Groundwater quality and non-carcinogenic health risk assessment of nitrate in the semi-arid region of Punjab, India
Akshay Kumar Chaudhry and Payal Sachdeva

ABSTRACT
Groundwater is the main source of water in the study area (Rupnagar District, Punjab), and its quality is essential since it is the primary determinant of the suitability of groundwater for drinking and irrigation purposes. In this study, data from 28 years have been used to evaluate the adequacy of groundwater for domestic and irrigation purposes and assess the potential human health impacts of nitrate contaminants. Results of sodium adsorption ratio, percentage sodium, magnesium hazard ratio, Kelley ratio, and residual sodium carbonate illustrate that most of the sampling locations were suitable for irrigational purposes and drinking water quality of the region mostly belonged to the ‘good’ class. The maximum nitrate concentration was observed in the northern and north-east parts of the area. Among the three age groups, children > female > male was found to be more prone to health risks with oral ingestion of nitrate. Uncertainties in the risk estimates were quantified using Monte Carlo simulation and sensitivity analyses. Thus, a proper management plan should be adopted by the decision-makers to improve the quality of drinking water in this area to avoid major health problems in the near future.

Key words | drinking water quality, endemic, health risk assessment, irrigation water quality, nitrate, oral ingestion

HIGHLIGHTS
- Results of SAR, %Na, MHR, KR, and RSC illustrate that most of the sampling locations were suitable for irrigational purposes.
- Deterministic risk assessment of nitrate exposure due to oral ingestion was carried out for three age groups (HQNitrate: children > female > male).
- Based on the probabilistic risk assessment, nitrate concentrations and daily ingestion rate were found to be the most relevant parameters.

doi: 10.2166/wh.2020.121
INTRODUCTION

Groundwater is the primary source of water in many semi-arid areas and is mostly used for irrigation, spraying, and industrial purposes. However, the increasing worldwide demand for water due to increasing urbanization and industrialization has led to problems of over-exploitation of these resources and conflict with competing demands, in particular with community drinking supplies. According to the Intergovernmental Panel on Climate Change (IPCC), about \( \sim 2.2-2.4 \) billion people live in water stress zones; these numbers are projected to rise dramatically due to population growth and climate change pressures (Ozsvath et al. 2013). The rapid growth of population, use of excessive fertilizers to increase agricultural productivity, disposal of contaminants (directly/or indirectly) into the river, improvements in environmental conservation, increasing industrialization, urbanization, climate change, cation exchange in the aquifer, microbiological and biological processes during oxidation/reduction and/or dissolution/precipitation of minerals in the modern era are some of the natural as well as anthropogenic challenges the groundwater is facing (Wheater et al. 2008).

Groundwater nitrate (NO\(_3^\)\(^-\)) contamination, in semi-arid regions of the world, has emerged as one of the serious issues and has also been seen as the primary cause of the degradation of groundwater quality (Nakazawa et al. 2016). In India, there are many states including the Rupnagar district of Punjab (study area) that contains nitrate-rich groundwater. Anthropogenic activities (i.e. use of excessive chemical fertilizers, industrial wastewater discharge, agricultural runoff, crop residues, etc.) are the primary cause for nitrate production in the study area groundwater. Septic tanks, urban wastewater, and soil and animal dung nitrogen are some of the other sources (Aquilina et al. 2012). Nitrate is also formed by the nitratine, tobelite, and nitrite-bearing rocks leaching (Suthar et al. 2009). Nitrates are important soil nutrients that are vital for natural vegetation and crops to grow. Excessive nitrate concentrations, however, can penetrate groundwater with a negative effect on associated ecosystems and human beings (Geleperin et al. 2010). Methemoglobinemia or ‘blue baby syndrome’, esophagus, gastric and stomach cancer, diabetic, and thyroid hypertrophy are the major possible health risks from nitrate (NAS 1981; Deroos et al. 2003). Thus, the consequences of exposure to high nitrate levels on human health as well on groundwater quality are therefore of great concern. Nitrate can reach the human body through two pathways, namely endogenous and exogenous. In the present study, only the exogenous pathway (i.e. through oral ingestion of nitrate contaminated water) is assessed.

