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Physico-chemical and Biological Properties of Groundwater Quality in Rural Settlement, Nadi, Fiji

Roselyn Naidu, Lionel Joseph[1] and Syed Sauban Ghani[2]*
School of Environment, The University of Auckland, City Campus, New Zealand
[1]Department of Science, The University of Fiji, Saweni Campus, Fiji
[2]General Studies Department, Jubail Industrial College, Jubail Industrial City – 31961, Saudi Arabia
✉ saubanghani@gmail.com

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Abstract: The current study investigated drinking water quality of samples taken from Arolevu village, a locality situated in Nadi, Fiji. The groundwater samples were collected and subjected to a comprehensive physicochemical and biological analysis. The analysis for the drinking water sample was conducted seasonally, six times a year, that is, three for the dry season and three for the wet season. The results retrieved from the analysis were compared to its maximum contamination levels (MCLs) based on the health-based guidelines provided by the World Health Organization (WHO). The WHO standards were used as an attribute to determine the sources of contaminants likely to be present at the study site. A degradation trend in drinking water quality in the context of climate change may lead to potential health impacts. Hence, it is important to understand seasonal variations in drinking water quality. A proper understanding of the drinking water quality through seasonal water analysis for nitrate, nitrite, potassium, calcium, magnesium and chlorine content as well as its microbiological presence to reduce preventable risks such as using calculated amounts of fertilisers and upgrading the sewerage system to alleviate drinking water contamination is devised through this study.

Key words: Temperature, pH, fecal coliform, residual chlorine, nitrate.

Introduction

Climate change is a phenomenon that is undeniably playing a crucial role in the supply and demand of water. The elevated concentration of greenhouse gases thickens the ozone layer. As a result, too much heat gets entrapped in the Earth's atmosphere causing a rise in temperature (Manabe, 2019). As the temperature increases, evaporation increases and this increased evaporation changes the precipitation patterns, which consequentially increases in rainfall in some parts of the region while declines in others (Bintanja, 2018; Manabe, 2019). Hence, if increased precipitation occurs, over a relatively short period of time but more profoundly then recharge of groundwater declines as water runs off into seas or rivers and flooding may result (Bintanja, 2018). It is also important to note that the evapotranspiration rate will not increase as much as precipitation because increased $CO_{2(g)}$ concentration urges stomata closure in leaves which reduces transpiration (Oki et al., 2006). Excess water run offs into seas or rivers stimulates sea level rise that can lead to saline water intrusion into groundwater aquifers near the coasts, eventually declining the available groundwater resources. Aladejana et al. (2020) mentioned that climate change can influence the level of chemical components and contaminants in ground water, for instance, temperature elevation causes increased dissolution, solubilisation,

*Corresponding Author

and degradation of chemicals and contaminants. In Fiji, precipitation occurs as rainfall rather than snow. When the snow melts during summer, water is infiltered into reservoirs gradually, however, when rain falls excess water is not infiltered efficiently but it runs off into seas and rivers. Therefore, Fiji is more prone to freshwater shortages. The changes in weather patterns arise from global warming that leads to droughts (Jang, 2012). Periodic drought lowers the water table, thereby hindering the flow of surface water into groundwater. It will, correspondingly, modify the water quality by reducing the dilution capability of contaminants and increasing the concentration of impurities (Aladejana et al., 2020). In addition, climate change models anticipate a higher prevalence of extreme precipitation events, lessened rainy days, and extended drought periods (Manabe, 2019). However, when rainfall does fall on drought-stricken parts, the dry soils are not able to absorb the water efficiently, increasing the chance of flooding (Oki et al., 2006).

The provision of high-quality drinking water is of paramount importance to human health and has been declared a basic human right by the United Nations Department of Public Information (2008). Although a major portion of Earth comprises of water, conversely, about 2.5% is freshwater of which only a minute fraction of about (6/100) is feasible as drinking water (Shrimali et al., 2008). Coastal countries such as the Pacific Island Countries (PICs) also known as Pacific Islanders often suffer with drinking water supply problems. They depend on rainwater, groundwater, and surface water as sources of drinking water (Mosley et al., 2004). Although complication is prevalent across the Pacific, the severity varies from country to country, especially the Fiji Islands, which is a victim to this problem too. Although a vast portion of Fiji receives treated freshwater services, it is not evenly distributed in many villages like Arolevu. This variability is due to the changing climate, geographical location, and socio-economic and environmental developments (Keresztesi et al., 2019). The present study anlyses water in terms of its quality by utilising some physico-chemical parameters and mitigation strategies.

