Assessment of Human Health Risk in Groundwater at Rural and Agriculture Areas in Sabah, Malaysia

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Abstract. Lack of treated water system in Sabah has increase human dependency to groundwater sources. The presence of contaminants such as nitrate in groundwater can pose severe health implications to human, such as methemoglobinemia and cancerous diseases. The objectives of this paper were to quantify the nitrate concentration in groundwater, to calculate potential human health risk exposure of nitrate in groundwater and to compare the potential human health risk exposure of nitrate between rural and agriculture areas. Six tube wells were selected at Inanam and Kota Belud district and involved one-hundred eighty respondents aged from 7 to 12 years old. The groundwater samples were analyzed using Cadmium Reduction method of HACH DR2800 Spectrophotometer and human health risk exposure were assessed using Chronic Daily Intake (CDI) and Hazard Index (HI) after set of information of respondents were obtained by questionnaires. Result obtained were showing mean ± S.D of nitrate levels in groundwater well and filtered water of agriculture (0.79 ± 0.33 mg/L; 0.33 ± 0.29 mg/L) and rural (0.50 ± 0.12mg/L; 0.53 ± 0.10 mg/L) areas were within the acceptable value limit set by National Drinking Water Quality Standard of Malaysia (10 mg/L). The statistical analysis of Kruskal-Wallis and one-way ANOVA test implied there were no significant differences of nitrate levels between two areas (p>0.05). Moreover, the mean ± S.D of CDI for agriculture and rural areas were 0.0064 ± 0.0056 mg/kg/day, 0.0140 ± 0.0096 mg/kg/day respectively and HI were less than 1. The insignificant differences of potential human health risk were noted in terms of gender and age of respondents between two areas. This specified that the human health risk of respondents involved in this study was in acceptable range and not exposed to severe health risks.
1. Introduction
In Malaysia, not more than 10 percent of the total water resources are taken up from groundwater [1]. The Head Director of National Hydraulic Research Institute of Malaysia (NAHRIM), Azuhan Mohamed said there is approximately 63.5 billion m$^3$ of groundwater storage in Malaysia. He also added that this abundant source can be an alternative in dealing the clean water crisis experienced by the country, particularly throughout drought season or high river contamination [3]. Furthermore, the previous official minister in Ministry of Natural Resources and Environment (NRE) stated that the development of groundwater well equipped with simple filtration system has been executed to overcome the treated water supply issue in remote villages in some states including Sabah [15]. In Sabah, specifically the west-coast areas are known to have highly groundwater resource potential [17]. The groundwater in Sabah are involves of nine urban water supply plans, wells for rural water supply plan and via industries. Almost 200 groundwater wells have been operated at remote areas such as remote villages, schools at south west coast and north-west coast as well as rural areas [24].

Nitrate (NO$_3^-$) can exist naturally and unnaturally the environment. Nitrates are commonly produced as ions via the fixation of nitrogen and oxygen in ecosystem. Due to its great water solubility, the nitrate can be found in the water body especially groundwater [2, 8]. The presence of nitrate as an excellent groundwater indicator are enhances by heavy usage of nitrogenous fertilizers from agricultural activities, massive run-offs from industry, unsecured sanitation, animal wastes, exoneration from waste water plant and many sources [4, 5, 13, 16, 19, 27, 28]. Due to nitrate capability to accumulate in body, severe lethal diseases may arise and pose health problem to human. Therefore, the World Health Organization (WHO) has set guideline value for nitrate is not exceeding 50 mg per liter to prevent methemoglobinemia in infants [25]. Meanwhile, the Ministry of Health Malaysia has approved tolerance limit of nitrate exposure in drinking water for not surpassing 10 mg per liter to avoid critical illnesses, for instance urogenital tract cancer, lung cancer and non-Hodgkin’s lymphoma [9, 10, 16].

Nowadays, the massive effluents from industrial areas, heavily anthropogenic sources and intensive agricultural activities such as uses of nitrogenous fertilizers are contributing to leaches of nitrate into the groundwater [7, 21, 27, 28]. Dissipation of nitrate from soils into groundwater and river can influence the level of nitrates [18, 27, 28]. Due to immobilized groundwater in wells, the nitrate can accumulate and contaminate the water.