In the study area, there has been a paradigm shift in the last decade from ‘groundwater development’ to ‘groundwater
management. It is primarily due to rapid industrialization, urbanization, unnecessary pumping for agronomic activities, and a rise in the region’s anthropogenic activities. Most factories in the region discharge their wastewater (directly or indirectly) with little treatment in adjacent areas, open pits, or field depressions that lead to nitrate contamination of the groundwater (Chaudhry et al. 2019c). In Punjab, several researchers studied groundwater quality for drinking and irrigation purposes using various parameters of water quality (Singh & Sekhon 1976; Dhillon & Dhillon 1991; Aulakh et al. 2007; Hundal et al. 2008; Chaudhry et al. 2019a). Yet, no studies in the study region deal with nitrate contamination and its assessment of human health risks. Comprehensive research was, therefore, conducted to elucidate the nitrate distribution pattern and also to assess the possible non-carcinogenic health risk (NCHR) from the ingestion of nitrate-exposed drinking water for three age groups (i.e. children and adults (males and females)). Furthermore, the drinking water quality index (WQI_D) was evaluated for the quantification of groundwater quality in the area. The suitability of groundwater for irrigational purposes has also been evaluated using parameters such as the sodium adsorption ratio (SAR), the sodium percentage (%Na), the magnesium hazard relation (MHR), and the Kelley Ratio (KR). Using Monte Carlo simulation and sensitivity analysis, the uncertainties in the risk estimates have been quantified too.

**Study area**

The town of Rupnagar is of considerable antiquity. The areal extent of the district is 1,414 km². It falls between north latitude 30°44’21″N–31°25’53″N and east longitude 76°16’26″E–76°43’21″E (Figure 1(a) and 1(b)). The climate in the region is distinguished by its general dryness (except during

![Figure 1](http://iwaponline.com/jwh/article-pdf/18/6/1073/824852/jwh0181073.pdf)
the south-west monsoon which constitutes about 78% of the total precipitation), with hot summer (45 °C) and cold winter (10 °C). Agriculture is considered to be the major source of the economy, covering nearly 55% of the region. Rice (350 km²) and wheat (440 km²) are the main crops grown here (Department of Agriculture & Farmer Welfare (DAFW) 2020). Soil consists predominantly of four main types of soil, namely ustochrepts, ustorthents, ustipsamments, and ustifluvents (Chaudhry et al. 2019b). The long-term trend of water level (evaluated using 17 years of data) shows a general decline in the entire district. The mean pre- and post-monsoon groundwater levels range from 2.48–18.81 and 2.50–18.49 mbgl (meter below ground level), respectively.

**MATERIALS AND METHODS**

**Data procurement and descriptive statistics**

Central Groundwater Board (CGWB) is a statutory body that works under the Ministry of Water Resources, India. All data regarding the country's physico-chemical parameters are monitored and analysed by them in their chemical laboratories using standard methods given in the Bureau of Indian Standards (BIS) IS:3025 (2004). For the present study, 11 parameters for the 14 sampling locations (i.e. various dug wells and boreholes) covered by the study area have been chosen which have consistency in their data set over 28 years (1990–2018). Supplementary Material, Table S1 lists the descriptive statistics and acceptable limitations of all the parameters as per the World Health Organization (WHO 2017). It has been evident from the results of the descriptive statistics that the concentrations of nitrate (NO₃⁻) was found to be well above the maximum acceptable limit of WHO (2017). The ionic-balance-error (IBE, the ratio of $((\Sigma\text{Cation} - \Sigma\text{Anion})/((\Sigma\text{Cation} + \Sigma\text{Anion}) \times 100))$) was evaluated for each groundwater sample to ensure accuracy of the study (Pastén-Zapata et al. 2014). The determined IBE was within the acceptable ±10% limit.

**Assessment of drinking and irrigation water quality**

The WQI₀ is a mathematical equation that gives a clear understanding of the quality of surface and groundwater for most domestic uses. WQI₀ is widely used worldwide for the assessment of both drinking and groundwater quality. Horton (1965) built the WQI and was subsequently developed and modified by Brown et al. (1972). Since then it has been used across the world in several studies (Asante-Duah 2002; Narsimha & Rajith 2018; Soleimani et al. 2020). To determine the suitability of the groundwater for drinking purposes, WQI₀ was computed using the methodology adopting in Subramani et al. (2005) and has been avoided here for brevity. The weight values for each parameter were calculated in terms of their relative value for overall drinking water quality at each sampling site (Supplementary Material, Table S2). Parameters NO₃⁻ and F⁻ were given a weightage (Wi) value of 5; for pH, electrical conductivity (EC), and SO₄²⁻ the weight of 3 was given. Due to their lesser importance in water quality, Cl⁻, TH, Ca²⁺, Mg²⁺, and HCO₃⁻ were given the minimum weight of 3 (Abbasnia et al. 2018). The groundwater quality can be divided into five zones based on WQI₀ results, namely excellent water (<50), good water (51–99), poor water (100–199), very poor water (200–300), and water unsuitable for human consumption (>300) (Samantray et al. 2009).

