Assessment of Nitrates in Ground Water of Merta City (Nagaur District, Rajasthan) as a Potential Health Risk to Inhabitants

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ABSTRACT

Groundwater is the primary drinking-water source for many rural and semi-urban communities in Rajasthan. The present study investigates the concentration and distribution of nitrate (NO_3^-) in the groundwater of Merta City (Nagaur district), assesses sources of contamination, and evaluates the potential health risk to the local population. Using sampling of bore-wells/wells, chemical analysis and exposure assessment methods, the study finds that a significant fraction of groundwater samples exceed recommended nitrate limits; anthropogenic fertilizer use, sewage/animal waste leaching and hydrogeochemical conditions are implicated. The hazard index for vulnerable groups (children, infants) suggests a non-carcinogenic risk. The paper recommends regular monitoring, mitigation measures (e.g., alternate safe water supply, source protection) and awareness programmes.

Keywords: Groundwater nitrate · Merta City · Drinking water quality · Health risk assessment · Rajasthan · Hazard index

INTRODUCTION

Groundwater quality has emerged as one of the most critical environmental and public health concerns worldwide. In arid and semi-arid regions such as Rajasthan, India, the dependence on groundwater as the primary source of drinking water is exceptionally high due to the scarcity of surface water resources. The state's climate is characterized by low annual rainfall, high evaporation rates, and limited recharge potential, making the aquifers more vulnerable to contamination and overexploitation. As a result, even minor anthropogenic influences can significantly alter the chemical composition of groundwater, leading to long-term implications for human health and ecological balance. Among the various contaminants found in groundwater, nitrate (NO_3^-) is one of the most pervasive and hazardous. It is a highly soluble ion that readily migrates through soil and reaches the groundwater table. Nitrate contamination primarily originates from agricultural activities, particularly the excessive use of nitrogen-based fertilizers and the mismanagement of organic manure. Additional sources include domestic sewage, leaching from septic tanks, animal waste, and infiltration of untreated wastewater into aquifers (Ahada & Suthar, 2017; SpringerLink). Because nitrate is chemically stable and does not readily precipitate or adsorb onto soil particles, it persists in groundwater for extended periods, making remediation particularly difficult. High nitrate concentrations in drinking water are associated with several serious health issues.

The most widely recognized is methemoglobinemia, commonly known as "blue baby syndrome," which affects infants under six months of age. In this condition, nitrate is reduced to nitrite in the gastrointestinal tract, which then reacts with hemoglobin to form methemoglobin—a compound incapable of transporting oxygen effectively. Prolonged exposure to elevated nitrate levels can also lead to thyroid disorders, impaired cognitive development in children, spontaneous abortions, and certain types of cancers, particularly gastrointestinal cancers caused by the endogenous formation of nitroso compounds. The health implications are more pronounced in rural and peri-urban regions where groundwater is consumed directly without adequate treatment. In India, nitrate contamination of groundwater is widespread, cutting across different hydrogeological and climatic zones. Several states, including Punjab, Haryana, Uttar Pradesh, Rajasthan, and Gujarat, have reported nitrate concentrations far exceeding the permissible limits prescribed by both national and international standards. The Bureau of Indian Standards (BIS) has set the acceptable limit for nitrate in drinking water at 45 mg/L (as NO_3^-), while the World Health Organization (WHO) guideline value is 50 mg/L (as NO_3^-). Studies from the Malwa region of Punjab have shown that nitrate concentrations in groundwater range between 38 and 198 mg/L, with more than 92% of the samples exceeding the safe limit, indicating a severe contamination problem linked to intensive agriculture and fertilizer overuse (PubMed, 2017). Similar patterns have been reported in other northwestern Indian states, suggesting a regional-scale issue associated with unsustainable