Experimental

Collection and Sampling

The analysis for the drinking water from borehole and wells were carried out six times a year; three each in the dry season, i.e., August, September and October, in the year 2016 and in the wet season i.e., November and December, 2016 and January, 2017. The analysis was done once per month. The drinking water samples were collected from nine households in Arolevu, Tunalia and Marasa settlements located 17°48′11.1″S and 177°24′58.2″E in Nadi. The selected households were labelled as Arolevu 1, Arolevu 2, Arolevu 3, Tunalia 1, Tunalia 2, Tunalia 3, Tunalia 4, Marasa 1 and Marasa 2. Different methods of water collection was applied for every chemical and biological analyses. The samples taken from water bores were allowed to run for a few minutes and refrigerated in the laboratory at a constant temperature of 4°C before analysis.

Chemical Analysis

To analyse nitrate and nitrite content in drinking water, the samples were transported in an ice pack at temperatures between 1 and 5˚C within 24 hours. Cadmium reduction Flow Injection Method (4500-NO_3-I) with a flow injection system comprising a multi-channel peristaltic pump (IPS-8, Ismatec, Zurich) and a rotary 6-port injection valve (Latek, Heidelberg) were used to detect nitrate and nitrite (Heubeck et al., 2014). Stock nitrate standard and stock nitrite standard were prepared by dissolving 1.444 g KNO_3 and 1.214 g KNO_2, respectively, in 600 mL water with addition of 2 mL chloroform in a 1-L volumetric flask. The nitrate and nitrite standards were prepared using the stock standards prepared by diluting with water and a manifold equivalent was set up and column was packed with copperised cadmium granules. The concentration of nitrate and nitrite in drinking water was determined using the linear calibration curves plotted.

Potassium in drinking water samples was detected by Flame Photometric Method (3500-K B) using the Model 410 Classic Flame Photometer (475 41 200) from Sherwood Scientific Ltd, UK at a wavelength of 766.5 nm (Clement et al., 2007). The procedure to use the equipment was similar to 3500-Na.B.4, however, the emission intensity was measured at 766.5 nm (Clesceri et al., 1998).

The concentration of calcium and magnesium was determined by Atomic absorption spectrometer (AAS) using a Perkin-Elmer apparatus model 703 with Direct Air-Acetylene Flame Method (3111 B) and the calibration curve was prepared by plotting absorbance of standards versus their concentrations on a linear graph (Batley et al., 1977).

Chlorine was analysed with a Perkin Elmer LAMBDA 35 UV-Vis spectrophotometer (USA) at a wavelength of 515 nm using DPD Colorimetric Method (Chaplin et al., 2007).

All reagents used were of highest analytical grade. Potassium nitrite, potassium nitrate and chloroform were supplied by Associated Chemical Supplies Ltd, Fluka Analytical (Buchs, Switzerland). Water for preparation of solutions was from a Milli-Q purification system (>18 MΩ-cm). The copperised cadmium tube was from Alpkem (Clackamas, Oregon, USA).

Microbiological Analysis

The microbiological analysis was carried out using the Fecal Coliform Membrane Filter Procedure 9222 D (Long et al., 2005). The volume of water sample to be examined were selected using the Table 9222 B (Clesceri et al., 1998). The sample volumes that yielded counts between 20 and 60 feacal coliform colonies per membrane were used. Since the bacterial density of the sample was unknown, the volumes were filtered several times to attain a countable density. After filtration, culture dish was prepared and placed in waterproof plastic bags, inverted, and the petri dishes were submerged in water bath and were incubated for about 24 hours at approximately 44.5°C. After incubation, the colonies were counted and the feacal coliform density were calculated and recorded as fecal coliforms per 100 mL.

Results and Discussion

Seasonal Precipitation

Water analysis was carried out during the wet season (November and December, 2016 and January, 2017) and the dry periods (August, September and October, 2016) to evaluate the concentrations of nitrate, nitrite, potassium, calcium, magnesium, residual chlorine and fecal coliform. The obtained results were compared with the maximum contamination levels (MCLs), a health-based guideline provided by WHO. The rainfall data showed that January (10.13 mm) received the most rainfall apart from February (since last trial was done in January). Conversely, the least rainfall was achieved in September (0.24 mm) due to it being a dry period. Except February (used as an additional month to compare the rainfall difference), January received more rainfall (10.13 mm) while September received the least rainfall (0.24 mm) in the Nadi area.

