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Health Risk Assessment of Heavy Metals in Drinking Water: A case study in Lenabatuwa Division of Southern Sri Lanka

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ABSTRACT

Groundwater is the major source of drinking water in the Lenabatuwa division, Kamburupitiya, Matara, Sri Lanka. This study was aimed to explore some heavy metal concentrations (Cu, Cd, Pb, Zn, Ni, and As) in drinking water and to assess the possible health risk for the people in the study area via drinking water usage. Heavy metal concentrations of the selected groundwater sources used by the locality for the drinking purpose were chemically analyzed using ICP-OES (Thermo scientific, ICAP Spectrometer 7000, UK). The values obtained were compared with the indices given by the world health organization (WHO) and Sri Lanka Standards (SLS) Institute. Average chronic daily intake (*ADI*), health risk quotient (*HQ*), and carcinogenic risk (*CR*) were calculated using the heavy metal concentrations. The majority of heavy metals investigated in this study area showed below the WHO and SLS standard limits. However, only a few samples were beyond the standard values of Pb and As. Moreover, drinking water quality is not according to the limits of pH. Based on the daily ingestion of water, it was revealed that the *HQ* is less than 1 in all samples showing no health hazard. However, according to the *CR,* the Pb concentrations in well water posed the lowest risk of 10^{-6}, and the As concentration was less to the highest risk having 10^{-4} in water samples in this area. Therefore, it is recommended to conduct routine monitoring in potable water sources, and appropriate measures should be taken to provide the provision of safe water to the residents in this area.

1. Introduction

Water acts as a vital commodity for the human, animal as well as for plants. However, polluted water may cause adverse effects on human life. Among such effects, waterborne diseases, kidney ailments, and cancers are the most threatening diseases for humans. Water is a major source that carcinogens can be entered into the human body. The heavy metals in the water reflect the high pollution due to persistence and bioaccumulation [1]. High concentrations of these metals such as As, Cd, Pb, and Cr in soil and water are highly toxic for humans, which may be the major cause of kidney, liver, and genotoxic carcinogen [2, 3, 4, 5]. Further, As can cause many serious health complications, including carcinogenesis, complications in the lungs, and skin [6, 7]. A high amount of Cu in drinking water may cause mental disorders [8]. Like many other heavy metals, Pb is considered a carcinogenic heavy metal, including several ailments damaging the nerves, kidneys, and memory relapses [9, 10, 11]. Zn toxicity causes anaemia [5], while Cd damages kidney functions and skeleton [11, 12].

Assessing health risk and multivariate statistical analysis for drinking water quality parameters have been reported by many researchers in the world [13, 14]. The existing heavy metals have been used to calculate ADI, HQ, and CR in Pakistan, Vietnam, and Turkey by Khan et al. (2008), Nguyen et al. (2009), and Kavcar et al. (2009) [15, 16, 17], respectively.

Cancer is one of the world's health concerns, and a scientific correlation between carcinogenesis and water quality would give a creditable conclusion. However, the scientific correlation between water quality and human health, especially carcinogenesis, has not been appropriately identified in Sri Lanka. This can be done by analyzing the drinking water sources for carcinogenic compounds such as heavy metals. Thus, a direct scientific relationship between water and cancer helps in controlling cancer incidence in targeted areas.

Health problems such as cancer and other digestive tract ailments were extensively reported in

Lenabatuwa division. During the period from 2015-2016, the cancer patients admitted to Karapitiya base hospital (Main Hospital for cancer patients in Southern Province), Sri Lanka from Lenabatuwa division, Kamburupitiya indicated the highest number of patients in Southern province according to the admissions of the cancer patients (unpublished data).

Further, by interviewing households in the study area, it was revealed that most of them use groundwater for drinking water as the main source for a long time since their birth. Therefore, this study was initiated to assess health risks regarding drinking water in this area. No research on water quality regarding heavy metal assessment and their toxicological hazards has been investigated in this area previously. Thus, this research targets examining the heavy metal concentration in groundwater and determining its possible health risk for the local population of Lenabatuwa division, Kamburupitiya Divisional secretariat (DS).

2. Material and Methods

2.1 Study area and sampling site

The sampling sites were located between 6^{o} 4' 25.2"- 6^{o} 4' 57.92" N latitudes and 80^{o} 32' 15.64"- 80^{o} 32' 42.44" E longitudes covering a total area of 2.5 km^2 (Figure 1) having a population of 1212. Total houses in this area are 290. The majority of the households consume well water and pipe-borne water from the water distributing springs for drinking and domestic consumption. The major occupation is agriculture, and 422 acres serve as cultivatable land for paddy, rubber, tea, cinnamon, and mixed cropping. Lenabatuwa Lake is the main source of irrigation in the area.

