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Mapping Nitrate Distribution And Non-Carcinogenic Health Risk Assessment Via Hazard Index For Infants

Shankar B.S *[1], Sreevidya Raman. S [2], Mahadeva Raju [3], Latha Sanjeev [4]
[*1] Department of Civil Engineering, Cambridge Institute of Technology, K.R. Puram, Bengaluru, Karnataka, India (SCOPUS ID: 22959200000, ORCID ID: 0000-0002-8384-0771, WEB OF SCIENCE ID: AAZ-7671-2020).
[2] Department of Civil Engineering, Cambridge Institute of Technology, K.R. Puram, Bengaluru, Karnataka, India.
[3] Department of Chemical Engineering, Dayananda Sagar College of Engineering, Bengaluru, Karnataka, India.
[4] Director, SLSTTIC pvt ltd, Bengaluru, Karnataka, India.

Corresponding Author Email id: shanky5525@gmail.com

Abstract
Nitrate contamination in drinking water has become a major public health concern, as high nitrate levels have been linked to various health issues. This study was conducted to assess nitrate concentrations in the groundwater of Bellandur by collecting and analyzing thirty groundwater samples during the pre- and post-monsoon seasons. Analysis results showed that 53.33% and 56.67 % of samples exceeded the BIS limit for nitrate in drinking water (45 mg/L) during pre- and post-monsoon seasons respectively. Health risks related to non-carcinogenic effects from nitrate exposure through drinking water were evaluated, focusing on infants who are particularly vulnerable to nitrate-induced methemoglobinemia. The Health Risk Index, HI was calculated based on Chronic Daily Intake (CDI), with findings indicating that 76.67% and 83.33% of the samples in the pre-and post-monsoon respectively, had HI values above 1, suggesting a significant risk of nitrate exposure, posing a health threat to the residents. This underscores the need for effective strategies to control and manage nitrate contamination sources, safeguarding groundwater quality in the area.

Keywords: Contamination, Chronic daily intake, Groundwater, Hazard index, Nitrate.

1. INTRODUCTION

Nitrates are naturally occurring ions in the environment as part of Earth's nitrogen cycle. They commonly appear in water-soluble forms and often combine with ions like potassium and sodium. In water, these nitrate salts tend to dissociate fully. Nitrates originate from the oxidation of nitrites and serve as essential nutrients for plants. In agriculture, large amounts of nitrates are applied through inorganic fertilizers[1]. However, extensive use of these fertilizers has led to groundwater contamination in agricultural areas due to elevated nitrate levels[2-5]. Additionally, the oxidation of nitrogen compounds and ammonia in wastewater contributes to nitrate formation.

Beyond agriculture, primary sources of nitrate in groundwater include wastewater disposal and waste materials from nitrogen-rich products, such as animal and human waste and septic systems[6]. Considerable efforts have been made to understand factors influencing nitrate concentration, such as dissolved oxygen, soil properties, redox conditions, and the presence of elements like iron[7].

Nitrate levels are considered a key indicator in assessing groundwater pollution from dispersed sources, making them commonly used to gauge groundwater vulnerability to contamination[8]. Nitrate ingestion through drinking water has been associated with diseases like multiple sclerosis, gastric cancer, and non-Hodgkin lymphoma[9,10]. High nitrate concentrations can lead to several severe health effects, the most concerning being methemoglobinemia, especially in infants, but also in pregnant women and the elderly[11]. Due to these risks, nitrate levels in drinking water need to be controlled. Prolonged consumption of water with elevated nitrate levels may impair oxygen transport in the blood, contributing to such conditions[12]. Nitrate concentrations in the groundwater samples were measured using a UV-visible spectrophotometer (Systronics 118 make) at a wavelength of 275 nm.

Awareness of the hazards posed by various chemicals in the environment has significantly increased recently[13]. This has led researchers to explore different methods for early risk assessment. The United States Environmental Protection Agency (USEPA) has established strict standards for 64 contaminants and developed detailed guidelines for health risk assessments across various categories[14]. This study on evaluating health risks associated with nitrate levels in groundwater uses a model based on risk assessment principles outlined in the report published by National Academy of Sciences[15], and NRC[16].

