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HEALTH RISK ASSESSMENT OF MANGANESE IN DRINKING WATER FROM GRAVITY FEED SYSTEM AMONG CHILDREN OF ORANG ASLI COMMUNITY

Haninah Fadiah M[1], Shaharuddin MS[1], Vera Yulyani[2]

[1]Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

[2]Department of Public Health, Faculty of Public Health, Universiti Malahayati, No. 27, Jalan Pramuka, 35153 Bandar Lampung, Indonesia

Corresponding author: Shaharuddin MS; shaha@upm.edu.my ; Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; +603-9769 2407

ABSTRACT

Objective: Manganese is an essential element for humans; however, high exposure to humans can give adverse health effects, especially neurobehavioral problems among children. Manganese may enter the human body through ingestion of drinking water from sources that are not treated such as gravity feed systems. This study aims to determine the health risk from exposure to manganese in drinking water from gravity feed systems among children of Orang Asli in Ulu Chuai Village, Rembau, Negeri Sembilan.

Method: A cross-sectional study design was conducted by collecting 38 samples of water from the household of Orang Asli Ulu Chuai Village to analyse the levels of pH and concentration of manganese in the drinking water. A questionnaire was used to interview 38 children aged 9 to 17 years old about their daily water intake and a weighing scale was used to measure their body weight.

Result: All respondents (38) were using the gravity feed system as their water source and 92.1% of the children drink water that has been boiled while 7.9% directly drink from the pipes. The median level of manganese (0.20 mg/L) was above the NDWQS (0.1 mg/L) while the mean level of pH (6.87) was between the standard (6.5 – 9.0). There was no significant correlation recorded between manganese concentration and the pH level while the maximum HQ value (0.1185) obtained was below 1.

Conclusion: High concentrations of manganese were found in the water from the gravity feed system; however, lower HQ values indicate no health risk was observed when the children consumed the water. Therefore, the water is considered safe, but actions need to be taken to ensure that the manganese concentration will not exceed the standards in the future.

Keywords: Manganese, gravity feed system, health risk, drinking water, children

1. Introduction

The gravity feed system is one of the water supply systems that is commonly used by the Orang Asli community which does not have any water treatment process before the water distributes to their houses. Manganese is a heavy metal that may enter the water through a reduction of rocks or soils in the water (Gray, 2008), especially from a gravity feed system where the distribution system is not monitored regularly. It can also be present in the environment especially water from human activities as the sources such as mining and leaching from a landfill near the area (Rollin, 2011). Health Canada stated that the prevalence of manganese in groundwaters is higher than in surface waters and it can be exposed to humans through the presence of metals in food, air, consumer products, soil as well as drinking water (Health Canada, 2016).

Inhalation and ingestion are the main routes of exposure to manganese in the human body where inhalation is mostly exposed to workers due to occupational factors while everyone that consumes food or drinking water that contains high amounts of manganese can be exposed through ingestion (Rollin, 2011). Manganese is easily absorbed by the body through the consumption of drinking water compared to ingested food. Therefore, levels of manganese in the source of drinking water are vital to be monitored to ensure it is between the standard limit set by the Ministry of Health in the National Drinking Water Quality Standard (NDWQS) so that negative health effects can be prevented.

Manganese concentration in drinking water should not be more than 0.1 mg/L based on the NDWQS from the Ministry of Health Malaysia (2016). Consumption of drinking water with a high level of manganese may give negative health effects on the body. Many enzymes including manganese superoxide dismutase arginase and pyruvate carboxylase require manganese as a cofactor; while in combination with vitamin K, manganese can aid in blood coagulation and hemostasis (National Institutes of Health, 2021). In addition, manganese has a function for bone formation, reproduction and immune response as it helps in the metabolism of amino acids, cholesterol, glucose and carbohydrate (Li & Yang, 2018). Thus, 42 per cent of manganese in the human body is stored in the bone while the rest may also contain in the liver, pancreas, kidney and brain (O'Neal et al., 2014). However, problems with memory, attention and motor skills may exist when children and adults consumed high levels of manganese for a long-time including consumption of drinking water (Minnesota Department of Health, 2021).