Groundwater is the predominant source of irrigation in the study region. The suitability of groundwater for irrigational purposes has been measured using parameters such as the SAR, the sodium percentage (%Na), the residual sodium carbonate, the MHR, and the KR. Supplementary Material, Table S3 elucidates all the details regarding the aforementioned water quality methods.

**NCHR assessment via oral ingestion**

A hazard quotient (HQₙitrate) risk assessment has been used as a deterministic method in the present study to determine the adverse health effects of nitrate exposure in groundwater resources. In the present study, only oral ingestion mode was considered. The chronic daily intake (CDI) of nitrate can, therefore, be determined by the following equation (Yuan et al. 2020):

$$\text{CDI} = \frac{N_C \times IR \times E_F R \times \text{ED}}{\text{BW} \times \text{AT}}$$

(1)

where CDI is the estimated daily oral nitrate ingestion rate (mg kg⁻¹ day⁻¹); N_C is the average nitrate concentration in
drinking water (mg/L); IR is the ingestion rate of water (L day\(^{-1}\)); \(E_{FR}\) is the frequency of exposure (day year\(^{-1}\)); ED is the duration of exposure for risk assessment (year); BW is body weight (kg); and AT is the averaging time (day). Table 1 lists the default values of the parameter used for HQ\(_{Nitrate}\) assessment. HQ\(_{Nitrate}\) is calculated using Equation (2), where RfD\(_0\) refers to reference dosage or minimal risk level (MRL) taken as 1.6 mg kg\(^{-1}\) day\(^{-1}\) for nitrate (USEPA 1993):

\[
HQ_{Nitrate} = \frac{CDI}{RfD_0}
\]  

(2)

If HQ\(_{Nitrate}\) exceeds 1, there is a possibility of adverse NCHR effects to occur, while HQ\(_{Nitrate}\) less than 1 indicates that people in the area are less likely to be at NCHR due to nitrate exposure (USEPA 2010).

Monte Carlo simulation (MCS) and sensitivity analysis

Since human health is related to a variety of different parameters, health risk evaluation is, therefore, a complex process. Thus, many uncertainties can arise during health risk assessment calculations. There is always a high degree of uncertainty involved when single-point values are used to measure the health risks exposure to any contaminants (Miri et al. 2018; Qasemi et al. 2018). For this reason, Monte Carlo simulations (MCS) have been used as a probabilistic method in this research to minimize the uncertainty of estimates. The parameters used in risk estimates and their probabilistic distributions for three age groups have been presented in Table 1. In this analysis, MCS was used and all the simulations were carried out using Crystal Ball software (version 11.1.1.1 Oracle, Inc., USA), and sensitivity analysis was performed using 10,000 trails.

RESULTS AND DISCUSSION

Spatial variability of nitrate in the study area

\(\text{NO}_3^{-}\) concentrations ranged from 2.98 to 78.76 mg/L, with an average of 27.32 mg/L, in the study area groundwater (Figure 2). Based on the Adimalla et al. (2018) classification, it was observed that out of 14 sampling locations, 21\% (three locations) exceeded the maximum acceptable limit of 45 mg/L and falls in the medium-risk category, which is not suitable for drinking purposes. No location falls in the high-risk category, while 79\% (11 locations) falls in the low-risk category (Supplementary Material, Table S4). A positive correlation (0.57) was observed between \(\text{NO}_3^{-}\) and \(\text{Ca}^{2+}\) (Supplementary Material, Figure S1), indicating long-term use of fertilizers, irrigation runoff, animal waste, crop residues, industrial discharge of nitrogen-containing waste, and andesine conversion to kaolinite in the region (Fernandes et al. 2008). Correlation with the rest of the physico-chemical parameters has been shown in Supplementary Material, Table S5.