Physical Analysis

The pH values of the water samples for wet season were slightly lower than the dry season (Table 1). Correspondingly, the average temperature for the wet season samples were slightly lower in comparison to those tested under dry season (Table 1). This is evident from the graphs of pH against temperature for dry season (Figure 1) and wet season (Figure 2). Graph shows a linear relationship of an increase in pH as the temperature increases since rain water is slightly acidic (pH of 5.6 on most occasions), therefore, making the samples pH slightly lower during the wet season (Keresztesi et al., 2019). The temperature variation

Table 1: The average pH and temperature analysis

Location	*pH (dry season)*	*pH (wet season)*	*Temperature (°C) (dry season)*	*Temperature (°C) (wet season)*
Arolevu 1	7.04	7.20	25.56	25.88
Arolevu 2	7.20	6.94	26.48	23.87
Arolevu 3	7.27	7.08	26.67	25.48
Tunalia 1	7.01	7.00	24.74	24.68
Tunalia 2	7.79	7.02	27.57	24.93
Tunalia 3	7.14	7.48	25.88	26.72
Tunalia 4	7.56	7.39	27.15	26.35
Marasa 1	7.07	7.00	25.68	24.47
Marasa 2	6.97	6.88	24.65	23.72

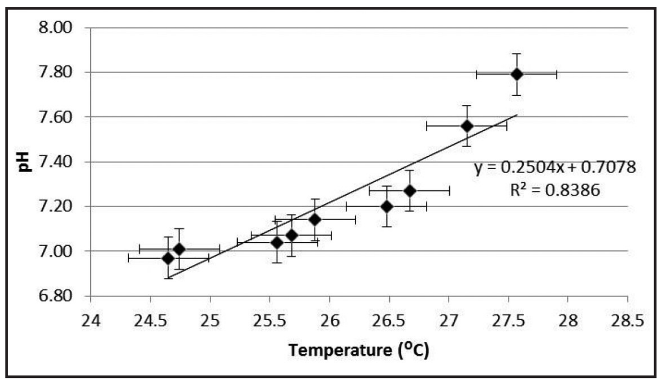

Figure 1: Plot of pH against temperature during the dry season.

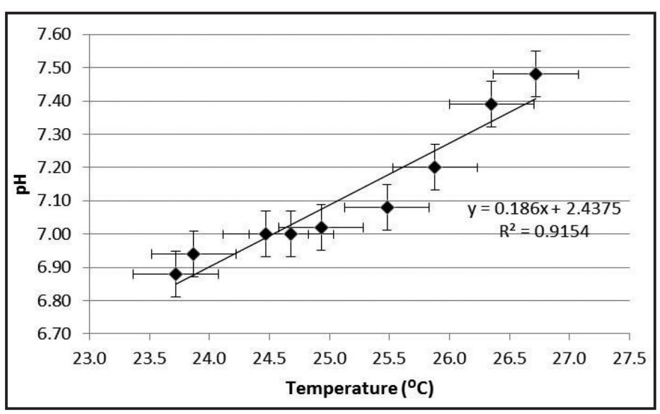

Figure 2: Plot of pH against temperature during the wet season.

in water samples during dry season is due to the heat from the sun, which also raises temperature of water, however, during wet season, there was more rain compared to the sun's heat to achieve a slight lower temperature of the water samples. There was a direct proportionality between pH and temperature of water samples, as the pH increased; there was an increase in the temperature of water as well. However, according to Castells et al. (2003) an increase in temperature should give a reduction in pH value. This is because increase in temperature increases the concentration of hydrogen [H^+] due to dissociation of molecules, leading to a lower pH value. R^2 expresses the strength of the relationship between the X (Temperature) and Y (pH) variables. It is the proportion of the variation in the Y (pH) variable that is explained by the variation in the X (Temperature) variable. R^2 can vary from 0 to 1; values near 1 mean there is very strong relationship between X and Y. The R^2 value (Figure 1) for dry season is slightly low as compared to wet season (Figure 2). This minor difference is observed as for the similar data, measuring Y (pH) over a smaller range of X (temperature) values yields a smaller R^2. pH values less than 6.5 and more than 9.2 impairs the taste of water but do not pose any health impact. A suitable range provided by World Health Organization (2011) is 6.5-8.5 and the values obtained is in range with the WHO standard.