Highlighting the importance of reassessing environmental health, doctors argue that civic authorities should inform the public—including medical professionals—about geographical areas that may present health risks. They stress that the government has a responsibility to provide this information to relevant authorities, healthcare providers, and the public, enabling them to take preventive action. Without a comprehensive understanding of environmental disease sources, doctors may only treat symptoms, sending patients back into potentially harmful surroundings[17]. This study, therefore, aims to evaluate nitrate contamination in the study area, assess health risks for the affected population, and recommend mitigation strategies.

2. MATERIALS AND METHODS

2.1 Study area description

The study area, Bellandur, is located in southern Bangalore, spanning 24 square kilometers and represented on the Survey of India's toposheet 57H/9. The terrain is gently undulating with only a few streams, or nallas, flowing from southwest to northeast, and lacks any prominent ridges or hills. Elevation varies from 900 meters at the highest point to 800 meters at the lowest, creating a 100-meter drop. The area features a dendritic drainage pattern with underlying gneiss and granite formations. Three main streams feed into the Bellandur tank, forming the watershed, and each stream passes through two or three tanks before reaching the Bellandur tank.

The regions of Madiwala, Agara, Koramangala, Challaghatta, and Bellandur fall within the existing sewerage zone, with sewage from Koramangala, Madiwala, and Agara draining into Bellandur tank, along with treated wastewater from the Challaghatta treatment plant. Currently, there are no catchments for these tanks, as upstream nallas have been developed into residential areas. Consequently, the dry tank serves as a repository for sewage from various parts of the city, with the BWSSB channeling untreated sewage into the Bellandur tank via stormwater drains. Additionally, around 200 industries are located within this area.

2.2 Sampling and Method of Analysis

In April (pre-monsoon) and November (post-monsoon) of 2023, a total of thirty samples were collected from both borewells and open wells in the region. These samples were stored following the guidelines outlined by APHA[18]. The geographical locations of the stations were accurately recorded using the Global Positioning System (GPS) , noting their latitude and longitude. The collection was done in 2litre polyethylene bottles, and preservation involved adding concentrated sulphuric acid to adjust the pH to around 2. The samples were stored at a temperature of 4°C, and laboratory analysis was conducted as per 'APHA'. The location map has been presented in Fig. 1.

