Nitrate in groundwater and related health risk: A case study in a village in Bachok district, Kelantan, Malaysia

Raja Adi Aiman RMM¹, Shaharuddin MS¹, Zaenal Abidin²

¹Department of Environmental and Occupational Health
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia

²School of Health Sciences Bhakti Husada Mulia
Madiun, East Java, Indonesia

*Corresponding author: Shaharuddin MS, Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.

Abstract.

OBJECTIVES: To determine concentration of nitrate in groundwater and its associated health risk to residents in Bukit Bator Village in Bachok district, Kelantan state, Malaysia.

METHODS: This study was implemented in the month of January 2019. A total of forty-five (45) respondents took part in the study with the same number of wells sampled for nitrate. Respondents were chosen based on the criteria that they only used groundwater for drinking and cooking and they do not have any type of filtration systems installed in their homes. Nitrate concentration was determined using a HANNA Instrument brand multimeter with an attached nitrate electrode. Samples were collected in duplicates and the readings were then averaged. Other data such as weight of respondents, age and depth of wells, as well as distance of well from source of nitrate were also recorded.

RESULTS: Nitrate in sampled groundwater ranged from 0.61 to 25.10mg/L NO₃⁻ with a mean of 3.61 +SD 1.88mg/L. Statistical analysis showed that there is a significant difference in nitrate concentration between sampling sites (p<0.05). In contrast, no significant relationships were found between nitrate concentration with age and depth of well, as well as distance to nitrate source (p>0.05). All respondents were calculated to have a Hazard Quotient (HQ) of less than 1 (HQ<1), meaning there is a potential non-cancer risk to the users.

CONCLUSION: Nitrate levels in groundwater is low and is not detrimental to health. Nevertheless, periodic assessment is encouraged to ensure the levels stay low at all times.

Keywords: Nitrate, groundwater, Hazard Quotient, Bachok, levels


Introduction

Nitrate (NO₃⁻) is compound which is colourless, odourless, and tasteless and can be found in groundwater¹. Production of nitrate and ammonium is soil is continuous, depending on nitrogen and water contents, amount of waste, temperature and type of soil². By referring to the nitrogen cycle, nitrogen is fixed to produce ammonia (NH₃) or ammonium (NH₄⁺) by combining with hydrogen. Then, nitrate is formed by soil bacteria in a process called nitrification, where at first, ammonia or ammonium is converted into nitrite (NO₂⁻), and then to nitrate by the oxidation process. Nitrate is then absorbed by plants and used to produce plant proteins³. Nitrates in concentrations over 45mg/L (as NO₃⁻) in water have been related to various cases of methemoglobinemia, notably in infants up to 6 months old, whose main liquid intake is powdered milk formula mixed with water containing high concentrations of nitrates. Alternative possible negative health effects related to the bodily function of nitrates in water for extended periods are detected in animal studies as well as changes in heart blood vessels, and behavioral effects. The possible association of nitrates in water with the formation of the potent carcinogenic nitrosamines continues to be to be determined. However, ample proof is presently offered to support the strict adherence to current nitrate water standard of 45mg/L. Nitrate contamination of both surface and groundwater is becoming more important as the problem is getting worse. Agricultural practices, usage of nitrogen-based fertilizers, improper discharge of wastewater and failure
of septic tank systems can be aforementioned as culprits to this problem\(^5\). There has been an association between an increased risk of thyroid cancer and the ingestion of nitrate from dietary and drinking water sources. Iodide uptake by the thyroid is disturbed by nitrate, potentially affecting thyroid function. In other words, consuming drinking water with higher levels of nitrate (more than 5mg/L) for longer periods may lead to an increased risk of thyroid cancer\(^6\).

By referring to the Drinking Water Quality Standard (DWQS) formulated by the Malaysian Ministry of Health, nitrate levels in both raw and drinking water must not exceed 10mg/L of NO\(_3\)-N\(^7\).

The aims of this study were to determine nitrate levels in groundwater in Bukit Bator village in Bachok district, Kelantan state and its associated health risk towards users.