Table 1 Parameters used in HQ\(_{Nitrate}\) analysis for three age groups

<table>
<thead>
<tr>
<th>Parameters used</th>
<th>Units</th>
<th>Distribution type</th>
<th>Children</th>
<th>Female</th>
<th>Male</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (BW)</td>
<td>kg</td>
<td>Lognormal</td>
<td>16.68 ± 1.48(^a)</td>
<td>60.40 ± 1.10(^a)</td>
<td>69.55 ± 1.10(^a)</td>
<td>Zhai et al. (2017), Miri et al. (2018), Ozsvath (2009)</td>
</tr>
<tr>
<td>Daily ingestion rate (IR)</td>
<td>L day(^{-1})</td>
<td>Uniform</td>
<td>Min: 0.3</td>
<td>Min: 1</td>
<td>Min: 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max: 0.5</td>
<td>Max: 1.5</td>
<td>Max: 1.5</td>
<td></td>
</tr>
<tr>
<td>Average lifespan (AT)</td>
<td>day</td>
<td>Fixed value</td>
<td>2,190</td>
<td>10,950</td>
<td>10,950</td>
<td></td>
</tr>
<tr>
<td>Frequency of exposure ((E_{FR}))</td>
<td>day year(^{-1})</td>
<td>Triangular</td>
<td>Min: 180</td>
<td>Min: 180</td>
<td>Min: 180</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mode: 345</td>
<td>Mode: 345</td>
<td>Mode: 345</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Max: 365</td>
<td>Max: 365</td>
<td>Max: 365</td>
<td></td>
</tr>
<tr>
<td>Duration of exposure (ED)</td>
<td>year</td>
<td>Fixed value</td>
<td>6</td>
<td>30</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Reference oral dosage (RfD(_0))</td>
<td>mg kg(^{-1}) day(^{-1})</td>
<td>Fixed value</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Mean ± Standard deviation.
Figure 2 | Spatial distribution of nitrate (mg/L) in the study area.
Assessment of groundwater suitability for drinking

The computed WQID values in the region ranged from 55.44 to 139.40. Eighty-six percent of the sampling locations (SL) in this study ranged from 51 to 99, thus, indicating good water quality in these regions. Moreover, 14% of the sampling locations ranged from 100 to 199, indicating poor water quality in these regions (Table 2). The highest WQID value was observed at two sampling sites Ahmedpur and Bhalan, mainly due to higher pH (7.76), EC (878 μS/cm), TH (344 mg/L), HCO3⁻ (364 mg/L), and F⁻ (4.9 mg/L) values. The spatial distribution map of the WQID has been prepared using the inverse distance weighted technique in ArcGIS 10.5 software (Figure 1(b)). The map indicates that the northern and central regions are of poor water quality primarily because of an increase in various anthropogenic activities in such regions (Sreedevi et al. 2018).

Assessment of groundwater suitable for irrigational practices

To assess groundwater suitability for irrigational purposes, SAR is an extremely important parameter based on sodium, calcium, and magnesium levels that largely affect the soil’s permeability and cause infiltration. According to Richards (1954), SAR can be classified into five classes (Table 3). In the study area, SAR values ranged between ‘1.92 and 31.93’, indicating that 93 and 7% of sampling location belongs to ‘excellent to good’ and ‘unsuitable’ groundwater class, respectively (Table 3). Additionally, the USSL diagram was also plotted which categorizes EC values for irrigation suitability (Supplementary Material, Figure S2). Based on EC, irrigation water can be classified into four classes (Table 3). As per the EC classification, roughly 43% of the sampling locations are in the high category of salinity, while 57% are in the medium category of salinity.

One more very important parameter is %Na which has been used widely to determine groundwater’s suitability for irrigation purposes. Also, significant sodium content relative to calcium and magnesium decreases the permeability of soil as sodium ions appear to be absorbed by clay particles, displacing calcium and magnesium ions, resulting in deflocculation and loss of soil tilth and permeability (Adimalla et al. 2018). In the study region, %Na values ranged between 19.99 and 65.45, and only one location was above 60–80, which lies under ‘very poor’ class for irrigation uses. Moreover, seven sampling locations lie under the ‘good’ class in the region (Table 3).