Microbiological Analysis and Chemical Analysis

Drinking water obtained from wells and bores have impurities posing microbiological and chemical hazards. Even though groundwater is not in direct contact with faecal coliform, contaminants like surface water and rainfall are the vector that can transmit faecal material into groundwater. Mosley (2015) stated that reduction in wet period increases the risk of faecal health hazard as most people reuse the contaminated water. WHO guidelines strongly suggests that faecal coliform, also known as thermotolerant coliform bacteria, must not be detectable in a 100 mL sample (World Health Organization, 2011). The risk is categorised as 0 cfu/100mL (conformity), 1–10 cfu/100 mL (low risk), 10–100 cfu/100 mL (intermediate risk), 100–1000 cfu/100M L (high risk), and >1000 cfu/100 mL (very high risk). Drinking water should not contain any faecal coliform capable of causing any health effects such as diarrhoea, cramps, nausea, headaches (Farooq et al., 2008). The microbiological level of faecal coliform could be raised due to seepage from inefficiently designed sewage systems. The actual levels of faecal coliform was high during wet season for eight out of the nine sampling stations. A very large increase was noted (2700 cfu/100 L) during the wet season for Tunalia 2 with a much higher increase (4300 cfu/100 mL) during wet season for Tunalia 3. Conversely, faecal coliform level was high during the dry season for Tunalia 4. It did match our hypothesis as (8/9) households had higher likeliness of fecal coliform during wet season. All the values exceeded the WHO guideline posing health risks to the locals.

Besides the microbial contamination, chemical contamination levels of nitrate, nitrite, potassium, calcium, magnesium, and residual chlorine are also analysed. Arolevu, Marasa and Tunalia villages are agricultural based locality and use of fertiliser is drastically altering the nitrogen cycle with accumulation of nitrate and nitrite in groundwater resources. Presence of nitrate and nitrite above the World Health Organization (2011) standards in drinking water e.g., 50 mg/L for nitrate and 3 mg/L for nitrite may affect human health. When nitrate is ingested, it is converted to nitrite that binds to the globular protein (haemoglobin) forming methaemoglobin, which, in turn, hinders the haemoglobin from releasing oxygen to the tissues. Nitrate contamination in drinking water also poses risk of ovarian and bladder cancer (Weyer et al., 2001). Nitrate content was high during wet season for Arolevu 1, Arolevu 3, Marasa 2, Tunalia 1, Tunalia 2 and Tunalia 3 but low during the wet season for Tunalia 4. During the dry season, it was high for Arolevu 2 and Marasa 1. Arolevu 2, Marasa 1 and Tunalia 4 did not go well with our hypothesis, as there was low seepage rate of nitrate into the groundwater. Importantly, none of the values exceeded the WHO guideline. As for nitrite content: it was high during dry season for Arolevu 1, was high during the wet season for Arolevu 2, Marasa 2, Tunalia 1, Tunalia 2, Tunalia 3, Tunalia 4 while slightly high during the wet season for Arolevu 3 and Marasa 1. For most of the households, our hypothesis was relatable as the seepage of fertilisers was involved and the values obtained did not exceed the WHO standards.

As far as hardness is concerned, it was high during wet season for Arolevu 1, Arolevu 3, Tunalia 1, Tunalia 3, Tunalia 4 while for dry season, it was high in Marasa 1, Arolevu 2, Marasa 2, Tunalia 2. The variation in hardness and the resulting values were below the WHO guideline. According to World Health Organization (2011), daily intake of more than 3000 mg of potassium is required for humans, so MCLs guideline value of potassium is not established by WHO. However, the level of potassium, was high during dry season for Arolevu 1 and Arolevu 3 and much high during the wet season for Arolevu 2, Marasa 1. Same values were obtained during both wet and dry seasons for Marasa 2, high during wet season for Tunalia 1, Tunalia 3 and Tunalia 4, high during dry season for Tunalia 2. Most of the households had more potassium present in the drinking water during the wet season without any associated health risks.

Chlorine efficiently inactivates a high mass of pathogens, hence, it is utilised widely as disinfectant due to its low cost and high effectiveness (Farooq et al., 2008). For adequate disinfection, sufficient amount of residual chlorine should be used (> 0.5 mg/L), however, the concentration should not exceed 5 mg/L (Munavalli et al., 2003). Thus, residual chlorine was of 0.05 g/mL concentration throughout dry and wet season, a value well below the WHO standard.

Conclusions

The experimental data gathered from this study was used as a baseline to create awareness amongst the villages about reducing water contamination and improving their drinking water quality. It also provides a better understanding of the climate change vulnerability to drinking water quality and better adaptation strategies to manage drinking water efficiently. To reduce preventable risks to the drinking water, improved environmental monitoring and assessment by communities are needed such as calculated use of fertilisers and upgrading the sewerage system. Intense rainfall for short period leads to seepage of few chemical component. The feacal coliform is found in the groundwater reserves, while water with high concentration of fecal coliform due to seepage is induced by intensified rainfall. Some adaptation methods suggested are as follows: increasing water supply, conserving water and decreasing water demands, and upgrade water management policies. More research needs to be done in Fiji regarding climate change affecting the water sector and possibly more research aid should given to deal with water related issues.

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