Sustainable Water Resources Management (2019) 5:1995–2000
https://doi.org/10.1007/s40899-019-00354-x

ORIGINAL ARTICLE

Quality of drinking water in Kathmandu valley, Nepal

Kanchan Thapa[1,2] · Sujen Man Shrestha[1] · Deepa Shree Rawal[1] · Bhoj Raj Pant[1]

Received: 31 May 2019 / Accepted: 17 August 2019 / Published online: 24 August 2019

Abstract
Present study was undertaken to analyze drinking water quality of Kathmandu valley with the estimation of essential minerals of public health concern. Twenty water samples of each source, viz. public water supply, private water supply, and processed drinking water supply, were randomly collected. Sample analysis was carried out for physical (temperature, pH, and electrical conductivity), chemical (calcium, magnesium, sodium, and potassium), and microbiological (total coliform—TC) parameters. It was found that the physical parameters such as temperature, pH, and electrical conductivity (EC) were within the World Health Organization (WHO) drinking water quality guidelines. Generally, for all the water sources the average concentration of calcium was below the WHO drinking water quality guidelines as well as DRI (Dietary Reference Index) recommendations. Moreover, the concentration of magnesium, sodium, and potassium was also found below the DRI recommendations for all the water sources. Microbiological parameter enumerated for TC in processed drinking water depicted bacterial population from 0 CFU/100 mL to 46 CFU/100 mL. The presence of TC in processed drinking water makes the water unacceptable for drinking purpose, although the physical parameters were almost within the WHO drinking water quality guidelines. The presence of required amount of minerals plays a critical role in maintaining human health system and vitality. Therefore, this study explores the quality of drinking water in the Kathmandu valley in terms of minerals and TC bacteria.

Keywords Total coliform · Dietary reference intake · Minerals · Water quality

Introduction

Water is one of the essential commodities required for living organism. Freshwater comprises 3% of the total water on earth where its access for human consumption is only 0.01% (Hinrichsen and Tacio 2002). Most of the water is either in the ocean or held in the Himalayas in the form of glaciers. Such kinds of water are out of the reach of human consumption. Moreover, this small proportion of freshwater available is also under the threat of pollution due to rapid population growth, unsystematic urbanization, and over-consumption in industries and agriculture. It is estimated that approximately 17% of global population fulfills their daily drinking water requirements from unprotected sources, 32% use the protected source of water, and 51% of the population depends on piped supply system for daily water requirement. In response to increasing water demand, exploration of new sources for drinking water such as recovered/recycled water, harvested rainwater, and desalinated water are increasing.

Similar to other urban areas of developing countries, Kathmandu, the capital city of Nepal, is also facing a critical problem of water in terms of both quality and quantity. Water demand in the Kathmandu valley is increasing due to the rapid growth of the urban population. The population of Kathmandu valley is 1.6 million, according to the census of 2011 (CBS 2012), and it is increasing continuously. Drinking water sources in the valley are limited and insufficient to meet the increased demand of treated water for the growing population. As an alternative, people in the valley depend on the private supply system (tanker water supply) and processed drinking water, which is popularly known as bottled water (Jha and Shreshtha 2013). Drinking water should be safe from the view of health perspective, and there should not be any existence of unwanted foreign matters. Additionally, the water used for drinking purposes should be rich in useful nutrients (minerals) recommended in the

✉ Bhoj Raj Pant
environmentnast@gmail.com

1 Nepal Academy of Science and Technology, Khumaltar, Lalitpur, GPO Box 3323, Kathmandu, Nepal

2 Present Address: Safa Sunaulo Nepal, Kathmandu, Nepal

DRI (DRIs 2004, FAO & WHO 1998). Nutrients such as sodium, potassium, calcium, and magnesium are essential for normal growth and physiological functions in the human body (Soetan et al. 2010).