There are no strong studies that show the results of the health effects of manganese in drinking water for adults. However, many studies have shown evidence of adverse health effects of manganese exposure on children, especially in terms of neurobehavioral effects. It's also uncertain, according to Ljung and Vahter (2007), if Mn exposure affects both younger and older children, or whether symptoms seen in older children are the result of newborn exposure; thus, according to the authors, more study is needed to determine the causal association between Mn exposure and children's health (Water Research Foundation, 2015). According to data from research by Bouchard et al. (2011), a 10-fold rise in tap water containing manganese was linked to a drop of 2.4 IQ points in the children. This revealed that exposure to manganese at levels in groundwater had a relationship with intellectual deficits in children. In addition, Khan et al. (2012) assert that their investigation into the relationship between manganese and arsenic exposure in drinking water and academic achievement in Bangladeshi children demonstrates a significant relationship between water containing more than 400 g/L and the reduced mathematic scores that were observed after adjusting for confounders. Recent research in Bangladesh has found a relationship between consuming high quantities of manganese in drinking water and neurotoxic effects in children that influence both their intellectual ability and neonatal mortality (Rollin, 2011).

According to Dion et al. (2018), a follow-up assessment of a cohort study of Canadian school-aged children shows there is a substantial decline in the IQ scores of kids who were previously reported to have been exposed to greater manganese concentrations. The association between exposure to high levels of manganese in drinking water and neurobehavioral effects in children, such as behavioural problems, a lower IQ, memory problems, and a lack of attention and coordination, is also supported by a number of other studies (Health Canada, 2016). All available research on children has demonstrated a reasonable association between increased manganese concentrations in drinking water and impaired neurological function, which is confirmed by the discovery of neurotoxicity in early-life rodent studies, despite differences in study design, demographic characteristics, nutrition, elemental drinking water composition, exposure length, and other confounding variables (Brown & Foos, 2009). According to tests on mice given 3 mg/L of manganese chloride to drink for 180 days while nursing, as well as additional studies on male rats given 1000 mg/L of water for 360 days, alterations in the neurotransmitter system during manganese intoxication were observed to vary with the period of exposure. The research demonstrates that manganese exposure raised the levels of dopamine, norepinephrine, and tyrosine in the corpus striatum (Health Canada, 2016).

By using gravity as a driving force, gravity feed systems are frequently utilised to transport surface water sources, primarily from rivers or reservoirs into homes or crops (Masseroni et al., 2017). The population of the hills, which is considered to be a hard-to-reach population and in need of support, uses a gravity feed system as a common water system. In Malaysia, there have been no studies as of yet which relate manganese exposure in drinking water from the gravity feed system among children of Orang Asli. There is a need to provide baseline data on heavy metals exposures in gravity feed systems in order to compare it to National Drinking Water Quality Standards (NDWQS). This is to ensure children from the Orang Asli community in the remote area were not subjected to high-level manganese exposures that have negative health effects such as poor neurobehavioral effects. Therefore, this study aims to determine the health risk from exposure to manganese in drinking water from gravity feed systems among children of Orang Asli in Ulu Chuai Village, Rembau, Negeri Sembilan.

2. Materials and Method

2.1. Sites and Population Description

This was a cross-sectional study conducted among children of the Orang Asli community aged 9 to 17 years old who lived in the Orang Asli community. This study was conducted at Orang Asli Ulu Chuai Village, Rembau, Negeri Sembilan that are using a gravity feed system as its source of water supply. The purposive sampling method was used to determine the sampling population based on a few exclusion and inclusion criteria. Figure 1 shows the study location where this research was conducted. The study population of this research was children of Orang Asli from Ulu Chuai Village, Rembau, Negeri Sembilan. The population was chosen because children and teenagers are the most susceptible to the negative health effects due to the higher consumption of dietary contain manganese. The inclusive criteria was children aged 9 to 17 years old that has been living in the community village since born or more than 9 years and only use a gravity feed system as the source of water supply. The exclusive criteria that were excluded were children who drink water from a water filter at home.