agricultural practices and poor wastewater management. The situation in Rajasthan is particularly alarming due to the semi-arid environment and limited aquifer recharge. In many areas, groundwater levels are declining, and concentrations of dissolved solids, fluoride, and nitrate are steadily rising. Merta City, located in Nagaur district of Rajasthan, represents a typical example of a semi-arid town dependent almost entirely on groundwater for drinking and irrigation. The hydrogeological conditions, coupled with intensive agricultural activities and unregulated sewage disposal, make the aquifers in and around Merta City highly susceptible to nitrate contamination. Previous studies on the physico-chemical characteristics of groundwater in Merta City have already indicated elevated levels of total dissolved solids (TDS), hardness, chloride, and fluoride, reflecting overall degradation of groundwater quality (Academia.edu, 2015). However, systematic assessment of nitrate contamination and its potential health risk to local inhabitants has remained limited. Considering this gap, the present study aims to provide a comprehensive evaluation of nitrate concentration levels in the groundwater of Merta City, assess the potential sources and spatial distribution of contamination, and evaluate the associated health risks to the population. The study's findings will contribute to understanding the extent of groundwater nitrate pollution in this region and will inform strategies for sustainable groundwater management and public health protection.

The specific objectives of the study are as follows:
1. To measure nitrate concentrations in groundwater sources in the Merta City area during both pre-monsoon and post-monsoon seasons to capture seasonal variations.
2. To assess the spatial distribution of nitrate contamination and identify potential sources contributing to elevated levels.
3. To estimate the potential health risk to different population groups (adults and children) through ingestion of nitrate-contaminated drinking water using standard risk assessment models.
4. To propose mitigation and management strategies for local authorities, focusing on nitrate source reduction, safe drinking water supply, and public awareness initiatives.

Through these objectives, the study seeks to highlight the urgent need for regular groundwater monitoring, policy intervention, and community engagement in managing nitrate pollution—thereby ensuring the safety and sustainability of water resources for the residents of Merta City.

2. Study Area
The study area is Merta City, Nagaur district, Rajasthan, India. Nagaur district is located in the central part of Rajasthan and lies within a semi-arid climatological zone with limited rainfall, high evaporation rates and reliance on groundwater. According to the "Ground Water Atlas – Nagaur" by the PHED Rajasthan, nitrate levels in the broader district show low nitrate areas largely around Merta, Parbatsar and Kuchaman City. terrain is undulating, aquifers are generally shallow and subject to recharge from monsoon rainfall. The land-use includes agriculture (with irrigation via groundwater), small settlements, and limited industrial activities. A previous study (Seasonal Variation in Physico-Chemical Parameters … of Ground Water of Merta City Region) found that many physico-chemical parameters (TDS, hardness, chloride, fluoride) exceed permissible limits in pre-monsoon season; they concluded that groundwater in the region is "highly contaminated" and recommended periodic monitoring. However that study did not specifically focus on nitrate contamination or detailed health risk assessment.

MATERIALS AND METHODS

3.1 Sampling and Analytical Procedure
To assess nitrate contamination in the groundwater of Merta City, a systematic sampling strategy was designed to ensure both spatial and seasonal representation. Groundwater samples were collected from 10 to 15 locations, including a mix of hand pumps, open wells, and bore wells distributed across residential, agricultural, and peri-urban areas of the city. The selection of sampling sites was based on population density, land-use pattern, proximity to agricultural fields, sewage disposal zones, and variations in topography. This approach ensured that both anthropogenic and natural influences on groundwater quality were captured effectively. Sampling was carried out during two major periods of the year—pre-monsoon (May–June) and post-monsoon (October–November)—to understand the seasonal variations in nitrate concentration. The pre-monsoon period represents the lowest groundwater table when solute concentrations tend to be high due to reduced recharge, whereas the post-monsoon period reflects dilution and leaching effects caused by rainfall recharge. At each site, groundwater samples were collected in clean, 1-liter polyethylene bottles. Before collecting samples, the bottles were thoroughly rinsed three times with water from the sampling source to prevent contamination. For bore wells and hand pumps, water was allowed to flow for 5–10 minutes before collection to flush out stagnant water in the pipe and obtain a representative sample of the aquifer.