Exposure of nitrate in human is mainly via daily consumption of well water in the contaminated areas [26]. Nitrate, if allows to accumulate in body, beyond certain threshold value set by Natural Drinking Water Quality Standard of Malaysia (NDWQS) and World Health Organization (WHO), it is believed to cause acute circulatory system disease such as methemoglobinemia, immune system disease such as non-Hodgkin’s lymphoma and gastroenteritis that inflamed stomach which might lethal to humans [7, 10, 16]. Thus, the risk assessment of nitrate contamination to human health are executed [6, 7, 11, 16, 18, 19, 26, 27, 28, 29].

The aim of this study was to assess the potential risk of nitrate exposure to human health in groundwater tube wells using Cadmium Reduction method. The nitrate concentration in groundwater tube wells involved were quantified and the potential human health risk due to nitrate exposure were calculated and compared between rural and agriculture areas.

2. Material and Methods
2.1 Description of Study Area
The selected wells in this study were at different land use type. Kota Belud was chosen as a representative for agricultural area in Sabah due to district active involvement in cultivation of paddy fields, while Inanam has been chosen to represent rural areas as some region still lacking basic
facilities such as tarred roads and clean water supplies [24]. One-hundred eighty respondents were chosen in this study to assess the potential risk exposure of nitrate to the health. The questionnaire was distributed among respondents aged from 7 to 12 years old as they were the primary consumer of the groundwater source. The questionnaire contained information required to fulfill the Chronic Daily Intake (CDI) and Hazard Index (HI) equations.

![Figure 1. The study areas at Inanam and Kota Belud District, Sabah.](image)

2.2 Water Sampling and Analysis

The samples were collected and stored in 50 ml polyethylene bottles for laboratory examination. The water samples were taken using sequential replicates technique, with 3 minutes interval for each station for identical analysis. The samples were analysed using Cadmium Reduction method of HACH DR2800 Spectrophotometer.

2.3 Statistical Analysis

The statistical analysis was executed using IBM Statistical Analysis Version 24. Both parametric and non-parametric analysis have been carried out to compare nitrate levels in unfiltered and filtered water samples and to compare the potential human health risk exposure for both rural and agriculture areas.

2.4 Risk Assessment

2.4.1 Chronic Daily Intake (CDI)

In assessing the risk of nitrate in drinking water, the CDI was calculated using the formula as below [7, 20, 27]:

\[
\text{CDI} = \frac{\text{Nitrate concentration in water} \times \text{Daily water consumption}}{\text{Body weight}}
\]
CDI = (C × DI)/BW \tag{1} 

where,

\begin{align*}
CDI & = \text{Chronic daily intake (mg/kg/day)} \\
C & = \text{Nitrate concentration in water (mg/L)} \\
DI & = \text{Average daily intake rate of water (L/day)} \\
BW & = \text{Body weight (kg)}
\end{align*}

2.4.2 \textit{Hazard Index (HI)}

To determine the total potential of nitrate in drinking water to produce non-carcinogenic health effects, HI was computed using the following equation [23];

\[
HI = \frac{CDI}{RfD} \tag{2}
\]

where,

\begin{align*}
HI & = \text{Hazard Index} \\
CDI & = \text{Chronic daily intake (mg/kg/day)} \\
RfD & = \text{Reference dose (mg/kg/day)}
\end{align*}

The HI value which less than or equal to one indicate that no adverse health issue was possibly to take place. While for HI value more than 1, it shown health exposure as nitrate concentration has surpassed the RfD value.

3. Results and Discussion

3.1 \textit{Quantification of Nitrate}

In this paper, the nitrate level was differed in each station as the wells were positioned at different land use type, namely agriculture and rural areas. As overall, the highest mean±S.D nitrate concentration of unfiltered groundwater samples was recorded at agriculture area, 0.93±0.50 mg/L with range of 0.4 to 2.0 mg/L, primarily due to excessive application of nitrogenous fertilizers and pesticides. Meanwhile at rural area, Inanam, the highest nitrate level in unfiltered groundwater sample was recorded with mean±S.D of 0.52±0.08 mg/L. The filtered water samples at agriculture area, Kota Belud were noted the highest nitrate concentration with mean±S.D of 0.59±0.28 mg/L of range 0.2 to 0.9 mg/L. Furthermore, nitrate concentration in filtered water at Inanam was the highest with mean ± S.D of 0.57±0.10 mg/L, representing rural area.