When bicarbonates and carbonates in groundwater surpass the amount of calcium and magnesium, it affects the groundwater suitability for irrigational purposes due to elevated bicarbonate and carbonate concentrations in such water. It helps precipitate the calcium and magnesium; hence, water is more concentrated in the soil. It would also induce an alkalinizing effect and increase the pH. Thus, if water analysis shows a high pH level, it may be a sign of a high carbonate and bicarbonate ion content. Therefore, RSC is a sodium level assessment in addition to calcium and magnesium, and water with higher RSC affects crop yields. According to Eaton (1950), RSC can be classified into three classes (Table 3). In the analysis, the measured RSC values ranged from −1.36 to 2.30 meq/L, and 11 sampling locations showed negative RSC values in the field, indicating that calcium and magnesium are not fully precipitated and the water is suitable for irrigational practices in such regions (CGWB 2013).

Calcium and magnesium usually do not act equally in soil systems, but in the water, they strike a balance among

| Table 2 | Sampling locations classification based on nitrate concentration |
|---|---|---|
| Sampling locations (SL) | WQI | Water type |
| Ahmedpur, SL1 | 139.40 | Poor |
| Bhalan, SL2 | 108.47 | Poor |
| Brahmpur, SL3 | 55.44 | Good |
| Chak Dera, SL4 | 76.90 | Good |
| Dhair, SL5 | 81.57 | Good |
| Saijowal, SL6 | 89.79 | Good |
| Singha, SL7 | 65.54 | Good |
| Soara, SL8 | 87.61 | Good |
| Kakrali, SL9 | 72.45 | Good |
| Dumewal, SL10 | 60.83 | Good |
| Nurpur Bedi, SL11 | 84.07 | Good |
| Bara Chaunta, SL12 | 62.23 | Good |
| Hardo Namoh, SL13 | 55.99 | Good |
| Ropar, SL14 | 67.64 | Good |
themselves. Magnesium affects the soil as water has more salinity and sodium, which contribute to alkaline soil formation. This alkaline soil has detrimental effects on crop yields (Wang et al. 2020). Besides, the excessive magnesium concentrations in water can cause harmful effects to plants due to decreased potassium availability in soils (Thapa et al. 2017). MHR was thus analysed to determine the quality of groundwater for irrigation uses. The estimated MHR values in the analysis ranged from 28.29 to 41.10 meq/L. Around 93% of the sampling sites were ideal for irrigation, while the remaining 7% were deemed unsafe and unsuitable for irrigation due to the MHR value of more than 50% (Table 3).

Kelley (1963) introduced an important criterion for evaluating irrigation water quality based on sodium levels calculated against calcium and magnesium. Water with KR > 1 is considered unfit for irrigation due to excessive sodium concentrations and the possibility of soil dispersion, whereas values below 1 are considered suitable for irrigation. The calculated KR values ranged from 0.25 to 1.74 meq/L and approximately 78% of the sampling sites were ideal for irrigation, while the remaining 22% were considered unsafe and unsuitable for irrigation due to the KR > 1.

Evaluation of NCHR assessment of nitrate

The NCHR assessment of oral ingestion exposure to nitrate contaminated drinking water at each sampling location was evaluated using the deterministic technique. Table 4 and Supplementary Material, Table S6 indicated the HQ\text{Nitrate} and CDI for each location. The range of HQ\text{Nitrate} for children, female, and male in the study region was 0.37 – 1.79 (average: 0.86), 0.36 – 1.54 (average: 0.77), and 0.35 – 1.37 (average: 0.71), respectively. Thus, as per the HQ\text{Nitrate} risk values, NCHR due to oral ingestion of drinking water contaminated with nitrate in the three age groups are in the following order: children > female > male. Additionally, the calculated HQ\text{Nitrate} was found to be above the safe limit of 1 at 22% of the sampling locations (Nurpur Bedi > Sajjowal > Dumewal). Also, it has been estimated that the real risks resulting from NCHR of nitrate would be greater. Considering the increasing trend in nitrate concentration in groundwater and the fragile environment, there is an