2.2. Sampling and Analysis

A questionnaire adapted from the National Human Exposure Assessment Survey (NHEXAS) was distributed among the respondents which were children aged 9 to 17 years old to collect information on their sociodemographics, usage of water and house area after getting permission from the parents. The weight of the children was also taken using a digital weighing scale and was used in the calculation for health risk assessment.

Water samples were collected from the 38 respondents' houses in August 2022. Duplicate samples were collected from each house in 250 mL HDPE bottles. Before collection of the samples, tap water was allowed to run for 2 minutes to let out any contamination in the tap. Then, the tap water was collected in the HDPE bottle to the tip of the bottle before being closed using the cap. The levels of pH were measured at the site by using a pH meter that was already calibrated using a buffer solution of pH 4, 7 and 10.

Manganese concentrations were analysed within 24 hours by using a HI801 Iris Visible Spectrophotometer with specific reagents for high-range manganese. The Manganese HR method was used as the procedure where 10mL of the unreacted sample was filled in the cuvette as well as a packet of HI93709A-0 Manganese High Range Reagent A. The cuvette was capped and shaken gently for 2 minutes to mix it. Then, one packet of HI93709B-0 Manganese High Reagent B was added and the cap was replaced before shaking the cuvette gently for 2 minutes. The cuvette was then placed in the holder of the spectrophotometer to analyze the data for manganese concentration which appeared on the screen. These steps were then repeated for each water sample.

2.3. Health Risk Assessment

In this study, the non-carcinogenic health risk was assessed using the chronic daily intake (CDI) of manganese and hazard quotient (HQ) based on the United States Environmental Protection Agency (USEPA) method (USEPA, 2004). The data obtained from the questionnaire, measurement and analysis were used in Equation 1 (Eq.1) to calculate the health risk assessment:

$$CDI = (CW \times IR \times EF \times ED) / (BW \times AT) \quad \text{(Eq.1)}$$

where CW is the average concentration of Mn (mg/L) in water, IR water is the ingestion rate of water, EF is the exposure frequency, ED is exposure duration, AT is the average time and BW is the body weight which all gained based on the questionnaire.

The HQ was calculated using Equation 2:

$$HQ = CDI / RfD \quad \text{(Eq. 2)}$$

RfD is the oral reference dose for Mn which is 0.14 mg/kg/day (Agency for Toxic Substances and Disease Registry, 2012). When the HQ is less than or equal to 1, the risk is regarded as negligible to low, and the exposed receptor population won't experience any unfavourable effects. However, when it is greater than 1, the risk is significantly high and there may be negative effects from the exposure.

2.4. Data Analysis

Microsoft Excel 2019 was used to calculate human health risk metrics and other general calculations. SPSS software version 26.0 was used to analyse the data. The results of the questionnaire given to the respondents and the measurements of manganese in a sample of drinking water were presented as descriptive statistics with mean, median, variance, standard deviation, maximum value, and lowest value. Shapiro-Wilk Test was carried out to test the normality of the data obtained and it indicated that the dataset for manganese concentrations was not normally distributed. Subsequently, a non-parametric One Sample Wilcoxon Signed-Rank Test was used to determine the significant difference between the manganese levels in drinking water and the standard limit of manganese from the National Drinking Water Quality Standard. The Spearman Correlation was also used to determine the association between levels of pH and manganese concentration in drinking water samples.

2.5. Ethical Considerations

The data collection was conducted after obtaining ethical approval from The Ethics Committee for Research Involving Human Subjects (JKEUPM). The ethical forms were first submitted to the Medical Research Committee, Faculty of Medicine and Health Science, University Putra Malaysia and approval for conducting the research was gained before the research started. Besides, the approval letter was also sent to JAKOA (Jabatan Kemajuan Orang Asli) and the head village of Ulu Chuai Village, Rembau, Negeri Sembilan. A written consent letter was then obtained from the parents of selected children prior to the research. An explanation and briefing were given to the respondents and the parents before the research was conducted. The information gathered during this research was confidential and kept for research purposes only.