[12] states the standard nitrate concentration was within 0 to 18 mg/L in groundwater. The low nitrate concentration in this study was possibly due to time the sampling session was executed. The samples were taken after the completion of harvest period of paddy, thus no application of fertilizers on the crop has initiated and no excessive leaching of nitrogenous fertilizers to groundwater [27]. Moreover, sampling activities has conducted during dry season in January to March 2018. Hence, occurrence of rainfall can affect the leaching rate of nitrate contamination to groundwater as water table increased and nitrate become mobilized in unsaturated zones and eventually leached to the groundwater [7, 27].
3.2 Concentration of nitrate levels between rural and agriculture areas

Table 1. The comparison of nitrate in unfiltered and filtered water samples between rural and agriculture areas.

| Sample   | Area     | District | Mean±S.D (mg/L) | Range (mg/L) |
|----------|----------|----------|-----------------|--------------|
| Unfiltered | Agriculture | Kota Belud | 0.79±0.33       | 0.40 – 2.00  |
|          | Rural    | Inanam   | 0.50±0.12       | 0.30 – 0.80  |
| Filtered | Agriculture | Kota Belud | 0.33±0.29       | 0.00 – 0.90  |
|          | Rural    | Inanam   | 0.53±0.10       | 0.30 – 0.70  |

The Kruskal-Wallis test showed there was a significant difference in the levels of nitrate in unfiltered groundwater samples between both areas (KW χ² = 18.575, df = 1, p = 0.000, p < 0.05) at 95% confidence level. Therefore, the nitrate concentration in unfiltered water of agriculture area was higher than rural area. The excessive application of fertilizer in preceding fertilization time may contribute to high nitrate contents in groundwater of agricultural area compared to rural area.

The statistical analysis of One-Way ANOVA test indicated there was a significant difference of nitrate levels between rural and agriculture areas in Sabah as determined by one-way ANOVA (F(1,52) = 10.812, p = 0.002, p < 0.05) at 95% confidence level. The anthropogenic activities such as industrial run-offs and animal farms waste disposal to groundwater system may be another contributing factor to high nitrate levels at rural areas. The leaches of excess nitrate contaminants might have occurred during sampling session [7, 27].

3.3 Concentration of Nitrate Levels Between Rural And Agriculture Areas

The Table 2 below showed that nitrate level in this study was relatively low compared to other studies and NDWQS standard. The low nitrate concentration at agriculture area may due to underdeveloped agriculture area in Sabah compared to other countries. In Sabah, agriculture activities were not actively exploited as the main country economic resources. Hence, the levels of nitrate in this study were lower compared to those at intensive agriculture area [7, 14, 27].

Table 2. The comparison of nitrate in unfiltered water samples to previous studies and standard of Natural Drinking Water Quality Standard of Malaysia (NDWQS) at agriculture area, Kota Belud.

| Area     | Mean±S.D (mg/L) | Mean±S.D of other studies (mg/L) | NDWQS Standard (mg/L) |
|----------|-----------------|---------------------------------|-----------------------|
|          |                 | [7,20]                          | [14,27]               | [14,16]               |                     |
| Agriculture | 0.79±0.33     | 1.66±2.11                       | 2.11±1.24             | 13.04±14.39          | 10.00               |
| Rural    | 0.50±0.12      | 1.26±0.28                       | 2.11±1.24             | 60.60±33.60          | 10.00               |

The mean±S.D of tube well at rural area was 0.50±0.12 mg/L indicate low when compared to the NDWQS standard and other studies. The low nitrate concentration may also because of efficient groundwater system directed at the area was ensuring the good quality and reliability of groundwater. As overall, the nitrate concentration in all wells involved in this study were within the permissible value limit set by NDWQS of Malaysia (10 mg/L).
3.4 Human Health Risk Assessment

3.4.1 Demographic Information

The respondent chosen in this study was consisted of 96 (53.3%) males and 84 (46.7%) females from six selected schools in Inanam and Kota Belud. The respondents were aged between 7 to 12 years old, with majority of the respondents’ body weight was between 21 to 30 kg (47.2%). Almost 118 respondents were consuming an average intake rate of water of 501 to 1,000 mL per day.