\textbf{Table 3 | Classification of groundwater for irrigation purposes}

<table>
<thead>
<tr>
<th>Methods used</th>
<th>Range</th>
<th>Classification for irrigation purposes</th>
<th>Range (in the study area)</th>
<th>No. of sampling locations</th>
<th>% of sampling locations</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAR</td>
<td>&lt;10</td>
<td>Excellent</td>
<td>1.92–31.93</td>
<td>9</td>
<td>64.29</td>
<td>Richards (1954)</td>
</tr>
<tr>
<td></td>
<td>10.0–18.0</td>
<td>Good</td>
<td></td>
<td>4</td>
<td>28.57</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.0–26.0</td>
<td>Poor</td>
<td></td>
<td>0</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;26.0</td>
<td>Unsuitable</td>
<td></td>
<td>1</td>
<td>7.14</td>
<td></td>
</tr>
<tr>
<td>%Na</td>
<td>&lt;20.0</td>
<td>Excellent</td>
<td>19.99–63.45</td>
<td>1</td>
<td>7.14</td>
<td>Wilcox (1948)</td>
</tr>
<tr>
<td></td>
<td>20.0–40.0</td>
<td>Good</td>
<td></td>
<td>7</td>
<td>50.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40.0–60.0</td>
<td>Poor</td>
<td></td>
<td>5</td>
<td>35.71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60.0–80.0</td>
<td>Very poor</td>
<td></td>
<td>1</td>
<td>7.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;80</td>
<td>Unsuitable</td>
<td></td>
<td>0</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>RSC</td>
<td>&lt;1.25</td>
<td>Good</td>
<td>−1.36–2.30</td>
<td>11</td>
<td>78.57</td>
<td>Eaton (1950)</td>
</tr>
<tr>
<td></td>
<td>1.25–2.50</td>
<td>Poor</td>
<td></td>
<td>3</td>
<td>21.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;2.50</td>
<td>Unsuitable</td>
<td></td>
<td>0</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>MHR</td>
<td>&lt;50.0</td>
<td>Suitable</td>
<td>28.29–41.10</td>
<td>13</td>
<td>92.86</td>
<td>Adimalla et al. (2018)</td>
</tr>
<tr>
<td></td>
<td>&gt;50.0</td>
<td>Unsuitable</td>
<td></td>
<td>1</td>
<td>7.14</td>
<td></td>
</tr>
<tr>
<td>KR</td>
<td>&lt;1</td>
<td>Suitable</td>
<td>0.250–1.74</td>
<td>11</td>
<td>78.57</td>
<td>Kelley (1963)</td>
</tr>
<tr>
<td></td>
<td>&gt;1</td>
<td>Unsuitable</td>
<td></td>
<td>3</td>
<td>21.43</td>
<td></td>
</tr>
<tr>
<td>EC (μS/cm)</td>
<td>&lt;250</td>
<td>Excellent</td>
<td>439.38–1,159.46</td>
<td>0</td>
<td>0.00</td>
<td>Wilcox (1948)</td>
</tr>
<tr>
<td></td>
<td>250–750</td>
<td>Good</td>
<td></td>
<td>8</td>
<td>57.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>750–2,250</td>
<td>Permissible</td>
<td></td>
<td>6</td>
<td>43.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;2,250</td>
<td>Unsuitable</td>
<td></td>
<td>0</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>
increasing need for rural communities to tackle the drinking water protection problem.

Several other public health studies also indicate that the NCHR of nitrate cannot be ignored in drinking water. Espejo-Herrera et al. (2015) suggested an increase in the risk of bladder cancer associated with the highest nitrate levels in drinking water. Su et al. (2013) conducted a study in the north-western province of China and found that agricultural areas in the region had a significantly high NCHR due to sewage irrigation. An NCHR evaluation was conducted by Wu & Sun (2015) in China, and it was found that the overall risk was primarily due to nitrate and high-risk regions were observed near the fertilizer plant. According to a study by Sadler et al. (2016) in Indonesia, it was found that if drinking water contaminated with high nitrate concentration is ingested within the first 3 months of pregnancy, there is a high risk of birth defects in susceptible populations. Zhai et al. (2017) from his study conducted in the rural part of China found out that children > female > male are at greater risk of health hazards from oral ingestion of nitrate drinking water, as nitrate concentration in groundwater of this region is observed several times higher than the safe limit. Thus, such results show that more attention should be paid to the toxicity of nitrates in groundwater and its risk to human health.