According to the purposive technique, water samples were collected from domestic wells, i.e., from cancer reported households, in Lenabatuwa division of Kamburupitiya DS. Also, water samples were collected from five natural water distributing springs in Kamburupitiya DS located between 6° 5' 45.68'' - 6° 5' 49.95'' N latitudes and 80° 35' 10.43'' - 80° 35' 39.35'' E longitudes which provide drinking water to the Lenabatuwa division and vicinity areas as pipe-borne water. These springs were considered for heavy metal analysis even though they are not located within the Lenabatuwa division as some households consume the pipe-borne water for drinking uses. The water distributed from these springs by community water systems is monitored infrequently and not purified before distributing to the public.

This area is fed by the Southwest monsoon rain, which usually receives from May to September with an annual rainfall of more than 2500 mm. The highest monthly average temperature is recorded in March, April, and May (30 ^{o}C), while the lowest average monthly temperature is encountered in November, December, and January (26 ^{o}C). The mean annual temperature is 26.7 ^{o}C. The average elevation of ridges is about 100 m above mean sea level. Metamorphosed Highland Complex rocks underlie the total area of the district. These rocks exposed in the area are composed of interlayered metasedimentary rocks, including garnet-biotite gneiss and massive charnokites [18]. The soil belongs to Ultisols that are mostly acidic soils.

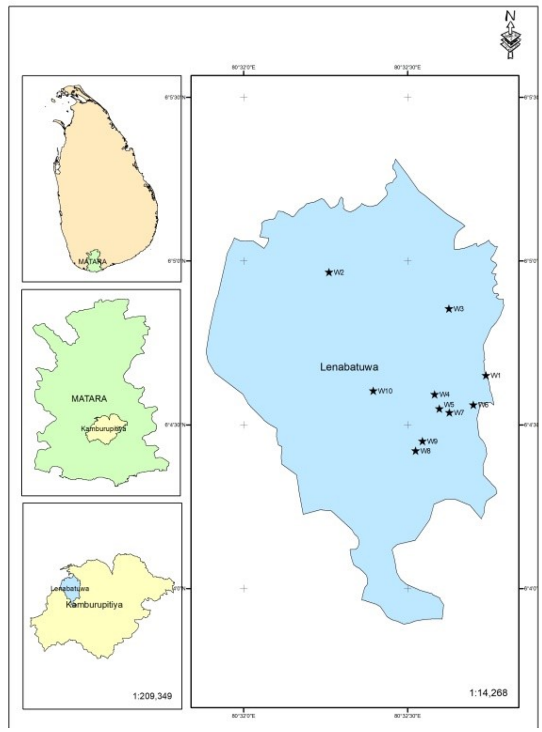

Figure 1: Map showing the sampling wells in the Lanabatuwa division.

2.2 Sampling

A total of 15 groundwater sample sites, including ten well water sampling sites and five spring water sampling sites, were selected. Samples were collected in pre-washed polyethylene bottles by deionized water. After collecting the samples, they were transported to the laboratory and stored less than 4 ^{o}C in a refrigerator. The GPS (global positional system) locations were recorded at each water source.

2.3 Interviews

Informal interviews with households were conducted at the time of sampling. Information such as type and history of ailments, drinking water sources, influence by agricultural fields, industry, etc., were obtained. The problems were thereby understood in-depth.

2.4 Analysis

The pH was measured onsite by a portable pH meter (HANNA HI 83099). The collected samples were filtered before analysis using Whatman No. 2 filter paper for analyzing heavy metals. They were kept in the refrigerator at 4^oC until analysis. All reagents used were in analytical grade, and certified standards were used (Fluka, Switzerland). Deionized water was used for preparing standard solutions to maintain the quality of calibration standards. Six heavy metals, namely Cu, Cd, Pb, Zn, Ni, and As were analyzed.

Heavy metals analysis was done in triplicate and was performed in the soil and water science laboratory of the Faculty of Agriculture, Rajarata University of Sri Lanka using an ICP-OE spectrophotometer (Thermo scientific, ICAP Spectrometer 7000 series, UK). A multi-element stock solution was used for the calibration. The stock solution of 100 mgL^{-1} was diluted according to the required working range.