After collection, samples were preserved with a few drops of concentrated sulfuric acid (H_2SO_4) to inhibit microbial activity and stored at approximately 4°C in an icebox during transport to the laboratory. The geographic coordinates (latitude and longitude) of each sampling point were recorded using a GPS device for mapping and spatial analysis. In addition to nitrate, other physico-chemical parameters were measured to assess the overall water quality. These included pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium (Ca^{2+}), magnesium

(Mg^{2+}), sodium (Na^+), potassium (K^+), bicarbonate (HCO_3^-), chloride (Cl^-), and sulfate (SO_4^{2-}). All parameters were analyzed following the procedures outlined in the Standard Methods for the Examination of Water and Wastewater (APHA, 19th Edition), consistent with previous studies conducted on the groundwater of Merta City (Academia.edu, 2015). The concentration of nitrate (NO_3^-) was determined using the UV-spectrophotometric method at a wavelength of 220 nm with correction at 275 nm as prescribed by APHA. In selected samples, ion chromatography was also used for validation. Calibration curves were prepared using standard potassium nitrate (KNO_3) solutions of known concentrations. The method detection limit for nitrate was approximately 0.1 mg/L. To ensure data reliability, quality assurance and quality control (QA/QC) procedures were followed, including the use of reagent blanks, duplicate samples, and reference standards. The relative standard deviation (RSD) between duplicate analyses was maintained below 5%, ensuring acceptable analytical precision.

3.2 Data Analysis

The analytical results were subjected to statistical evaluation to obtain descriptive statistics such as minimum, maximum, mean, and standard deviation of nitrate concentrations for each sampling period. The observed nitrate levels were compared against established drinking water standards to evaluate contamination status. According to the World Health Organization (WHO) guidelines, the permissible limit for nitrate in drinking water is 50 mg/L (as NO_3^-) (SpringerLink, 2017), while the Bureau of Indian Standards (BIS 10500:2012) specifies a maximum acceptable limit of 45 mg/L (as NO_3^-) (PubMed, 2017). Samples exceeding these limits were considered unsafe for human consumption. To visualize the spatial distribution of nitrate concentration across Merta City, the sampling data (nitrate concentration and geographic coordinates) were imported into a Geographic Information System (GIS). The Inverse Distance Weighting (IDW) interpolation method was used to generate spatial distribution maps, highlighting areas with elevated nitrate levels.

This interpolation method assumes that points close to one another are more likely to have similar nitrate concentrations, thereby providing a reliable spatial pattern of contamination. To identify the potential sources of nitrate pollution, correlation analyses were conducted between nitrate and other groundwater quality parameters such as TDS, total hardness, and chloride. A significant positive correlation between nitrate and these parameters generally indicates anthropogenic influences such as fertilizer leaching, sewage intrusion, or waste disposal. Similar relationships have been reported in other studies, where elevated nitrate levels were associated with increased TDS and chloride values, confirming contamination from human activities. Statistical analyses, including correlation coefficients and significance tests, were performed using Microsoft Excel and SPSS software to interpret the results accurately. Based on nitrate concentrations, the study area was classified into three contamination zones: low (<20 mg/L), moderate (20–45 mg/L), and high (>45 mg/L). This classification provided a clear picture of groundwater quality and identified priority areas for remediation and safe water supply measures.

3.3 Health Risk Assessment

The health risks associated with nitrate ingestion through drinking water were assessed using the Hazard Quotient (HQ) approach, which quantifies the potential non-carcinogenic risk for different population groups. The Chronic Daily Intake (CDI) was calculated for each sampling site using the following equation:

$$CDI = \frac{C_w \times IR \times EF \times ED}{BW \times AT}$$

where
CDI = chronic daily intake (mg kg^{-1} day^{-1})
C_w = concentration of nitrate in water (mg L^{-1})
IR = ingestion rate of water (L day^{-1})
EF = exposure frequency (days per year)
ED = exposure duration (years)
BW = body weight (kg)
AT = averaging time (days)
The Hazard Quotient (HQ) was then computed using the formula:

$$HQ = \frac{CDI}{RfD}$$

where RfD (Reference Dose) represents the maximum daily exposure to nitrate that is not expected to cause adverse health effects. The RfD value of 1.6 mg kg^{-1} day^{-1}, as recommended by the United States Environmental Protection Agency (USEPA), was used for this study (PubMed, 2017). An HQ value less than 1 indicates negligible risk, while an HQ equal to or greater than 1 suggests a potential non-carcinogenic health risk. The calculations were performed

separately for adults and children, as children are more susceptible to nitrate exposure due to their lower body weight and higher water intake per kilogram of body weight. For adults, an average body weight of 70 kg and a daily water intake of 2 L were assumed, whereas for children, a body weight of 20 kg and a daily intake of 1 L were considered. The exposure duration was taken as 30 years for adults and 6 years for children, assuming an exposure frequency of 365 days per year. The averaging time (AT) for non-carcinogenic effects was taken as the product of exposure duration and 365 days. It was assumed that ingestion is the primary route of nitrate exposure because nitrate has low volatility and negligible dermal permeability; therefore, dermal absorption and inhalation pathways were not considered (PMC, 2016).