3.4.2 Potential Human Health Risk Exposure Of Nitrate Between Rural And Agriculture Areas

By employing the equations, the HI value for both areas were less than 1. This implied excellent disposal management system and modest usage of fertilizers which can be causative factors of minute concentration of nitrate in groundwater tube well prevents the occurrence of critical diseases such as methemoglobinemia, cancerous diseases, non-Hodgkin lymphoma, thyroid gland hypertrophy and more to impact residents who reside near the study area. Hence, this specified that the health status of respondents was in safe range to acquired severe nitrate-borne diseases from drinking groundwater.

In this study, the HI value was less than 1 with calculated mean±S.D of 0.0040±0.0035. The HI value for agriculture area involved was low once it was compared to other studies conducted previously at agricultural area of Kelantan [7, 14, 27]. Thus, this indicated that the status of human health towards nitrate exposure in groundwater in this study was in safe range from acute nitrate-borne diseases.

By using the same CDI and HI formulas to assess of human health risk exposure of nitrate contamination in groundwater of rural area (Inanam), the mean±S.D of CDI was 0.0140±0.0096 mg/kg/day. Ninety respondents were chosen with mean body weight of 28.16 kg and average daily intake rate of water was 0.70 L per day.

The calculation of Hazard Index (HI) was by dividing the CDI with reference dose (RfD) value of 1.6 mg/kg (USEPA, 2013). The HI value that less than or equal to one indicates no possibly for harmful health concerns to occurs. If HI value was more than one, it stipulates adverse health problems. Table 4.9 tabulates the mean ± S.D Chronic Daily Intake (CDI) and Hazard Index (HI) values for rural area, Inanam.

Table 3. The assessment of Chronic Daily Intake (CDI) and Hazard Index (HI) of agriculture area, Kota Belud.

| Nitrate Level (mg/L) | Average Daily Intake Rate of Water (DI) (mL) | Body Weight (BW) (kg) | Chronic Daily Intake (CDI) (mg/kg/day) | Hazard Index (HI) |
|----------------------|---------------------------------------------|-----------------------|----------------------------------------|------------------|
| Mean                 | 0.33                                        | 0.53                  | 26.69                                  | 0.0064           | 0.0040          |
| Median               | 0.20                                        | 0.50                  | 24.65                                  | 0.0048           | 0.0030          |
| Standard Deviation   | 0.29                                        | 0.38                  | 9.91                                   | 0.0056           | 0.0035          |
| Range                | 0 – 0.90                                    | 0.1 - 1.5             | 12.40 – 60.90                          | 0.0013 – 0.0334  | 0.0008 – 0.0209 |

By employing the same equation, the HI value for rural area in this study was less than 1 with calculated mean±S.D of 0.0880±0.0060. When compared to previous study conducted at rural area by [14, 16, 20], the HI in this study was relatively low. This implied excellent disposal management system and modest usage of fertilizers which can be causative factors of minute concentration of nitrate in groundwater tube well. Hence, this specified that the health status of respondents was in safe range to acquired severe nitrate-borne diseases from drinking groundwater.
Table 4. The assessment of Chronic Daily Intake (CDI) and Hazard Index (HI) of rural area, Inanam.

| Nitrate Level (mg/L) | Average Daily Intake Rate of Water (DI) (mL) | Body Weight (BW) (kg) | Chronic Daily Intake (CDI) (mg/kg/day) | Hazard Index (HI) |
|----------------------|---------------------------------------------|-----------------------|----------------------------------------|------------------|
| Mean                 | 0.53                                        | 0.70                  | 28.16                                  | 0.0140           | 0.0880           |
| Median               | 0.50                                        | 0.50                  | 26.05                                  | 0.0111           | 0.0069           |
| Standard Deviation   | 0.10                                        | 0.30                  | 8.94                                   | 0.0096           | 0.0060           |
| Range                | 0.3 – 0.7                                   | 0.22 – 1.50           | 17.5 – 64.1                            | 0.0019 – 0.0450  | 0.0012- 0.0281   |

In overall, there was no significant difference of the potential human health risk exposure of nitrate contamination in groundwater tube well between rural and agriculture areas. The human health risk of respondents involved in the study areas were more or less the same. Hence, the occurrence of critical diseases such as methemoglobinemia, cancerous diseases, non-Hodgkin lymphoma, thyroid gland hypertrophy and more were less potentially to impact residents who reside near the study area.