Sodium is required to maintain body fluid volume and blood pressure in human. However, excess sodium can cause acute and long-term health problems such as hypertension and cardiac diseases (NRC 1989). Calcium supports in the repair, maintenance, and strengthening of bone functions (Welten et al. 1994; Bonjour 2005; Azoulay et al. 2001). Similarly, magnesium regulates enzymatic function in the human body. Its deficiency exhibits impaired growth, skeletal abnormalities, reproductive deficits, ataxia of the newborn, and defects in lipid and carbohydrate metabolism (Keen et al. 1999). Moreover, water rich in such minerals can provide supplemental source of essential minerals and can supply over one-third of the recommended dietary nutrients to the human body (Azoulay et al. 2001). Therefore, the main objective of this study was to analyze water quality and estimate minerals in the waters supplied in Kathmandu valley to ensure public health and safety.

Materials and methods

Materials

Sterilized polyethylene bottles (250 mL) were used for sample collection from the public and private water sources. Processed water (different brands of bottled water) packed in polypropylene terephthalate (PET) bottles were purchased from grocery stores in Kathmandu and Lalitpur districts.

Sodium hydroxide, sodium chloride, potassium chloride, ammonia buffer solution, eriochrome black-T, ethylenediaminetetraacetic acid (EDTA) were of analytical grade and purchased from local suppliers in Kathmandu. Membrane filter papers (0.45-µm pore sized Whatman filter paper) and M-endo agar Hi-media were used for estimation of coliform bacteria.

Sample collection and analysis

Samples were randomly collected from the public supply system (piped supply—20), private supply system (tanker water—20), and processed water (bottled water—20) from grocery stores in Kathmandu and Lalitpur districts of Kathmandu valley during January and February of 2015. Samples were collected in an icebox and transported to the laboratory within 6 h. Samples were stored in a refrigerator at ~ 4 °C until analysis. The standard method for analysis of water and wastewater (Greenberg et al. 2005) was used for sample collection, transportation, and analysis. The temperature and pH were measured in situ using a pH meter (EC 210 Rocker). The electrical conductivity (EC) in water was measured using a conductivity meter (HI 8633 Hanna).

Chemical parameters analyzed for the estimation of calcium and magnesium were measured volumetrically. For the determination of calcium, 50 mL of water sample was taken in an Erlenmeyer flask and 2 mL of 1 N sodium hydroxide solution was added followed by the addition of murexide indicator. This solution was allowed to stand until the development of pink color which was titrated against EDTA solution until the color of the solution changed from pink to purple. For analysis of magnesium, 50 mL of sample was taken in Erlenmeyer flask, where 1 mL of ammonia buffer solution was added followed by adding eriochrome black-T indicator. The solution was titrated against EDTA solution till the color of the solution becomes blue. The data obtained from titration were calculated to estimate the concentration of calcium and magnesium in water. Sodium and potassium were analyzed using a flame photometer. The standard solution for background correction was prepared by dissolving 2.542 g sodium chloride and 1.907 g potassium chloride in de-ionized water.

The microbiological parameter was analyzed to enumerate TC bacteria in processed drinking water. The water samples collected from the public water source and private supply systems were not tested for the presence of bacteria. This is because most of the water of these types of sources reportedly have high contamination of coliform. The WHO drinking water quality guidelines assert to analyze TC and *E. coli* (*Escherichia coli*) in water; however, the present study is limited to analyze only TC bacteria. The TC is indicator organism; its presence in water indicates the possibility of bacterial contamination (DoH 2016). The TC bacteria are abundant in nature and generally harmless to public health. Water tests for all possible pathogens are complex, time-consuming, and expensive. Therefore, for this study TC bacteria were only analyzed because of the simple, inexpensive analyzing method and the characteristics of the nonpathogenic nature of TC bacteria. If the test result reveals TC in water, there is a need to monitor the source and control bacterial contamination for safe drinking water (DoH 2016).