**Evaluation of sensitivity analysis**

The qualitative sensitivity analysis was performed to identify the key major performance parameters in the risk estimates of the model. Results of the NCHR sensitivity study (oral ingestion) are shown in Table 5. For oral ingestion exposure, NC and IR were found to be the most influencing parameters in all of the three age groups with correlation coefficients ranging from 0.91 to 0.95 and 0.19 to 0.23, respectively. Thus, a decrease in NC and IR will reduce the NCHR of oral intake of nitrate through drinking water. It was also found that sensitivity was inversely related to BW.

**CONCLUSIONS**

The present research focuses primarily on evaluating NCHR due to nitrate in groundwater using two specific approaches: deterministic and probabilistic by using HQNitrata formula and sensitivity analysis using the MCS technique. The following conclusions can be taken from the ongoing investigation. The findings of the calculation of HQNitrata showed that nitrate had NCHR in children > female > male. To evaluate the most effective parameter in increasing NCHR, the results of the sensitivity analysis showed that NC and IR had the greatest effect on increasing sensitivity in the three age groups studied. Also, the WQID as a whole revealed that the northern and central regions are of poor water quality primarily because of an increase in various anthropogenic activities and industrialization in the region. SAR, sodium percentage, RSC, MHR, and KR are

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Table 4 | HQNitrata exposure due to oral intake

<table>
<thead>
<tr>
<th>Sampling locations</th>
<th>Male</th>
<th>Female</th>
<th>Children</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahmedpur</td>
<td>0.54</td>
<td>0.58</td>
<td>0.63</td>
</tr>
<tr>
<td>Bhalan</td>
<td>0.76</td>
<td>0.82</td>
<td>0.93</td>
</tr>
<tr>
<td>Brahmpur</td>
<td>0.52</td>
<td>0.55</td>
<td>0.60</td>
</tr>
<tr>
<td>Chak Dera</td>
<td>0.57</td>
<td>0.60</td>
<td>0.67</td>
</tr>
<tr>
<td>Dhair</td>
<td>0.59</td>
<td>0.63</td>
<td>0.70</td>
</tr>
<tr>
<td>Saijowal</td>
<td>1.51</td>
<td>1.46</td>
<td>1.70</td>
</tr>
<tr>
<td>Singha</td>
<td>0.47</td>
<td>0.50</td>
<td>0.54</td>
</tr>
<tr>
<td>Soara</td>
<td>0.49</td>
<td>0.51</td>
<td>0.55</td>
</tr>
<tr>
<td>Kakrali</td>
<td>0.66</td>
<td>0.71</td>
<td>0.79</td>
</tr>
<tr>
<td>Dumewal</td>
<td>1.00</td>
<td>1.10</td>
<td>1.25</td>
</tr>
<tr>
<td>Nurpur Bedi</td>
<td>1.37</td>
<td>1.54</td>
<td>1.79</td>
</tr>
<tr>
<td>Bara Chaunta</td>
<td>0.48</td>
<td>0.50</td>
<td>0.54</td>
</tr>
<tr>
<td>Hardo Namoh</td>
<td>0.35</td>
<td>0.36</td>
<td>0.37</td>
</tr>
<tr>
<td>Ropar</td>
<td>0.49</td>
<td>0.52</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Bold values indicate non-carcinogenic risks in the age groups.

---

Table 5 | Sensitivity analysis results (rank correlation) of different age groups exposed to nitrate

<table>
<thead>
<tr>
<th>Type of exposure</th>
<th>Parameters</th>
<th>Age group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oral ingestion</td>
<td>NC, IR, BW</td>
<td>Children</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Male</td>
</tr>
<tr>
<td>NC</td>
<td>0.91</td>
<td>0.94</td>
</tr>
<tr>
<td>IR</td>
<td>0.25</td>
<td>0.19</td>
</tr>
<tr>
<td>BW</td>
<td>0.01</td>
<td>-0.08</td>
</tr>
</tbody>
</table>

Downloaded from http://iwaponline.com/jwh/article-pdf/18/6/1073/824852/jwh0181073.pdf by guest
used in the study region to assess the suitability of ground-
water quality for irrigation. According to them, a
significant number of sampling sites has been suggested to
be ideal for irrigation and drinking purposes. The results
of this study thus provide useful information for future
work planning and are critical for assessing the possible
health consequences of exposure to nitrates in the study
region.

ACKNOWLEDGEMENTS

We thank CGWB, Chandigarh, for their cooperation and
providing us with the necessary physico-chemical data sets
needed for this study.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplemen-
tary Information.