3. Results

This study was able to recruit 38 participants consisting of 23 females and 15 males from 9 years old to 17 years old. The average body weight of the respondents was 43.9 kg. Each respondent has a varied daily water intake. Out of 38 respondents, 1 (2.6%) respondent consumed less than 0.5 litres of water per day, whereas 29 respondents (76.3%) consumed between 0.5 to 1.5 litres and 8 respondents (21.1%) consumed between 1.6 to 3.0 litres per day (Table 1).

Table 1. Gender, average weight of respondents and water intake (liter/day) (n = 38)

Variable	Freq (%)	Mean ± SD	Median (IQR)	Min – Max
Male	15 (39.5)			
Female	23 (60.5)			
The overall weight (kg)		43.90 ± 14.62	45.2 (17.3)	18.1 – 74.9
Male weight (kg)		41.73 ± 13.67	45.8 (21.9)	18.1 – 60.4
Female weight (kg)		45.32 ± 15.33	44.5 (23.2)	20.8 – 74.9
Daily water intake (l/day)				
< 0.5	1 (2.6)			
0.5 – 1.5	29 (76.3)			
1.6 – 3.0	8 (21.1)			
>3.0	0			

3.1. Water analysis

Each water sample was analysed for pH level and manganese (Mn) concentration. The average pH was 6.87, with a standard variation of 0.14 (Table 2). The range of pH levels was between 6.57 to 7.10 which was under the range of acceptable limits by the National Drinking Water Quality Standards (NDWQS). Additionally, the mean concentration of Mn was 0.15 mg/L, with a 0.06 standard deviation and 0.20 mg/L median with a 0.10 mg/L interquartile range. A comparison of the manganese concentration with the NDWQS showed that the median was above the acceptable limit (0.1 mg/L). Figure 2 and Figure 3 show the levels of pH and Mn concentrations for all samples with the standard limit by NDWQS.

Table 2. Average levels of pH and Mn concentrations (n=38)

Variable	Mean ± SD	Median (IQR)	Min	Max
pH Level	6.87 ± 0.14	6.86 (0.22)	6.57	7.10
Mn concentration	0.15 ± 0.06	0.20 (0.10)	0.00	0.20

There was no significant correlation between Mn and pH (Table 3). Based on the results of the correlation test, the correlation coefficient, r was -0.071 with a p-value of 0.671.

Table 3. The correlation between levels of pH and manganese concentrations (n = 38)