**Methods**

This cross-sectional study was conducted in January 2019 during the paddy harvest season at Bukit Bator village (6°00'03.9"N, 102°21'20.7"E), Bachok district in Kelantan state (Figure 1). This village is located approximately 30kms from Kota Bharu city, the capital of Kelantan state. The study population was residents of Bukit Bator village in Bachok district (Figure 1).

![Figure 1: Location of Bukit Bator village. Inset: Location of Bachok district within Kelantan state](image)

The sampling method used in this study was purposive sampling. A total of 45 respondents were selected based on criteria such as lifelong residents and use of groundwater as the main source of water supply. Residents were excluded if they installed a water filtration system or are using other sources of water. Questionnaires were used to gather socio-demographic and groundwater information. Data on age and depth of wells were obtained from the respondents themselves. Distance of wells from nitrate source (septic tank) was calculated using Google Maps by connecting the two points using an imaginary straight line drawn on the map.

Groundwater samples were collected in duplicates and stored in pre-cleaned high density polyethylene (HDPE) bottles and analyzed immediately using a Hanna Instrument model HI98190 portable PH/ORPASE multimeter with an attached nitrate electrode.

To determine exposure of nitrate in drinking water, the daily intake dose (DID) is first calculated using the following equation\(^8\):

\[
CDI = \frac{C \times DI}{BW}
\]

Where,
- CDI = Chronic Daily Intake (mg/kg/day)
- C = Nitrate concentration in water (mg/L)
- DI = Average daily intake rate of water (L/day)
- BW = Body weight (kg)
Next, the Hazard Quotient (HQ) is calculated using the following equation:

\[
HQ = \frac{CDI}{RfD}
\]

Where,
HQ = Hazard Quotient,
CDI = Chronic Daily Intake (mg/kg/day),
RfD = Reference dose (mg/kg/day)

If the HQ value is more than 1 (HQ>1), it shows a significant risk level for the likelihood of adverse non-carcinogenic health impact. RfD value used in this study is 1.6mg/kg/day\(^9\).

Statistical Program for Social Science software (SPSS for Windows) version 22 was used to analysed data.

**Results**

A total of 45 respondents with the same number of sampling locations were chosen as they adhere to the inclusive and exclusive criteria. Analysis showed that nitrate in groundwater ranged from 0.61 – 25.10 (mg/L) with a mean and standard deviation of 3.61 ±SD 1.88mg/L (Table 1 and Figure 2).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range (mg/L)</th>
<th>Mean (mg/L)</th>
<th>(±)SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate levels in groundwater</td>
<td>0.61 -25.1</td>
<td>3.61</td>
<td>1.88</td>
</tr>
</tbody>
</table>

**Table 1:** Levels of nitrate in Bukit Bator village (N=45)

![Nitrate levels from each sampling location](image)

Based on the Table 2, the total number of respondents was 45. Male residents accounted for the majority of respondents (24 - 53.3%) while the remainder was female (21 - 46.7%).

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>24</td>
<td>53.3</td>
</tr>
<tr>
<td>Female</td>
<td>21</td>
<td>46.7</td>
</tr>
<tr>
<td>Total</td>
<td>45</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**Table 2:** Number of male and female respondents (N=45)
Table 3 and 4 correspond to the age and depth of wells to the source of nitrate (septic tank). Table 3 shows that most number of samples were collected from wells aged more than 20 years old with a frequency of 25 (55.6%). This was followed by the 10-15 years old group (9 - 20%), less than 5 years old and 5-10 years (both 5 - 11.1%) groups and lastly the 15-20 years old group (1 - 2.2%).

**Table 3: Age of wells (N=45)**

<table>
<thead>
<tr>
<th>Age Group (years)</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5</td>
<td>5</td>
<td>11.1</td>
</tr>
<tr>
<td>5-10</td>
<td>5</td>
<td>11.1</td>
</tr>
<tr>
<td>10-15</td>
<td>9</td>
<td>20.0</td>
</tr>
<tr>
<td>15-20</td>
<td>1</td>
<td>2.2</td>
</tr>
<tr>
<td>&gt;20</td>
<td>25</td>
<td>55.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>45</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

Table 4 shows the depth of wells sampled. Most wells had depths of 5-10 meters (26 - 57.8%). This is followed by wells with depths of 15 – 20 meters (8 – 17.8%) 10-15 meters (6 – 13.3%) and less than 5 meters (5 – 11.1%).

