, ammonium buffer, phenolphthalein, SPANDS reagent, zirconyl chloride octahydrate, sodium fluoride, Nessler’s reagent, silver nitrate, potassium chromate, magnesium chloride, magnesium acetate, potassium nitrate, acetic acid, barium chloride, sodium sulphate, brucine sulphanilic acid solution, sodium chloride, sodium arsenite, EDTA,
eryochrome black T, starch solution, potassium iodide and sodium hydroxide used for the analysis were AR grade and purchased from local suppliers in Kathmandu, Nepal. Membrane filter (Whatman) and M-endo agar Hi-media were used in the estimation of *E. coli* and TC bacteria. The pH meter, nephelometer, conductivity meter, spectrometer, and atomic absorption spectrometer available in the laboratory were used for instrumental analysis.

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

**RESULTS AND DISCUSSION**

Currently, processed water has become one of the major sources of drinking water in Kathmandu valley. The prevalent usage of processed water is due to the inaccessibility of treated water within the valley. The increased number of water processing industries registered in the valley provides strong evidence for the requirement of processed water that can be used for drinking and household applications in the valley.

**Characteristics of water sample**

The samples were characterized for physical, chemical, and microbiological parameters. The physical characterization was carried out to determine pH, electrical conductivity (EC), and turbidity. The results are presented in Table 2.

The average value of pH, EC, and turbidity of processed water was found to be 6.6, 56.5, and 1.2, respectively. These values are within the recommendations of DFTQC. The pH of water indicates acidity and alkalinity, which depends on the concentration of hydrogen and hydroxyl ions (Deshwal *et al.* 2016). The reason for acidity is the presence of carbon dioxide which dissolves in water to form carbonic acid, thus increasing the acidity of water (Bialkowski 2006). The deviation of drinking water pH from normal pH (neutral pH) can affect public health and the water purification system (USGS 2015). The EC of water shows the presence of dissolved ionic substances, as the EC increases with the increase of ionic concentration. Additionally, organic matter containing ionic charges also contribute to the increase of EC in water. The turbidity of the water depends on the presence of suspended matters, such as: inorganic, organic and microbiological substances (Sawyer *et al.* 2003). Generally, it demonstrates that the values of pH, EC, and turbidity of processed drinking water are within the standard provided by the DFTQC.

Chemical parameters were estimated to determine the concentrations of iron, manganese, arsenic, cadmium, chromium, fluoride, lead, ammonia, chloride, sulphate, nitrate, copper, total hardness, zinc, and residual chlorine (Table 3). Of these parameters, the concentrations of fluoride and ammonia exceeded the DFTQC recommendations (DFTQC 2018). The minimum and maximum values of fluoride

| Parameter                  | Concentration (mg/L) | Minimum | Maximum | Average | DFTQC |
|----------------------------|----------------------|---------|---------|---------|-------|
| Iron                       | 0.1                  | 0.53    | 0.11    | 0.3     |       |
| Manganese                  | 0.01                 | 0.01    | 0.1     | 0.1     |       |
| Arsenic                    | 0.001                | 0.001   | 0.001   | 0.01    |       |
| Cadmium                    | 0.001                | 0.001   | 0.001   | 0.003   |       |
| Chromium                   | 0.001                | 0.001   | 0.001   | 0.05    |       |
| Fluoride                   | 0.001                | 2.37    | 1.13    | 1.5     |       |
| Lead                       | 0.01                 | 0.01    | 0.01    | 0.01    |       |
| Ammonia                    | 0.48                 | 4.66    | 1.84    | 1.0     |       |
| Chloride                   | 1.42                 | 22.72   | 9.25    | 200     |       |
| Sulphate                   | 4.48                 | 15.98   | 6.11    | 250     |       |
| Nitrate                    | 0.02                 | 1.4     | 0.26    | 50      |       |
| Copper                     | 0.1                  | 0.1     | 0.1     | 2.0     |       |
| Total hardness             | 4.0                  | 156     | 28.66   | 200     |       |
| Zinc                       | 0.1                  | 0.1     | 0.1     | 4.0     |       |
| Residual chlorine          | ND                   | ND      | ND      | 0.2     |       |

DFTQC, Department of Food Technology and Quality Control (2018).

| Parameter                  | Minimum | Maximum | Average | DFTQC |
|----------------------------|---------|---------|---------|-------|
| pH                         | 5.6     | 7.9     | 6.6     | 0.62  |
| Electrical conductivity    | 5.0     | 229.0   | 56.5    | 53.0  |
| (μS/cm)                    |         |         |         | 1,500  |
| Turbidity (NTU)            | 0.3     | 5.9     | 1.2     | 0.92  |

DFTQC, Department of Food Technology and Quality Control (2018).
estimated in the processed water were 0.001 and 2.37 mg/L. These values do not satisfy the DFTQC recommendations (0.5–1.5 mg/L). Weathering of fluoride-containing minerals and rocks under the Earth’s surface can be a source of fluoride in natural waters. Similarly, disposal of untreated industrial wastes in open fields around water sources can be an anthropogenic source of fluoride in water bodies. However, in the case of processed water, the presence of fluoride may be the result of handling errors of machines during water production and improper maintenance. Optimum levels of fluoride in drinking water are essential, and deviations from these optimum levels can cause serious health implications. The overdose of fluoride (>1.5 mg/L) may result in bone demineralisation by damaging bones and joints (Kanduti et al. 2016), while fluoride deficiency (<0.5 mg/L) may cause osteoporosis, which leads to a decrease in bone mass and an increase in bone fragility (Kleerekoper 1998).