Few factors such as awareness level and filtration system may be influencing the potential health risk to human. High level of awareness on how important the good water quality at all schools was contributing to reduction in risk exposure of nitrate pollution in the groundwater. Furthermore, the installed filtration system in groundwater tube well to filtrate contaminant particles before human consumption was causing diminishing in chances to acquire health complications among respondents.

4. Conclusion

The quantification of nitrate concentration in unfiltered groundwater samples noted mean ± S.D of 0.79 ± 0.33 mg/L and 0.50 ± 0.12 mg/L while in filtered groundwater samples noted mean ± S.D of 0.33 ± 0.29 mg/L and 0.53 ± 0.10 mg/L for both agriculture and rural areas respectively. In this study, the nitrate concentration in groundwater of agriculture area at Kota Belud and rural area at Inanam were within the tolerable range based on NDWQS and WHO standard values. Several contributing factors such as no intense application of fertilizers on the crop during sampling session and existence of water filtration system at schools involved were impacting to low nitrate level.

The human health risk exposure of nitrate contamination of all respondents involved in this study were considered low with mean ± S.D of HI were 0.0040 ± 0.0035 and 0.0880 ± 0.0060 for both agriculture and rural areas correspondingly. The HI value below 1 indicates all respondents were in safe range and not exposed to unfavorable nitrate-borne diseases that may impact their living. The insignificant differences were also noted on the potential human health risk exposure of nitrate contaminants in groundwater tube well in term of gender and age of respondents that take part in this study. High awareness level on importance of clean water sources for everyday consumption as well as health educational programs where partly responsible for low hazard risk of respondents involved.

5. References

[1] Abd-Razak Y and Abd-Karim M H 2009 Groundwater colloquium: groundwater management in Malaysia - status and challenges. Akademi Sains Malaysia, Putrajaya
[2] Alighardashi A and Mehrani M J 2017 Survey and zoning of nitrate-contaminated groundwater in Iran. Journal of Materials and Environmental Sciences. 8(2) 4339-4348
[3] Berita Harian 2017 January 21 Malaysia ada 63.5 bilion padu air bawah tanah Berita Harian Retrieved from https://www.bharian.com.my/node/237483
[4] Bouman B A M, Castañeda A and Bhuiyan S I 2002 Nitrate and pesticide contamination of groundwater under rice-based cropping sistems: Evidence from Philippines. Agriculture
Ecosystems and Environment. 92 185–199

[5] Evans A E V, Hanjra M A, Jiang Y, Qadir M, and Drechsel P 2012 Water Quality: Assessment of the Current Situation in Asia. International Journal of Water Resources Development. 28(2) 195–216

[6] Fabro A Y R, Avila, J G P, Alberich M V E, Sansores S A C and Camargo-Valero M A 2015 Spatial Distribution of Nitrates in Drinking Water in Merida, Mexico. Applied Geography. 65 49–57

[7] Jamaludin N, Sham S M and Ismail S N S 2013 Health risk assessment of nitrate exposure in well water of residents in intensive agriculture area. American Journal of Applied Sciences. 10(5) 442–448

[8] Lasagna M, De Luca D A and Franchino E 2016 Nitrate contamination of groundwater in the western Po Plain (Italy): the effects of groundwater and surface water interactions. Environmental Earth Sciences. 75(3) 1–16

[9] MOH Malaysia. (2010). National Drinking Water Quality Standards (NDWQS): Engineering Services Division

[10] Moore E, Matalon E, Balazs C, Firestone L, De Anda S, Guzman M, Ross N and Luu P 2011 The Human Costs of Nitrate-contaminated Drinking Water in the San Joaquin Valley. The Pacific Institute