Results and discussion

Altogether 60 water samples were collected from the public water supply system in the Kathmandu and Lalitpur districts. Of these sources, public drinking water supply is limited in the valley, and responsible institution for water distribution is *Kathmandu Upatkya Khanipaani Limited (KUKL)*. Drinking water demand in the valley is approximately 366 million liters per day (MLD), and supply is limited to 187 MLD (Udmale et al. 2016). Hence, there is a huge gap between demand and supply, and sufficient amount of drinking water has not been supplied to the consumers. Insufficient water supply has compelled people to look for an alternative source to fulfill their daily need. Therefore, as an alternative solution most of the people in the valley rely on private water supply for drinking and other domestic purpose. Similarly, the water supplied by the private sector (tanker water) is available in the big tankers of 5000–10,000 L capacities and processed drinking water in the form of PET bottle and jars of 0.5 L, 1 L, and 20 L capacity. However, the source of water supplied by the private suppliers in the valley is mostly underground (deep boring of depth > 100 m) and some surface (spring) water which is not safe for drinking purpose. Moreover, the private water supply and processed drinking water are currently fulfilling the demand of water across the valley and have now gained commercial status.

Physical and chemical analyses

The samples were analyzed for physical, chemical, and microbiological parameters and results are presented in average values. Physical parameters were analyzed for temperature, pH, and EC (Table 1).

The average value of water temperature for public supply, private supply, and processed drinking water was 12.9 °C, 14 °C, and 14.7 °C, respectively. The WHO has not recommended specific guideline for drinking water temperature, and water temperature does not have any significant importance from the prospect of health and safety. Nevertheless, the European Economic Community (EEC) and Canadian drinking water guidelines have recommended maximum drinking water temperatures of 25 °C and 15 °C, respectively (Azoulay et al. 2001).

The average pH value of the public, private supply systems, and processed drinking water samples was 6.9, 7.7, and 6.8, respectively. These values are within the WHO recommendations for drinking water quality guidelines (Table 1). The pH generally has no direct impact on public health. However, exposure to extreme pH (either acidic or basic pH) results in eyes, skin, and mucous membrane irritations. Eye irritation and exacerbation of skin disorders have been associated with pH greater than 11. In addition, pH 10–12.5 has been reported to cause swollen hair fibers and gastrointestinal irritation (WHO 1986). Exposure to low pH (acidic pH) can result in similar effects. Water below pH 4 may cause redness and irritation of the eyes and the severity of which increases with decreasing water pH (pH < 4). The pH of water < 2.5 can damage the epithelium irreversibly (WHO 1996).

The EC of water samples collected from the public supply system, private supply system, and processed drinking water was 194.3, 184.5, and 53.9 µS/cm, respectively. These values agree the WHO drinking water quality guidelines (Table 1). The EC of the water is due to the presence of ionic substances and increases with the increase in the ionic concentration of water. Ionic substances released from metal, nonmetal, metalloid, and even organic substances are responsible for EC in water. These substances are available in water bodies due to percolation of leachate produced from waste materials and poor sanitation practices around the sources. The accepted value of EC reveals that the ionic substances are not in excess in tested water samples.

Chemical parameters were analyzed to estimate calcium, magnesium, sodium, and potassium ion in water samples (Table 2). These are the minerals required for normal growth of the human physiological system and considered as essential minerals.

Average calcium concentration was 17.7 mg/L, 27.1 mg/L, and 2.9 mg/L in the samples collected from the public supply system, private supply system, and processed drinking water, respectively (Fig. 1). The magnesium was 24.2 mg/L, 25.3 mg/L, and 9.4 mg/L. Similarly, the sodium and potassium were 9.6, 6.4, and 8.5 and 1.0, 0.65, and 0.6 mg/L, respectively. The WHO guideline value for minerals in drinking water is not available except for the calcium ions (250 mg/L). The calcium ion concentration estimated in the samples was far below the recommendations of the WHO drinking water quality guidelines (Fig. 1).

Minerals such as calcium, magnesium, sodium, and potassium are essential for normal growth and body functions. Inadequate intake of calcium increases the risk of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance, and obesity (WHO 1996). Magnesium content less than the DRI value causes endothelial dysfunction, increases vascular reactions, elevates circulating levels of creative protein, and decreases insulin sensitivity.