	Sig. (2-tailed)	Correlation coefficient, r
pH - Mn	0.671	- 0.071

* *p is significant when <0.05*

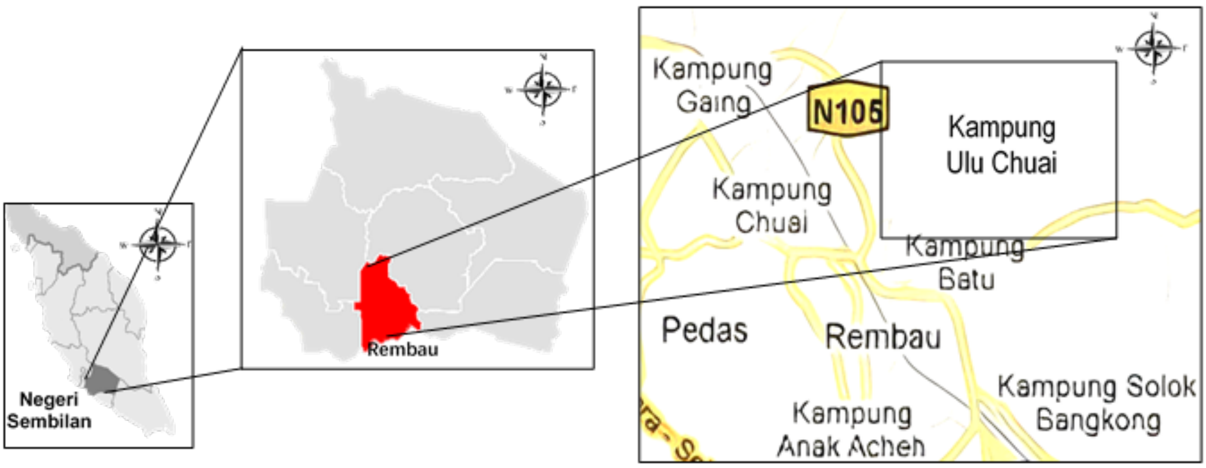

Figure 1. The study location

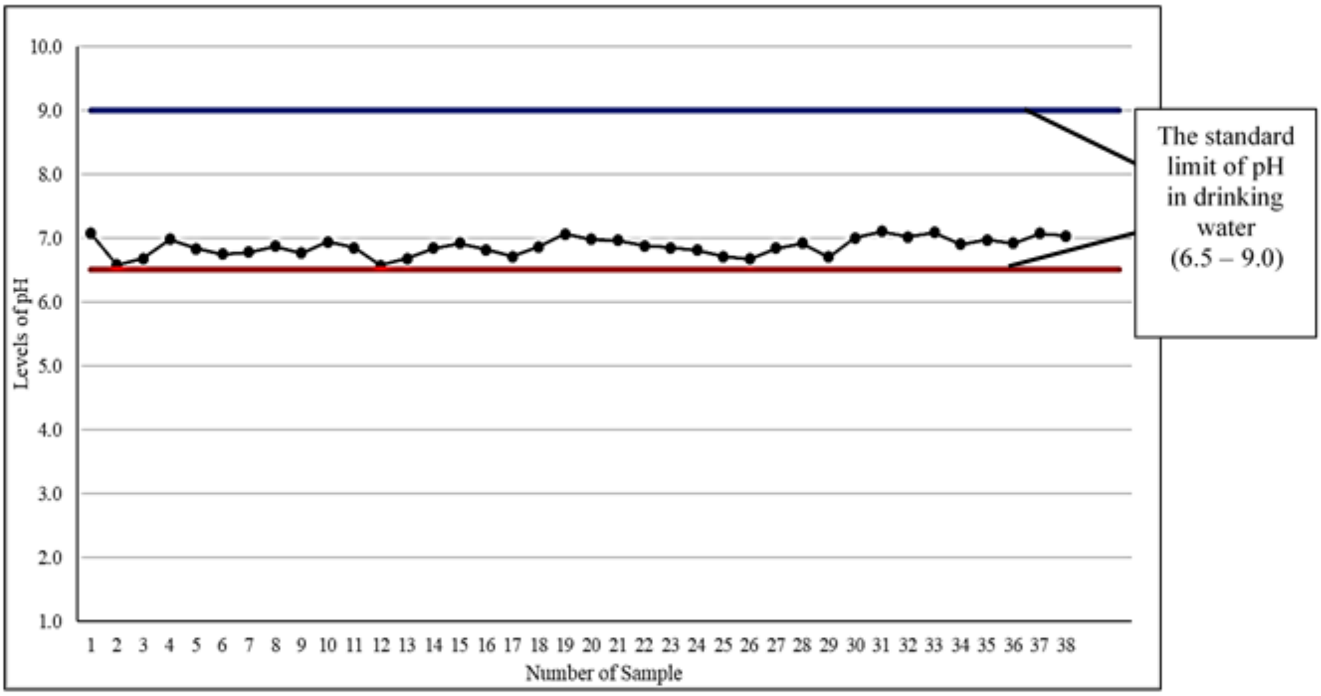

Figure 2. Levels of pH for water samples with standard limit from NDWQS.