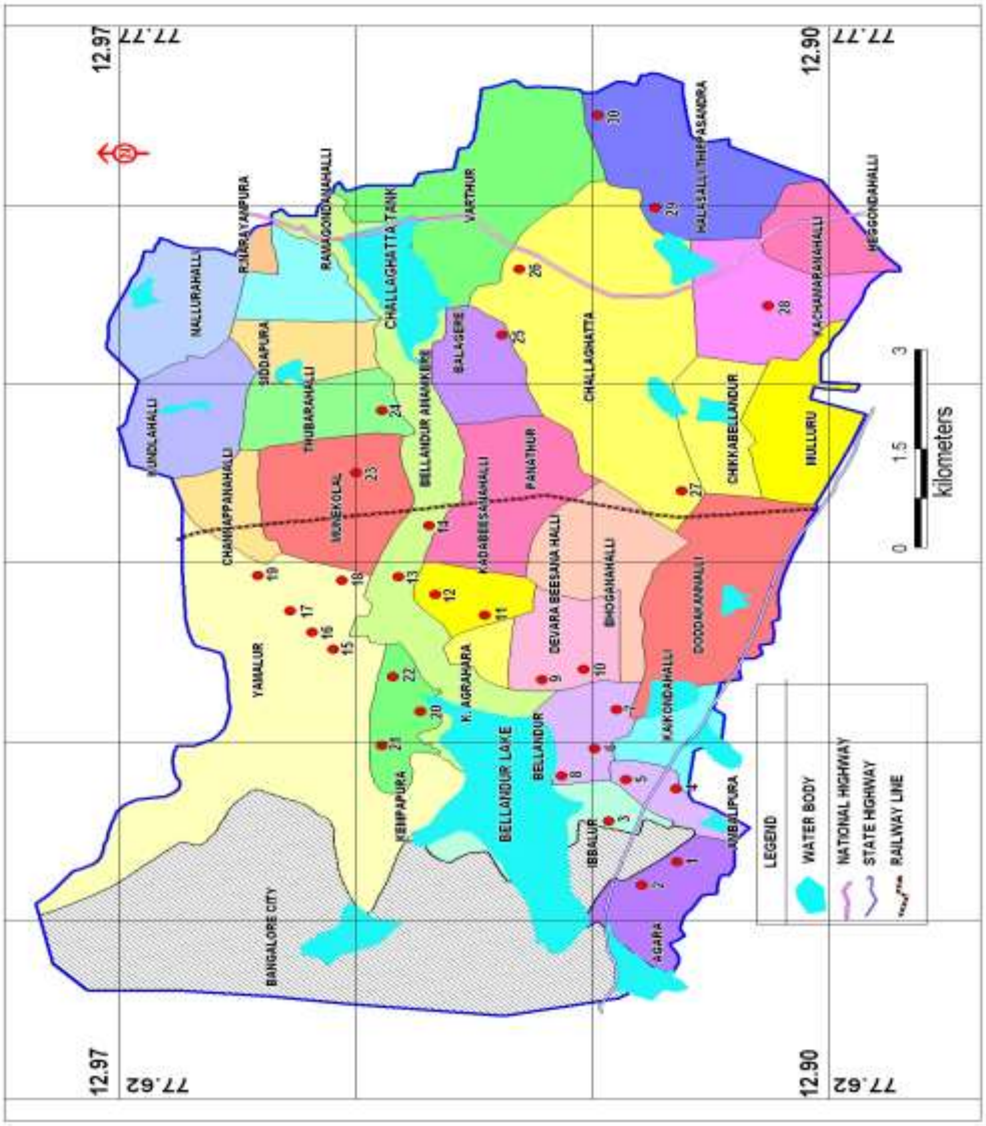

Figure 1: Location map of Bellandur area showing the sampling stations

2.3 *Non-carcinogenic Health Risk Assessment through Hazard Coefficient*

The health risk appraisal was carried out to assess the possible risks entailed by groundwater nitrate levels used for supply systems. The Hazard Index (HI) was computed to determine the extent of risk involved with the consumption of nitrate. HI is an index indicating the risks entailed by exposure to a substance, with increased HI denoting enhanced possibilities of adverse health outcomes. The 'U.S. Environmental Protection Agency' (USEPA) established the relationship for determining the HI[19]. It is calculated by the ratio of the Ingested Dose (ID) to the Reference Dose (RfD), where RfD is the concentration of a substance that has no adverse health effects over a specific duration.

$$HI = \frac{\text{Injected dosage}}{\text{Reference dosage}}$$

In order to determine exposure of nitrate in drinking water, chronic daily intake (CDI) was first calculated using the following equation:

$$CDI = \frac{\text{C x DI}}{BW}$$

where,
'CDI = Chronic Daily Intake (mg/kg/day),
C = Nitrate concentration in groundwater (mg/L),
DI = Average daily intake rate of water (L/day),
BW = Body weight of the exposed individual (kg)
To assess the significant exposure and overall potential for non-carcinogenic health effects caused by nitrate in drinking water, the Hazard Index (HI) was calculated using the following equation :

$$HI = \frac{\mathrm{CDI}}{RfD}$$

where,
HI = Hazard Index,
CDI = Chronic Daily Intake (mg/kg/day),
RfD = Reference dose (mg/kg/day)
For this calculation, the ingestion rate (IR) of bottle-fed infants was taken as 0.3 L, and body weight (BW) as 5.2 kilograms. The ID values were calculated accordingly. An RfD value of 1.6 mg/kg/d for N-NO_3 equivalent to 7.0875 mg/kg/d of NO_3 was also used. If the HI value is equal to or greater than 1, it points toward the possibility of non-carcinogenic toxic health effects, which require urgent attention. The greater the HI, the higher the risk of harmful health effects from non-carcinogenic toxicity[20].