[11] Sadler R, Maetam B, Edokpolo B, Connell D, Yu J, Stewart D, Park M J, Gray D and Laksono B 2016. Health risk assessment for exposure to nitrate in drinking water from village wells in Semarang, Indonesia. Environmental Pollution. 216 738–745

[12] Schmoll O 2006 Protecting Groundwater for Health: Managing the Quality of Drinking Water Sources. (1st ed.), IWA Publishing, London, 678

[13] Shamsuddin A S, Syed Ismail S N, Mohd. Sham S and Zainal Abidin E 2014 Nitrate in groundwater and excretion of nitrate and nitrosamines in urine: a review. International Journal of Sciences: Basic and Applied Research. 15(2) 176–191

[14] Shamsuddin A S, Syed Ismail S N, Zainal Abidin E, Ho Y B and Juahir H 2016. Contamination of nitrate in groundwater and evaluation of health risk in Bachok, Kelantan: A cross-sectional study. American Journal of Applied Sciences. 13(1) 80-90

[15] Sinar Harian. (2014, April 16). 'Boleh ambil air bawah tanah tetapi…'. Sinar Harian. Retrieved from http://www.sinarharian.com.my/mobile/nasional/boleh-ambil-air-bawah-tanah-tetapi-1.271271.

[16] Suthar S., Bishnoi P, Singh S, Mutiyar P K, Nema A K and Patil N S 2009 Nitrate contamination in groundwater of some rural areas of Rajasthan, India. Journal of Hazardous Materials. 171(1–3) 189–199

[17] Thompson T, Fawell J, Kunikane S, Jackson D, Appleyard S, Callan P, Bartram J and Kingston P 2012 Chemical Safety of Drinking-Water: Assessing Priorities for Risk Management. International Journal of Environmental Studies. 69(6) 1001–1001

[18] Tirado R 2007 Nitrates in drinking water in the Philippines and Thailand. Greenpeace Research Laboratories Technical Note, (November)

[19] Tirkey P, Bhattacharya T, Chakraborty S and Baraik S 2017 Assessment of groundwater quality and associated health risks: A case study of Ranchi city, Jharkhand, India, 5(May). 85–100

[20] Tociu C, Marcu E, Ciobotaru I E and Maria C 2016 Risk assessment of population exposure to nitrates/nitrates in groundwater: a case study approach. 13(3) 39–45.

[21] Tredoux G, Engelbrecht P and Israel S 2009 Nitrate in Groundwater. Why is it a Hazard and How to Control It? Report to the Water Research Commission by CSIR, Natural Resources and the Environment, Stellenbosch, (August), 1–21.

[22] USEPA 2013 Integrated Risk Information System (IRIS). United States Environment Protection Agency

[23] USEPA 2017 NATA: Glossary of terms. National Air Toxics Assessment. Retrieved from https://www.epa.gov/national-air-toxics-assessment/nata-glossary-terms#hi
[24] Utusan Borneo. (2016, October 19). Bangun sumber air bawah tanah. Utusan Borneo. Retrieved from https://www.pressreader.com/malaysia/utusan-borneo-sabah/20161019/282432758682695

[25] WHO 2011 *Nitrate and nitrite in drinking-water: background document for development of WHO Guidelines for Drinking-water Quality*. World Health Organization

[26] Wongsanit J, Teartisp P, Tharnpoophasiam P and Worakhunpiset S 2015 Contamination of nitrate in groundwater and its potential human health: a case study of lower Mae Klong river basin, Thailand. *Environmental Science and Pollution Research*. 22(15) 11504–11512

[27] Zahari A A and Sham M S 2014 *Nitrate Levels in Groundwater and Health Risk Assessment In Three Villages in Pasir Puteh , Kelantan*. 5(3) 139–148

[28] Zawawi M M A, Yusoff M K, Hussain H and Nasir S 2010 Nitrate-Nitrogen Concentration Variation in Groundwater Flow in a Paddy Field. *The Institution of Engineers, Malaysia*, 71(4) 2–10

[29] Zhai Y, Zhao X, Teng Y, Li X, Zhang J, Wu J and Zuo R 2017 Groundwater nitrate pollution and human health risk assessment by using HHRA model in an agricultural area, NE China. *Ecotoxicology and Environmental Safety*. 137 130–142

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