2.5 Assessing heavy metal risk

Assessment of heavy metal risk was done using two assessment techniques, including (a) Exposure assessment, i.e., average chronic daily intake (ADI), and (b) health hazard assessment, i.e., Health risk quotient (HQ) and carcinogenic risk (CR).

Exposure assessment

The average chronic daily intake (ADI) in μg/kg/day by oral consumption was tested using the formula below (US EPA, 2005).

$$ADI=(C \times WCR)/BM \qquad (1)$$

where C, WCR, BM represent the heavy metal concentration in water (μg/L), average water consumption rate (2 L/day), body mass (62 kg), respectively.

Health hazard assessment

The Health risk quotient (HQ) and carcinogenic risk (CR) were calculated using equations 2 and 3 (US EPA, 2005), respectively.

$$HQ=ADI/TRD \qquad (2)$$

The oral heavy metal reference toxic dosage (TRD) for As, Pb, Cd, Ni, Cu, and Zn are 3E-04 mg/kg/day, 3.6E-03 mg/kg/day, 5E-04 mg/kg/day, 2E-02 mg/kg/day, 3.7E-02 mg/kg/day, 3E-01 mg/kg/day, respectively (US EPA, 2005).

$$CR=ADI \times CSF \qquad (3)$$

The cancer slope factor (CSF) and average daily dose (ADI) for a particular heavy metal are used to calculate CR. US EPA (2005) has given the CSF for As and Pb as 1.5 $(mg/kg\text{-}day)^{-1}$ and 0.0085 $(mg/kg\text{-}day)^{-1}$, respectively. According to their recommendations, if the CR exceeds one in a million (1.0E-06), the cancer risk would be significant. Risks of 1.0E-06 or lifetime cancer risk correspond to heavy metal concentrations considering lifetime exposure, which may originate one cancer incidence in a one million population.

2.6 Statistical Analysis

Data were analyzed using descriptive and inferential statistics using Excel 2010 and one-way ANOVA performed by SPSS version 25.

3. Results and Discussion

3.1 Groundwater characteristics

The results of the groundwater analysis were summarized in Table 1. Figure 2 shows the values of pH and heavy metals in well-water and spring-water in the study area and compares with the SL standards (1983) [19] and WHO standards (2008) [20]. pH in drinking water is considered an important parameter by various researchers [21]. However, pH is not a drinking water quality parameter under WHO regulations mentioning that it has no direct effect on human health. Yet, WHO gives a permissible range of 6.5-8.5. The pH indicates some indirect effects on water quality as some metal ions will increase its solubility and help pathogens to survive (US, EPA, 1977) [22]. Further, the deviation of pH from the permissible range indicates pollution by heavy metals [23].

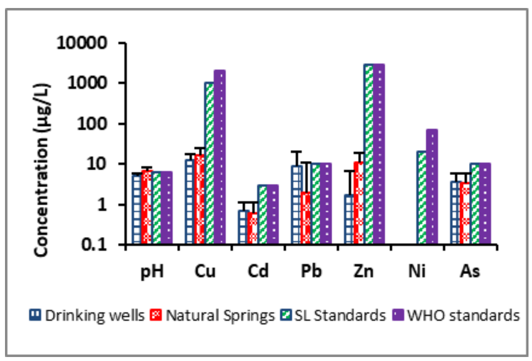

Figure 2: Comparison pH and heavy metals in well-water and spring-water in the study area with the SL standards and WHO standards.

High levels of pH can cause drinking water a bitter taste [24]. The pH of well water ranged from 4.34-6.73, 90% of wells having low pH than both WHO and SLS limits. However, spring water ranged from 5.50-7.48, which all the springs had pH within the permissible limit except in one spring. pH value in drinking water may vary due to rainfall, temperature fluctuations, agricultural activities, and natural processes. Water with low pH values is mostly contaminated with pollutants and hazardous for drinking uses.