REFERENCES

Abbasnia, A., Yousefi, N., Mahvi, A. H., Nabizadeh, R., Radfard,
M., Yousefi, M. & Alihmohammadi, M. 2018 Evaluation of
groundwater quality using water quality index and its
suitability for assessing water for drinking and irrigation
purposes: case study of Sistan and Baluchistan province
Adimalla, N., Li, P. & Qian, H. 2018 Evaluation of groundwater
contamination for fluoride and nitrate in semi-arid region of
Nirmal Province, South India: a special emphasis on human
25 (5), 1107–1124.
Aquilina, L., Vergnaud-Ayraud, V., Labasque, T., Bour, O., Molénat, J.,
Ruiz, L., de Montety, V., De Ridder, J., Roques, C. &
Longuevergne, L. 2012 Nitrate dynamics in agricultural
catchments deduced from groundwater dating and long-term
nitrate monitoring in surface- and groundwaters. Sci. Total
Asante-Duah, K. 2002 Public Health Risk Assessment for Human
Aulakh, M. S., Garg, A. K. & Kabba, B. S. 2007 Phosphorus
accumulation and leaching, and residual effects on crop
yields from long-term applications in subtropics. Soil Use
Manage. 23, 417–427.
Brown, R. M., McClelland, N. I., Deininger, R. A. & O’Connor, M. F.
1972 A water quality index-crashing the psychological barrier.
In: Indicators of Environmental Quality. Environmental
Science Research, Vol. 1 (W. A. Thomas ed.). Springer,
Boston, MA.
Bureau of Indian Standards (BIS) 2004 Water and Wastewater –
Methods of Sampling and Test. Bureau of Indian Standards
Publ. No. IS:3025, New Delhi, India.
Central Groundwater Board (CGWB) 2015 Groundwater Yearbook
Resources, New Delhi, India.
contamination characterization using multivariate statistical
analysis and geostatistical method. Water Supply 19 (8),
2309–2322.
Chaudhry, A. K., Kamal, K. & Alam, M. A. 2019b Mapping of
groundwater potential zones using the fuzzy analytic
hierarchy process and geospatial technique. Geocarto Int.
Chaudhry, A. K., Kumar, K. & Alam, M. A. 2019c Spatial
distribution of physico-chemical parameters for groundwater
quality evaluation in a part of Satluj River Basin, India. Water
Supply 19 (5), 1480–1490.
Department of Agriculture and Farmer Welfare (DAFW) 2020
Varieties of Major Crops Grown in Rupnagar. Government of
Punjab, India.
2003 Nitrate in public water supplies and the risk of
colon and rectum cancers. Epidemiology 14 (6),
640–649.
Dhillon, K. S. & Dhillon, S. K. 1991 Selenium toxicity in soils,
plants, and animals in some parts of Punjab, India. Int. J.
Eaton, F. M. 1959 Significance of carbonates in irrigation waters.
Soil Sci. 69 (2), 123–134.
Espejo-Herrera, N., Cantor, K. P., Malats, N., Silverman, D. T.,
Tardón, A., García-Closas, R., Serra, C., Kogevinas, M. &
Villanueva, C. M. 2015 Nitrate in drinking water and bladder
Fernandes, P. G., Carreira, P. & da Silva, M. O. 2008 Anthropogenic
sources of contamination recognition – Sines coastal aquifer
Geleperin, A., Moses, V. J. & Fox, G. 1976 Nitrate in water supplies
Horton, R. K. 1965 An index number system for rating water
Hundal, H. S., Singh, K. & Singh, D. 2008 Arsenic content in
ground and canal waters of Punjab, North-West India.
Kelley, W. P. 1965 Use of saline irrigation water. Soil Sci. 95 (6),
355–391.
Miri, M., Bhatnagar, A., Mahdavy, Y., Basiri, L., Nakhaei, A.,
Khosravi, R., Esfami, H., Ghasemi, S. M., Balarak, D.,
Alizadeh, A., Mohammadi, A., Derakhshan, Z., Fallahzadeh,
R. A. & Taghavi, M. 2018 Probabilistic risk assessment of


Richards, L. A. 1954 *Diagnosis and Improvement of Saline and Alkali Soils*. Agric Handbook 60. USDA, Washington, DC, USA.


First received 9 May 2020; accepted in revised form 14 September 2020. Available online 17 October 2020