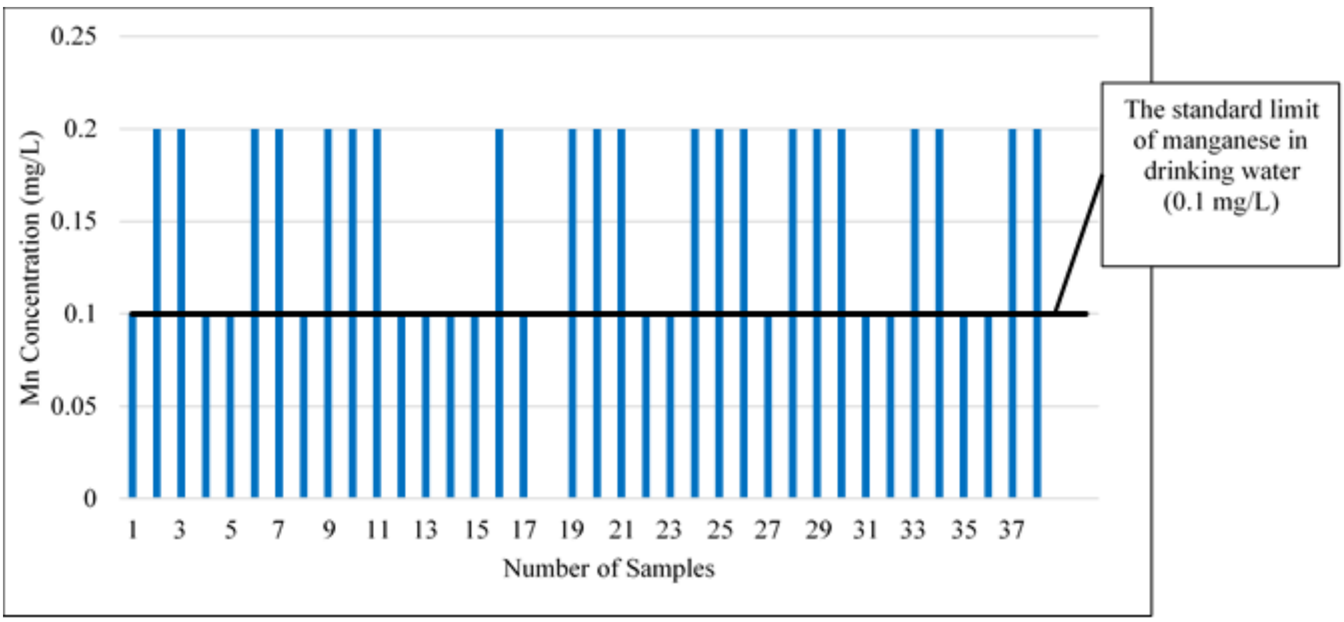

Figure 3. Manganese concentration for water samples with standard limit from NDWQS.

3.2. Health Risk Assessment

The average chronic daily intake of manganese obtained using Equation 1, was 0.0045 mg/kg/day, with a standard deviation of 0.0040. The minimum and maximum chronic daily intakes, respectively, were 0.0008 mg/kg/day and 0.017 mg/kg/day. The hazard quotient (HQ), had a mean of 0.032 with a standard deviation of 0.028 and a range between 0.0057 to 0.12, which were below 1 (Table 4). Thus, the children were not exposed to any health risks due to manganese concentration in their water sources.