Table 1 Physical parameters

Source	Temperature (°C)			pH			EC (µS/cm)		
	Min	Max	Aver.	Min	Max	Aver.	Min	Max	Aver.
Public supply	12.0	14.2	12.9	5.9	7.9	6.9	45	451.5	194.3
Private supply	12.1	15.6	14.0	6.1	8.4	7.7	4	327	184.5
Processed DW	14.2	14.8	14.7	5.2	7.7	6.8	1	165	53.9
WHO guidelines		NA			6.5–8.5			500	

NA not available

Table 2 Mineral content in drinking waters

Source	Average mineral concentration (mg/L)											
	Calcium			Magnesium			Sodium			Potassium		
	Min	Max	Aver.	Min	Max	Aver.	Min	Max	Aver.	Min	Max	Aver.
Public supply	4.0	38.4	17.7	4.0	56.9	24.2	2.6	19.0	9.6	3.5	7.3	1.0
Private supply	2.4	65.7	27.1	2.0	60.5	25.0	3.7	29.5	6.4	1.0	2.3	0.6
Processed DW	0.8	6.0	2.9	6.0	14.9	9.4	2.0	19.7	8.5	6.1	6.1	0.6
WHO guideline	250			NA			NA			NA		
DRI (mg/day)	1000–1300			420			1500			3000–4700		

NA not available

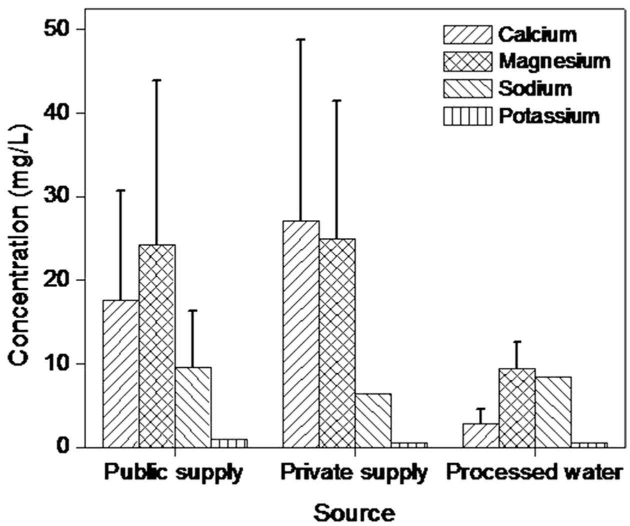

Fig. 1 Mean concentration (± SD) of minerals in drinking water

Sodium overdose results in hypernatremia which constantly increases the risk of hypertension. Deficiency of potassium in the human body causes muscular weakness, respiratory difficulties, and cardiac disturbances such as atrial or ventricular arrhythmias (Vander et al. 2001). The WHO dietary guidelines have recommended a reduced dose of sodium and increased potassium content in the diet (WHO 2013). Such combinations of dietary intakes can reduce the risk of hypertension and heart diseases (Aaron and Sanders 2014).

The Dietary Reference Intakes (DRIs) have recommended essential minerals required for perfect human health (Table 2). As shown in Table 2, the DRIs requirements for calcium, magnesium, sodium, and potassium is 1000–1300 mg, 420 mg, 1500 mg, and 3000–4700 mg, per day, respectively (FAO and WHO 1998; DRIs 2004).

A person can fulfill essential minerals mostly from the food intake including water as recommended in Table 2. However, the water alone also contains such minerals to some extent and can be a good source of nutrients. The minimum quantity of drinking water required per day for normal human physiological functions is about 2 L (Azoulay et al. 2001). Therefore, calcium, magnesium, sodium, and potassium were also estimated in 2 L of drinking water collected from different sources (Table 3).

Table 3 Minerals in two liters of drinking water

Average minerals in 2 L of drinking water (mg)				
Source	Calcium	Magnesium	Sodium	Potassium
Public supply	35.4	48.4	19.2	2.0
Private supply	54.2	50.0	12.8	1.2
Processed DW	5.8	18.8	17.0	1.2

The result demonstrates that the only minimum amount of minerals required for human health can be obtained from 2 L of drinking water supplied by private, public, and processed water supplies (Table 3). The amount of minerals estimated in 2 L of water reveals that the mineral content is below the DRI guidelines. For processed drinking water, these values are 5.8 mg/L, 18.8 mg/L, 17.0 mg/L, and 1.2 mg/L which shows that the amount of calcium is very less than for other two water supplies. Nevertheless, the minimum amount of minerals required for normal growth of the human body can be fulfilled from other food sources than the drinking water alone. It is difficult to assess the exact amount of minerals that the drinking water should provide for normal body functions. However, in USA 6% and 31% of calcium and magnesium, respectively, are fulfilled by drinking water. In European countries, bottled water contains 20–58% calcium and 16–41% magnesium as DRI for adults (Azoulay et al. 2001). Drinking water with minerals, lower than the recommended amounts, may affect body metabolism (Qiu et al. 2015).