3. RESULTS AND DISCUSSIONS

3.1 *Analysis of nitrate concentration in groundwater*

The analysis of groundwater during both dry and wet seasons indicated that 53.33% of the pre-monsoon samples and 56.67% of the post-monsoon samples contained nitrate concentrations above the allowable upper limit of 45 mg/L, as prescribed by the Bureau of Indian Standards (BIS, 2012)[21].The pre-monsoon average, minimum, and maximum nitrate values were 394.0, 6.0, and 90.96 mg/L, respectively, whereas the post-monsoon values were 418.0, 6.0, and 101.6 mg/L, respectively. The range and average nitrate values in groundwater samples from different sources are presented in Table 1. Figure 2 illustrates the percentage of samples for various nitrate concentration ranges. Nitrate levels were slightly elevated in the post-monsoon season, possibly owing to subsurface drainage conditions, increased aquifer material interaction of groundwater over a longer period, and greater anthropogenic influences[22]. Nitrate levels were also higher in open wells than in borewells and hand pumps from Table 1. This could be as a result of inadequate infrastructure, poor maintenance, and improper upkeep of open wells.
The excessive discharges of municipal, domestic, or industrial wastes, and percolating drains and inadequate treatment of sewage most probably led to the high content of nitrates in the region[23.]

Table 1: Range of Nitrate concentrations and their mean values in groundwater samples

S. No	Source	No of samples	Range of Nitrate concentration, mg/l		Mean concentration of Nitrate (mg/l)	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
a	Open well	04	210- 394	224- 418	281.0	307.3
c	Hand pump	09	06- 266	06- 292	85.33	96.77
c	Borewell	17	04- 280	08- 284	49.24	55.94

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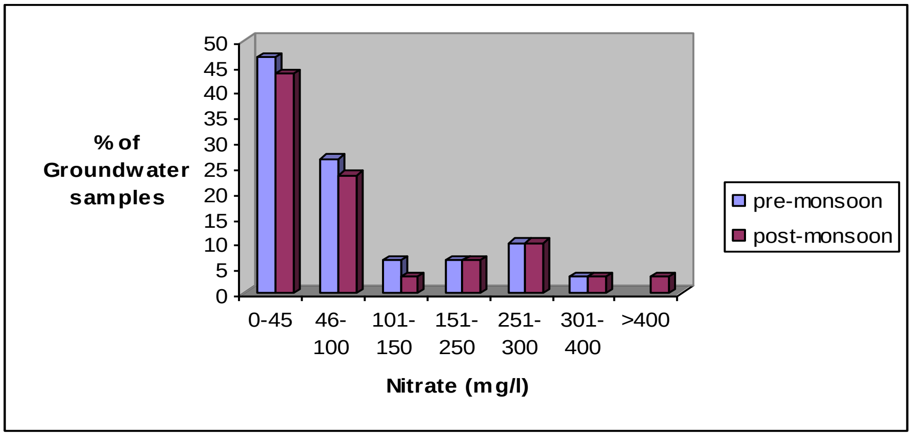

Figure 2: Sample percentage based on different ranges of nitrate concentration

3.2 Hazard characterization and Health Risk assessment

For the estimation of daily nitrate exposure in an individual, the chronic daily intake data were used. Table 2 shows results of the pre-monsoon and post-monsoon hazard index analysis. The study reveals that 25 post-monsoon and 23 pre-monsoon samples contained HI values greater than 1, which represents a high health risk due to nitrate contamination in groundwater. The HI values varied from 0.21 to 15.06, with mean HI values of 3.27 for the pre-monsoon and 3.67 for the post-monsoon season. These results reveal that 76.67% of the pre-monsoon and 83.33% of the post-monsoon water samples possessed HI values greater than the critical value of 1, indicating a high risk of toxic health effects through excessive nitrate content. Immediate measures need to be taken to counteract this risk and safeguard the public from harmful effects of drinking such polluted water. Figures 3.1 and 3.2 show the potability of groundwater with respect to HI values for dry and wet seasons, respectively.