Table 4. Chronic daily intake and hazard quotient (n = 38)

Variable	Mean ± SD	Median (IQR)	Min	Max
CDI	0.0045 ± 0.0040	0.0030 (0.0031)	0.0008	0.017
Male	0.0038 ± 0.0020	0.0030 (0.0026)	0.0017	0.0085
Female	0.0050 ± 0.0049	0.0031 (0.0038)	0.0008	0.017
Hazard Quotient	0.032 ± 0.028	0.022 (0.022)	0.0057	0.12

4. Discussion

This village has been using water from a gravity feed system for their daily routine since the 1900s. There is a limitation for the village to access clean water from Syarikat Air Negeri Sembilan Sdn Bhd (SAINS) due to their relatively remote location in a hilly area; thus, the easiest way for this community to get access to clean water is by using a gravity feed system to get the water from the top of the hill. To prevent stomachache and diarrhoea, 92.1% (35) of the respondents drank water that had previously been boiled, while 7.9% (3) drank water straight from the pipes. The Centers for Disease Control and Prevention, CDC (2020), recommends boiling water before consuming it as one of the reliable methods to avoid any water-borne infections by eliminating bacteria, parasites, and viruses.

According to Cohen & Colford's (2017) analysis, numerous Asian countries, including China, Mongolia, Indonesia, and Vietnam, with estimates of 85%, 95%, 91%, and 91% of rural populations, respectively, utilise boiling drinking water. According to the results of the systematic review and meta-analyses, boiling significantly protects against infections and other organisms that spread through water (Cohen & Colford, 2017). However, boiling water will not reduce the manganese, instead, it may concentrate the levels of manganese more. Thus, manganese can only be eliminated from water by combining a number of techniques, such as oxidation and adsorption in a water filtering system that can eliminate both dissolved and particulate forms of manganese (World Health Organization, 2021).

4.1. Water analysis

The levels of pH for water samples in this study were between the NDWQS (6.5 – 9.0). It has almost similar results to a study by Roslan and Mohd (2017) on drinking water quality for rural water supply in 8 villages in Jelebu, Negeri Sembilan that use gravity feed systems which had a pH range between 6.8 and 7.2. They concluded that this neutral pH indicated that the sources of water in the villages are not contaminated by any chemicals or fertilisers (Roslan & Mohd, 2017). The results of a different study by Zainol et al. (2021) on the geographical analysis of groundwater in the Urbanized Langat Basin revealed that the pH values of 45 groundwater samples ranged from 4.40 to 7.42 with a mean of 6.13 ± 0.89. The study suggested that the use of fertiliser in plantation regions close to the Langat Basin, which flows into the groundwater and changes the pH of the water, may be the source of numerous samples having a lower pH value than NDWQS (Zainol et al., 2021).

The results of Mgbenu & Egbeuri's study (2019) on the health risk assessment of water resources in the Umunya district, southeast Nigeria, show that the majority of the study samples recorded pH values below the limits of 6.5 - 8.5, which supported their claim that the slightly acidic waters can be caused by the use of chemical fertiliser closer to the water sources area, which causes the chemicals to leach into the aquifer systems. It explained this study's findings, which showed that the value of pH in the water at Ulu Chuai Village was within the NDWQS while being far from any plantations or agricultural regions.

The average manganese concentration showed 21 water samples (55.3%) had exceeded the NDWQS recommended value. The manganese concentration in water samples from 16 houses (42.1%) was between the recommended value while another one sample (2.6%) reported no manganese content was present in the water. Roslan & Mohd (2017) studied several parameters including manganese in drinking water from 8 villages in Jelebu, Negeri Sembilan that are using gravity feed systems. The study claimed that the findings of lower manganese concentrations in all samples may be due to zero human activities that can pollute the water near the sources.

However, the prolonged use of gravity feed system water from the sources on the hill may be the root of the elevated manganese concentration (0.2 mg/L) in this study. Long-term use of a gravity feed system can lead some naturally manganese-containing rocks to progressively dissolve and enter the water which can flow to the villages (Gray, 2008). Manganese concentrations in the samples from tubewells were reported to be higher than the Bangladesh standard and NDWQS (0.1 mg/L) according to a study by Ghosh et al. (2020) on human health risk assessment of elevated and variable iron and manganese intake with groundwater in Jashore, Bangladesh as the manganese concentrations ranged from 0.016 to 2.108 mg/L with a median of 0.298 mg/L.