**Table 4: Depth of wells (N=45)**

<table>
<thead>
<tr>
<th>Depth group (m)</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5</td>
<td>5</td>
<td>11.1</td>
</tr>
<tr>
<td>5-10</td>
<td>26</td>
<td>57.8</td>
</tr>
<tr>
<td>10-15</td>
<td>6</td>
<td>13.3</td>
</tr>
<tr>
<td>15-20</td>
<td>8</td>
<td>17.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>45</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

Next, the distance of wells from the sources of nitrate was also taken into account. Distance ranged from 1 – 40 meters with a mean of 13.044 ± SD 7.675 meters.

Nitrate levels between sampling sites were significantly different according to the One-sample T-test calculation (p<0.05). However, Spearman’s rho correlation did not find any relationship between age, depth and distance of source of nitrate with nitrate levels (p>0.05).

All respondents have a HQ of less than 1 (Table 5).

**Table 5: Hazard Quotient (HQ)**

<table>
<thead>
<tr>
<th>Hazard Quotient (HQ)</th>
<th>No. of Respondent</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HQ&lt; 1</td>
<td>45</td>
<td>100</td>
</tr>
<tr>
<td>HQ&gt;1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Discussion**

No sampling sites exceeded the maximum concentration limit of the Drinking Water Quality Standard as shown in Table 1. The most probable reason for this is that this study was conducted after the rainy season and also during the paddy harvesting period. The nitrates in groundwater can be higher during the rainy season, where all the nitrates in soils penetrate through the soil and seep into the water table at a rapid rate before it decreases throughout the rainy season. It will then become constant in the dry season due to the immobilization of nitrates as precipitation decreased. This is the reason why the nitrate was low in all samples³⁰.

Difference in nitrate levels among sampling sites may likely be caused by different types of nitrate source present near the sites (such as animal farming and agricultural practices) as well as the distance from the nitrate.
source itself. The amount of nitrate present on site as well as type of soil may influence the leaching process into groundwater. On HQ, it is shown that no results exceeded 1. This is because the level of nitrate in groundwater for all sample was below the maximum allowable level of 45mg/L. Therefore, the risk towards non-carcinogenic health impact due to nitrate contamination in groundwater for respondents are likely to be low. A case study in Northwest China found that agricultural sewage irrigation areas showed strong health risks compared to those of the city which were relatively small. There was no relationship between nitrate levels in groundwater samples with age, depth and distance of wells from the source of nitrate. This may be due to varying degrees of difference in the age and depth of wells, as well as distance of wells from source of nitrate (septic tank). A study in Rural New York State showed that wells that were located on large farms, or springs, or shallow or dug, were more likely to have elevated concentrations of nitrate. Another study in Taihu Lake basin in China also found the indirect relationship between nitrate levels and depth of wells. It is recommended that wells are drilled for more than 10m to decrease the risk of ingestion of nitrate-N in high amounts in their water.

Nitrate levels in all sampling sites were below the maximum acceptable value. Results from the calculation of the Hazard Quotient show that in nitrate terms, there is a potential non-cancer risk to the users. However, periodic assessment of nitrate is still important as to ensure the levels remain low. Groundwater sources used primarily for drinking and cooking purposes must be located as far away as possible from nitrate-polluting sources such as septic tanks, animal farms and intensive agricultural areas as to limit the pollution that may give rise to human health problems. Seasonal variations of rainfall and period of agricultural activity may also play a role in the concentration of nitrate in groundwater. Another thing to ponder is to disseminate “best management practices” for nitrogen fertilizer usage among farmers so as to minimize groundwater pollution.

Acknowledgements

We would like to thank villagers from Bukit Bator village, Bachok district, Kelantan for their un-dividing support in making this study a success. Our gratitude also goes to Bachok District and Land Office for providing essential information pertaining to the local population and location of wells. Appreciation goes to the Environmental Health Lab, Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia for providing equipment used in this study.

References