Microbiological analysis

Bacterial population in the processed drinking water was enumerated from 0 CFU/100 mL to 46 CFU/100 mL. These

Table 4 Microbiological analysis of processed drinking water (PDW)

Sample code	Total coliform/100 mL of water (CFU)	Average
PDW-1	0	
PDW-2	0	
PDW-3	0	
PDW-4	2	
PDW-5	46	
PDW-6	2	
PDW-7	4	
PDW-8	18	
PDW-9	0	
PDW-10	0	9.7
PDW-11	0	
PDW-12	34	
PDW-13	0	
PDW-14	21	
PDW-15	16	
PDW-16	0	
PDW-17	31	
PDW-18	0	
PDW-19	20	
PDW-20	0	

are the minimum and maximum TC enumerated in water samples. As shown in Table 4, 50% samples satisfied the WHO drinking water quality guidelines (0 CFU/100 mL) and remaining 50% samples were found contaminated with TC bacteria. The processed water is considered safe for drinking purpose; however, most of the brands of the processed water exceeded drinking water guidelines with TC contamination. For ethical reason, the brand name of the processed water sample has not been disclosed and represented with code numbers from PDW-1 to PDW-20 (Table 4).

The presence of TC in the public and private water supplies is common in the valley. This was the reason all the samples collected from public and private water supplies were not analyzed for the TC count. Similar studies carried out to enumerate the bacterial population in the drinking water sources of Kathmandu valley reported maximum TC in groundwater (Subedi and Aryal 2010; Pant 2011). The bacterial population was far beyond the WHO drinking water quality guidelines. For drinking water, TC should be 0 per 100 mL of water (WHO 1996). Use of TC containing drinking water may causes diarrhea, dysentery, hepatitis, and cholera in severe cases (Subedi and Aryal 2010).

There are different methods to control TC bacteria in drinking water. In general, different chemicals can be added in water for decontamination. Similarly, the SODIS (solar water disinfection) is another water treatment method, where the water is exposed to the sunlight in PET (polyethylene terephthalate) bottle. Besides, a safe and reliable method of water decontamination is boiling. Heating the water to boiling temperature (~ 100 °C) kills most of the pathogenic organisms (WHO 2011).

Government initiation can play a positive role to make people aware about the importance of boiled water. Moreover, people in the valley are self-conscious about the hazard of TC bacteria; therefore, most of the people use boiled water for drinking purpose.

Conclusions

The water samples collected from public water supply, private water supply, and processed drinking water in the Kathmandu valley were analyzed for physical (temperature, pH, and electrical conductivity), chemical (calcium, magnesium, sodium, and potassium), and microbiological (TC) parameters to ensure the drinking water quality. The physical parameters were within the WHO drinking water quality guidelines. Chemical parameters analyzed for essential minerals (sodium, potassium, calcium, and manganese) in public and private water supplies were beyond the DRIs recommendations. For the processed drinking water, the minerals were below the guideline values and TC contamination was in 50% of the water samples. The water supplied across the valley for drinking and household use has less amount of essential minerals such as calcium, magnesium, sodium, and potassium than DRI values with TC contamination in most of the processed water. Therefore, use of such types of water may pose risk to human health.

Recommendations

The quality of drinking water supplied in the Kathmandu valley is poor mainly due to the presence of TC bacteria. Similarly, the essential minerals recommended in the DRIs are below the guideline values in most of the water supplied for drinking purpose. To maintain the drinking water quality standard, government initiation and effort is a must to provide safe drinking water to ensure public health and safety. For this, water quality monitoring and analysis should be carried out in a regular time interval. Subsequently, public and private partnership is required to provide public awareness about the water sources, its quality, and the importance of safe drinking water.