Table 4 demonstrates that no significant correlation between pH and manganese levels was found throughout the study. This conclusion was consistent with research by Rahman et al. (2021), which assessed the health risks of manganese from drinking water for high school students in south-western Bangladesh and found no relationship between the pH of the water and the content of manganese. There were negligible and extremely weak relationships between pH and manganese levels, according to a study of drinking water quality, exposure, and health risk assessment for primary school students in the south-west coastal region of Bangladesh (r = 0.18) (Rahman et al., 2021).

However, according to different research by Amfo-Otu et al. (2014), there was a negative correlation (r = -0.723) between pH level and manganese content in groundwater from hilly locations in Ghana, indicated that variations in the pH of the water are linked to manganese concentrations. According to the same study, the negative association suggested that more manganese dissolves from soil minerals into the water when the pH level is lower and more acidic (Amfo-Otu et al., 2014). In Ibadan, Nigeria, groundwater from wells and borehole water samples had a negative association (r = - 0.511) between pH level and manganese contents, according to research by Moyosore et al. (2014). Furthermore, a study of the association between water pH and other water quality indicators in Tarkwa, Ghana, revealed a weakly negative correlation (r = - 0.272) between pH level and manganese concentrations in groundwater.

4.2. Health Risk Assessment

The average CDI of manganese for children was 0.0045 mg/kg/day. The mean CDI of manganese was calculated as 0.0038and 0.0050 mg/kg/day for males and females, respectively. The mean hazard quotient (HQ) from manganese intake was lower for all children in the village (0.0322 ± 0.0284). The maximum value of CDI manganese did not exceed RfD (0.14 mg/kg/day) which was derived by the US EPA (IRIS 2011) (Agency for Toxic Substances and Disease Registry, 2012). Thus,it gave the maximum result of the calculation for HQ values obtained as less than 1 (0.1236). The findings of this study werefound in agreement with the previous studies. The HQ of manganese for children in five regions of southwest Bangladesh was estimated to be 0.02 in research by Rahman et al. (2021).

Studies on HQ in manganese have shown mixed findings. Onesuch study was conducted in the Jashore District of Bangladesh on health risk assessment of manganese intake with groundwater and revealed that children who drank water there had maximum HQ levels of more than 1 (1.004) (Ghosh et al., 2020).When HQ values are more than 1, it means that drinking water exposure to manganese may have adverse health impacts, including neurobehavioral problems just as concluded in a study by Bouchard et al. (2011) which stated that intellectual impairments in children can be affected by the exposure to manganese concentration in water. Thus, from the mean HQ value (0.0322 ± 0.0284) of manganese in this study, it can be concluded that the consumption of drinking water exposed to manganese by the children in the village does not pose a risk of non-carcinogenic health problems.

5. Conclusion

In conclusion, water from the gravity feed system in Orang Asli Ulu Chuai Village was generally of good quality. The pH range in the water was between 6.57 to 7.10, which was within the NDWQS accepted range. However, the median manganese level in the water was 0.20 mg/L, which was higher than the manganese standard limit set by the NDWQS. Children of Orang Asli in Ulu Chuai Village have HQ values ranging from 0.0057 to 0.1236, which was below 1. Therefore, there was no harm to the health especially neurobehavioral effects for children in the community when consuming water from the gravity feed system.

Future research was recommended to also take into account the health risks associated with manganese in food, given that manganese may also be exposed from ingestion of food, in order to identify the primary cause of excessive manganese exposure in people. Additionally, more research should be done to analyse the risk of exposure to manganese through other routes, such as ingestion, inhalation, and dermal absorption, since this can assist to ascertain whether other environmental variables can also lead to manganese exposure. It is also advisable to do additional research utilising biological samples as biomarkers, such as blood or urine, in order to ascertain the children's real exposure levels to manganese and provide reliable results. Besides, it is also recommended to study the HQ of manganese in drinking water from the gravity feed system among children in their lifetime exposure and comparing them with the current data to determine the health risk of the manganese exposure to the children when they consumed the drinking water in their lifetime period.

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