The presence of ammonia was found with a maximum concentration of 4.66 mg/L in 48% of samples (Figure 2). Natural and anthropogenic sources are the main causes of ammonia in water (ATSDR 2004). Decomposition of organic matters, animal excreta, and dead plants/animals can contribute to naturally occurring ammonia. Similarly, sewage/wastewater effluents and runoff from areas with intensive animal husbandry are other major sources of ammonia in the environment.

The maximum concentration of ammonia was estimated far above the guidelines recommended by DFTQC (1.5 mg/L), however the mean value was within the standard. The presence of ammonia in water is an indicator of water contamination, primarily due to sewage and animal waste (WHO 2017a, 2017b). Long-term ingestion of water containing more than 1 mg/L ammonia may damage internal organ systems (ODHC 2000). The iron, manganese, arsenic, cadmium, chromium, lead, chloride, sulphate, nitrate, copper, total hardness, and zinc in processed water are within the recommendations of DFTQC (DFTQC 2018) (Figure 2).

**Microbiological analysis**

*E. coli* and TC bacteria in the processed water samples exceeded the recommendations of DFTQC (Table 4). Bacterial populations ranged from 0 to >300 CFU/100 mL of water. *E. coli* and TC bacteria were present in 74 and 92% of the samples, respectively.

The average values of bacterial populations varied and counted at 54.4 CFU/100 mL for *E. coli* and 204.4 CFU/100 mL for TC (Figure 3). These results reveal that most of the processed water samples were above the recommendations of DFTQC (0 CFU/100 mL). The presence of TC and *E. coli* in the processed water samples indicates the lack of sanitation measures adopted during water production and delivery of processed water. As we observed during sampling, most of the water-carrying containers were not cleaned properly; the surfaces of the bottles were scratched, and some jars were even broken (Figure 4). This factor can also be a major contributor to bacterial contamination found in processed water.
As can be seen in Figure 4, the interior part of the container looks dirty with scratches at the bottom. For ethical reasons, the identity of the processed water-producing industry has not been disclosed. Water containing high levels of total coliform and E. coli is hazardous to health and can cause gastrointestinal disorders, typhoid, hepatitis, and cholera.

Coliform is a group of bacteria present in open environments and also in the intestine of warm-blooded animals. Their presence in waters indicates bacterial contamination (Odankar & Ampofo 2015). The TC group of bacteria includes faecal and environmental species, whereas E. coli is of faecal origin (WHO 2017a, 2017b).

Previous investigations carried out for the presence of bacteria in processed water support our findings. A study carried out for enumeration of the TC bacteria in bottled water (processed water) found that the levels exceeded the WHO drinking water quality guidelines (0 CFU/100 mL), with bacteria found in 63.3% of samples (Thapa et al. 2012). Subedi & Aryal (2010) have reported TC and E. coli in 91.5 and 59.6% of bottled water in the Kathmandu valley. The presence of TC in 75 and 89% samples and E. coli in 54.2 and 66% (Budathoki 2010; Rai et al. 2015) of different bottled water brands reveal that processed water is highly contaminated due to the presence of E. coli and TC bacteria.

Drinking water should be free from bacterial contamination. To avoid bacterial contamination (TC and E. coli) in water, care must be taken during water production and handling of containers.

**CONCLUSIONS**

Processed water samples in the Kathmandu and Lalitpur districts of Kathmandu valley were characterized for drinking water quality. The water samples were randomly collected from public places and characterized for physical, chemical, and microbiological parameters. The processed water samples were contaminated with fluoride, ammonia, E. coli, and TC bacteria. The maximum and minimum concentration of fluoride was estimated at 0.001 and 2.73 mg/L, respectively. These values do not comply with the recommendations of the DFTQC (0.5–1.5 mg/L). The maximum of 4.66 mg/L ammonia estimated in the samples is far beyond the drinking
water quality standard (1.5 mg/L). The average number of bacteria enumerated for \textit{E. coli} and TC exceeded the DFTQC (54.4 CFU/mL and 204.4 CFU/mL). The physical and chemical parameters characterized for the estimation of pH, EC, turbidity, iron, manganese, arsenic, cadmium, chromium, lead, chloride, sulphate, nitrate, copper, total hardness, zinc, and residual chlorine were within the recommendations of DFTQC.

**RECOMMENDATIONS**

Processed water analysed for drinking water quality is poor due to the presence of \textit{E. coli}, and TC bacteria. The fluoride and ammonia estimated were beyond the guideline values, further deteriorating the quality of water. Processed water that contains bacteria (\textit{E. coli} and TC), and chemicals (ammonia and fluoride) should be improved by implementing adequate treatment methods and adopting proper testing and monitoring to ensure that the water is safe for drinking purposes. Contamination of water with \textit{E. coli} and TC bacteria indicates the lack of sanitation during the production of water, whereas excess ammonia and fluoride in water may be due to the improper handling and maintenance of machinery. Regular maintenance of machinery along with sanitation around water collection areas is highly recommended to produce processed water free from contaminants. Regular monitoring of water quality of processed water at the water source, processing industry, and distribution outlets for quality assurance is suggested from this study. Regular awareness programs including basic scientific knowledge about the water pollution, purification and health impacts should also be conducted, targeting the local people. Moreover, this study also recommends the proper management of the water processing industries and regulation amendments for safe drinking water quality assurance.

**ACKNOWLEDGEMENTS**

The authors are grateful to the Vice Chancellor of the Nepal Academy of Science and Technology for his encouragement and support in carrying out this work.

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First received 19 September 2019; accepted in revised form 13 December 2019. Available online 6 February 2020