Table 1: pH and the heavy metal concentrations (µg/L) in groundwater samples in the study area

Parameters	Groundwater					
	Well-water N[a]=10			Spring water N[a]=5		
	Range	Mean	Standard Deviation	Range	Mean	Standard Deviation
pH (1:2.5)	4.34-6.73	5.20	0.67	5.50-7.48	6.77	1.55
Cu (µg/L)	<1.00[b]-22.00	12.70	8.25	9.00-34.00	17.00	8.34
Cd (µg/L)	<1.00[b]-2.00	0.70	0.67	<1.00[b]-2.00	0.60	0.68
Pb (µg/L)	<1.00[b]-34.00	9.00	11.50	<1.00[b]-10.00	2.00	9.55
Zn (µg/L)	<1.00[b]-12.00	1.70	3.95	1.00-22.00	10.80	7.29
Ni (µg/L)	<1.00[b]	<1.00[b]	<1.00[b]	<1.00[b]	<1.00[b]	<1.00[b]
As (µg/L)	2.00-8.60	3.55	2.41	<1.00[b]-6.80	3.48	2.34

a = number of samples, b = below detection limit

SLS and WHO recommend a permissible limit of Cu content in drinking water as 1000 µg/L and 2000 µg/L, respectively. Cu content in groundwater in the study area was well below permissible limits. However, the highest copper concentration (34 µg/L) was found in spring water (Table 1). Cu content may vary widely with the variations in water characteristics, such as pH. According to both standards, Cd concentrations in unpolluted natural waters should be below 3.0 µg/L. Cd varied between <1.00-2.00 µg/L in selected groundwater samples of the area. The permissible value for Pb in drinking water is 10.0 µg/L. According to the analytical results, well water showed a higher Pb, and 40% of the sample sites showed beyond the permissible level. However, spring water shows below the standard level of Pb concentration (Figure 2).

Zn concentration is higher in spring water samples than well water samples. However, Zn concentration in all the samples was below the permissible level of 3000 µg/L. In all groundwater samples, the Ni concentration was below the detection level. The maximum allowable level of As indicated by WHO standard in drinking water is 10.0 µg/L. All the groundwater samples contained As lower than the standard limit. However, the maximum As content (8.6 µg/L) was found in well water. [25]. Moreover, the National Research Council of the US (2001) [26] has illustrated the relationship between water quality and quantity.

Numerous factors may affect water quality, such as geological factors, hydrological factors, land use patterns, and climate variations.

3.3 Human health risk assessment

Even though the households in this area have many health problems, they cannot afford bottled water for drinking due to the low income. Therefore, their main source of drinking water is well water or pipe born water from springs. None of these sources are purified or treated before consumption.

Among average *ADI* values, the highest values were observed for Cu in well water and spring water (Figure 3) in this area. This is due to the high Cu concentration in drinking water compared to other heavy metals. Thus, according to the *ADI* values, the heavy metal intake varies in order of Ni<Cd<Zn<As<Pb<Cu in well water and Ni<Cd<Pb<As<Zn<Cu in spring water, respectively (Figure 3).

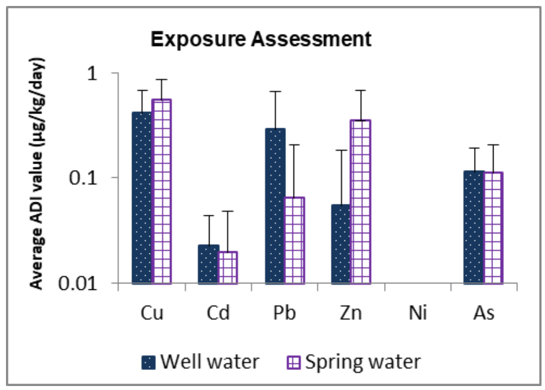

Figure 3: Average daily intake (*ADI*) values of the heavy metals in drinking water

Khan et al. [15] showed that health hazard risk increased when the *HQ* values were higher than 1. Arsenic showed higher average *HQ* values in both well water and spring water than other heavy metals (Figure 4). However, these values have not exceeded the recommended *HQ* value. Regarding the As, higher *HQ* values may be recognized due to its contaminated nature with a higher concentration and low *TRD* values. The *HQ* values of As ranged between 0.04 – 0.93 and 0.00-0.63 in well water and spring water, respectively. Even though the concentration of Pb in well water exceeds the permissible limit of WHO and SLS, the *HQ* value was less than 1. This may be due to its high *TRD* value. According to the *HQ* values, Ni, Cd, Pb, Cu, and Zn had low health risk to households in the study area. Although the risk is low, the *HQ* indices were comparatively high in Cd and Pb. The *HQ* values of the well water and spring water were increased as Ni<Zn<Cu<Cd<Pb<As and Ni<Zn<Cu<Pb<Cd<As, respectively (Figure 4).