Table 2: Results of Hazard Index (HI) analysis for pre-monsoon and post monsoon seasons

Sample no	Pre- Monsoon		Post- Monsoon	
	NO_3 concentration, mg/l	Hazard Index (HI)	NO_3 concentration, mg/l	Hazard Index (HI)
P1	66	2.38	82	2.96
P2	210	7.57	224	8.08
P3	54	1.95	52	1.87
P4	18	0.65	27	0.97
P5	24	0.87	33	1.19
P6	102	3.68	104	3.75
P7	290	10.45	335	12.08
P8	126	4.54	155	5.59
P9	32	1.15	40	1.44
P10	10	0.36	10	0.36
P11	22	0.79	28	0.98
P12	6	0.22	8	0.29
P13	84	3.03	97	3.50
P14	58	2.09	68	2.45
P15	50	1.80	54	1.95
P16	280	10.09	284	10.24
P17	6	0.22	6	0.22
P18	394	14.20	418	15.07
P19	32	1.15	40	1.44
P20	78	2.81	92	3.32
P21	32	1.15	40	1.44
P22	52	1.87	66	2.38
P23	266	9.59	292	10.53
P24	230	8.29	252	9.08
P25	20	0.72	20	0.72
P26	28	1.01	35	1.26
P27	55	1.98	62	2.24
P28	40	1.44	48	1.73
P29	36	1.30	41	1.48
P30	28	1.01	38	1.37

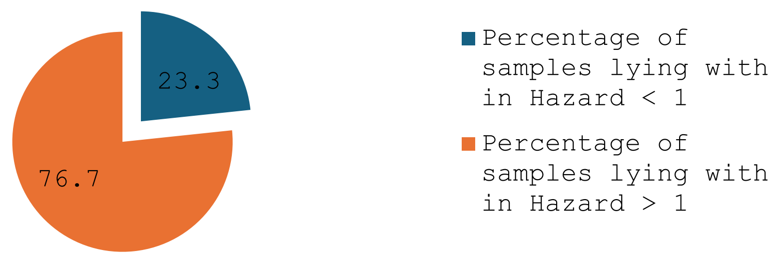

Figure 3.1: Potability with respect to HI values in the groundwater during pre- monsoon

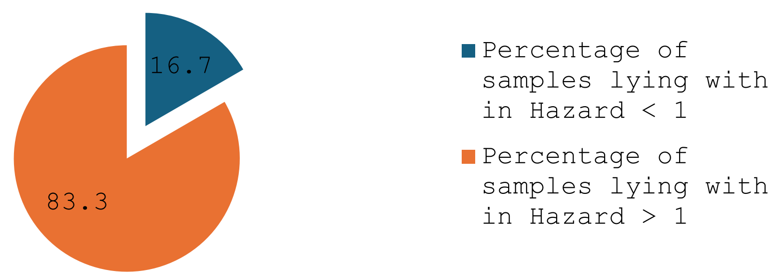

Figure 3.2: Potability with respect to HI values in the groundwater during pre- monsoon

CONCLUSIONS

The nitrate analysis in groundwater revealed that 53.33% and 56.67 % of samples exceeded the BIS maximum allowable limit for nitrate in drinking water (45 mg/L) during pre- and post-monsoon seasons respectively. The HI was calculated based on Chronic Daily Intake (CDI), with findings indicating that 23 samples (76.67%) in the pre-monsoon and 25 samples (83.33%) in the post-monsoon season had HI values above 1, suggesting a significant risk of nitrate exposure, posing a health threat to residents due to elevated nitrate levels in the groundwater.

Elevated nitrate underscores the need to protect water supplies from contamination, as this is essential to safeguard public health and reduce potential liability. Wells that are poorly constructed or improperly located are more likely to experience high nitrate concentrations. Therefore, any new well shall be placed at least 100 feet upstream from septic systems, chemical storage facilities etc. The use of fertilizer and practices adapted for irrigation should align with the crop uptake to minimize nitrate hazard in groundwater. Limiting nitrogenous fertilizer use can reduce nitrate leaching. Treatment methods such as distillation, ion exchange, and reverse osmosis, are available to reduce its levels, despite these being costly options. Periodical monitoring, alongside health education programs, is essential for mitigating nitrate contamination in agricultural and other vulnerable areas.

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