Acknowledgements Current study is a program of Nepal Academy of Science and Technology. The authors are grateful to the Vice Chancellor of the academy for his keen interest and encouragement to carry out this work.

Author contributions BRP supervised entire work. KT and SMS were involved in sample collection and analysis. DSR contributed to data analysis and manuscript preparation.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

References

Aaron KJ, Sanders PW (2014) Role of dietary salt and potassium intake in cardiovascular health and disease: a review of the evidence. Mayo Clin Proc 88(9):987–995

Azoulay A, Garzon P, Eisenberg MJ (2001) Comparison of the mineral content of tap water and bottled waters. J Gen Intern Med 16(3):168–175

Bonjour JP (2005) Dietary protein: an essential nutrient for bone health. J Am Coll Nutr 24(6):526–536

CBS (2012) Central bureau of statistics. National population and housing census 2011. National Planning Commission (NPC), GoN

DoH (2016) Coliform bacteria and drinking water. Department of Health, US. https://www.doh.wa.gov/Portals/1/Documents/Pubs/331-181.pdf. Accessed 25 Aug 2019

DRIs (2004) Dietary reference intakes (DRIs). Nutr Rev Wiley Online Libr. https://doi.org/10.1111/j.1753-4887.2004.tb00011.x

FAO & WHO (1998) Vitamin and mineral requirements in human nutrition, 2nd edn. Food and Agriculture Organization and World Health Organization, Geneva

Greenberg AF, Clescerl LS, Eaton AD (2005) Standard methods for the examination of water and wastewater, 20th edn. American Public Health Association (APHA), Washington DC

Hinrichsen D, Tacio H (2002) The coming freshwater crisis is already here. Finding the source: the linkages between population and water, Woodrow Wilson international center for scholars. ESCAP publication, Spring, Washington, DC

Jha PK, Shreshtha KK (2013) Climate change and urban water supply: adaptive capacity of local government in Kathmanu city, Nepal. J For 11:62–81

Keen CL, Ensunsa JL, Watson MH, Baly DL, Donovan SM, Monaco MH, Clegg MS (1999) Nutritional aspect of manganese from experimental studies. Nerotox 20:213–226

NRC (1989) Recommended dietary allowances, 10th edn. National Research Council, Washington DC

Pant BR (2011) Ground water quality in the Kathmandu valley of Nepal. Environ Monit Assess 178:477–485

Qiu Z, Tan Y, Zeng H, Wang L, Wang D, Luo J (2015) Multi generational drinking of bottled low mineral water impairs bone quality in female rat. PLoS One. https://doi.org/10.1371/journal.pone.0121995

Soetan KO, Olaiya CO, Oyewole OE (2010) The importance of mineral elements for humans, domestic animals and plants: a review. Am J Food Sci 4:200–222

Subedi M, Aryal M (2010) Public perception about drinking jar water and its bacteriological analysis. Nepal Med Coll J 12:110–114

Udmale P, Ishidaira H, Thapa BR, Shakya NM (2016) The status of domestic water demand: supply deficit in the Kathmandu valley, Nepal. Water 8:196

Vander A, Sherman JH, Luciano DS (2001) Human physiology: the mechanism of body function. McGraW-Hill, New York

Welten DC, Kemper HC, Post GB, Van MW, Twisk J, Lips P, Teule GJ (1994) Weight bearing activity during youth is a more important factor for peak bone mass than calcium intake. J Bone Miner Res 9:1089–1096

WHO (1986) Health impact of acidic deposition, 20th edn. World Health Organization, Geneva

WHO (1996) Guidelines for drinking water quality, 20th edn. World Health Organization, Geneva

WHO (2011) Emergency treatment of drinking-water at the point of use, World Health Organization. https://www.who.int/water_sanitation_health/publications/2011/tn5_treatment_water_en.pdf. Accessed 25 Aug 2019

WHO (2013) Guidelines on dietary salt and potassium. World Health Organization, Geneva