Carcinogenic risk (*CR*) was determined according to US EPA (2005) [27] equations. The *CR* indicates a statistical probability for the occurrence of cancer in an individual due to exposure. *CR* was calculated only for As and Pb by the values given by the US EPA. According to the results, the *CR* indicated low in Pb and less to the highest risk in As. The average *CR* value for As in well water samples and spring water samples in the study area was 1.71E-04 and 1.68E-04, which was considered higher than the benchmark level (1.0E-06). This probability value of As shows a lifetime cancer risk of around 2.0E-04, corresponding to 2 cancer cases per ten thousand people. Evans et al. [25] stated that one person in a million (10^{-6}) is the standard *CR* of drinking water in the USA. The average *CR* value of Pb in well water showed 2.46E-06 indicating a low risk. Further, the average *CR* of Pb in spring water (5.48E-07) is below the benchmark level. According to the calculations in the Lenabatuwa area, the *CR* values were lesser than the values stated by Nguyen et al. (2009) [16] in Vietnam and much higher than the values stated by Khan et al. [30] for drinking water in Pakistan.

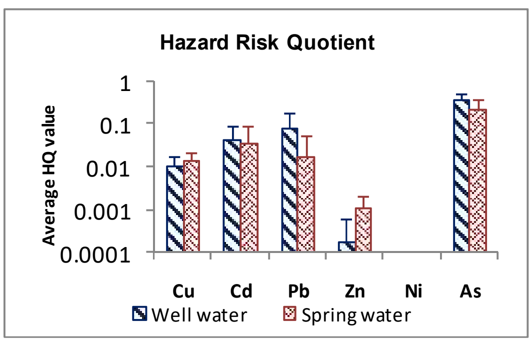

Figure 4: Average Hazard Risk Quotient (*HQ*) calculated for heavy metals in Lenabatuwa Division

The drinking water contamination with heavy metals is accountable for many human health ailments [16, 31]. During the interviews with people in this area, many respondents complaint about different health disorders such as gastritis, liver and kidney ailments, hyperkeratosis (thickening of the epidermis), and cancer.

3.4 Limitations of the study

The *ADI* calculation was done for the Lenabatuwa population using a water consumption value of 2 L/day given by the US EPA. However, many previous studies had used a different daily consumption rate according to diverse regions and climates [23]. Based on a survey, Gillies and Paulin [28] had used an average daily water consumption rate of 1.256 L/day. Moreover, research done in Korea has used the daily consumption rate as 2.56 L/day [29]. Further, Lim et al. [23] stated the limitation of their study using 2 L/day for average water consumption as it may be biased due to respondents' recalling information. Thus, the daily water consumption rate will affect the assessment outcome of *ADI*, *HQ,* and *CR* values study areas, which were 1.71E-04 and 1.68E-04, which is considered higher than the benchmark level (1.00E-06).

The drinking water contamination with heavy metals is accountable for many human health ailments [16, 31]. During the interviews with people in this area, many respondents complaint about different health disorders such as gastritis, liver and kidney ailments, hyperkeratosis (thickening of the epidermis), and cancer.

Furthermore, the respondents' bodyweight was assumed less (62 kg) in the present study than the US EPA's recommended value (70 kg). Less value was used in many studies than the US EPA's suggested value [21, 32, 33]. If the body weight were anticipated 70 kg for the study area's respondents, the health risk assessment would have been given incorrect estimation according to gender body mass variation.

The present study was conducted only for the Lenabatuwa division as a case study to assess the drinking water samples' health risk. Nevertheless, a comprehensive risk assessment must be done for the whole Kamburupitiya divisional secretariat or the district level regarding the drinking water contaminant occurrence. Thus, a large number of data should be analyzed to obtain a more reliable conclusion of water quality deterioration in the area.

4. Conclusion

Results reveal that the majority of well water samples are highly acidic. The majority of the heavy metal concentrations were found within the WHO standards and SL standards. However, only a few samples showed higher concentrations in Pb and As than their standard limits. According to the one-way ANOVA, well water and spring water showed significant variation in pH and Zn. The health risk assessment results of *ADI* and *HQ* indicated low health risk considering the daily intake of drinking water, especially As. However, according to the *CR* calculation, the drinking water showed a high carcinogenic risk of As and Pb in the study area.

It is recommended that routine monitoring should be done in potable water sources in the study area to determine their suitability for drinking purposes. Moreover, the long-term sampling data may give a clear picture of the water quality of this area. However, currently, the local authorities' funds for water quality assessment in this area are minimal. Thus, to overcome the public's health risks in this area, funds should be allocated for routine drinking water analysis or alternatives to drinking water. Furthermore, proper treatment techniques to provide safe water to the individuals in this area, proper awareness programs, and preventive health screening clinics should be introduced by the local authorities.

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