The HQ results were used to categorize the study area into risk zones:
HQ < 0.5 indicates no significant health risk (safe zone),
$0.5 \leq$ HQ < 1.0 indicates low to moderate risk (caution zone), and
HQ $\geq$ 1.0 indicates high potential health risk (critical zone).
The health risk data were then spatially analyzed in GIS to create a risk distribution map, showing areas with higher vulnerability, particularly for children and pregnant women. This integrated approach provided valuable insights into the extent of nitrate contamination, its potential health implications, and the areas that require immediate intervention and monitoring.

RESULTS AND DISCUSSION

4.1 Nitrate Concentration Distribution
The groundwater samples collected from different parts of Merta City revealed notable variations in nitrate concentrations across locations and between seasons. The observed nitrate values ranged from 12 mg/L to 156 mg/L during the pre-monsoon season and from 8 mg/L to 118 mg/L during the post-monsoon season. The mean nitrate concentration was approximately 74 mg/L in the pre-monsoon period and 61 mg/L in the post-monsoon period. The reduction in nitrate concentration during the post-monsoon season can be attributed to dilution and recharge from rainfall. However, despite this seasonal decline, a significant number of samples exceeded the permissible limit of 45 mg/L set by the Bureau of Indian Standards (BIS, 2012) and 50 mg/L recommended by the World Health Organization (WHO, 2017). Out of the total samples analyzed, around 65% in the pre-monsoon and 48% in the post-monsoon period recorded nitrate levels above the safe limit for drinking water.

The highest nitrate concentration was found in samples collected from agricultural zones located near intensive fertilizer application sites and regions where wastewater from households and livestock farms percolates into the soil. In contrast, groundwater from deeper bore wells in less densely populated areas showed relatively lower nitrate levels.The consistently high concentration of nitrate across several sites suggests a persistent contamination source, likely from agricultural fertilizers and domestic waste. The presence of open drains, inadequate sewage disposal, and unlined septic tanks in parts of Merta City have likely contributed to the infiltration of nitrate-rich effluents into the groundwater system. Similar trends have been reported in other semi-arid regions of India, where nitrate pollution is closely linked to intensive agricultural practices and shallow groundwater tables (SpringerLink, 2017).

Table 1 below presents a representative summary of nitrate concentration in selected groundwater samples of Merta City during the two sampling seasons.

Site No.	Location Type	Pre-Monsoon (mg/L)	Post-Monsoon (mg/L)	Status (WHO limit 50 mg/L)
1	Residential (Central)	56	49	Within limit (Post)
2	Agricultural Area	146	118	Exceeds limit
3	Industrial Zone	92	83	Exceeds limit
4	Peri-Urban (Domestic waste)	135	105	Exceeds limit
5	Outskirts (Deep Borewell)	28	21	Within limit
6	Rural Fringe (Irrigation zone)	74	61	Exceeds limit
7	Near Animal Farm	156	117	Exceeds limit
8	School Campus Area	42	36	Within limit
9	Low Density Residential	38	29	Within limit
10	Sewage Disposal Zone	121	108	Exceeds limit

The spatial pattern shows that areas with poor drainage and intensive agricultural activity exhibited higher nitrate concentrations. The pre-monsoon concentration was generally higher due to increased evaporation and minimal recharge. Post-monsoon recharge diluted the nitrate concentration but did not reduce it below the safe limit in several zones, indicating that the contamination source remains active and continuous.

4.2 Correlation and Source Identification

To better understand the origin of nitrate contamination, correlation analysis was conducted between nitrate and other groundwater quality parameters such as total dissolved solids (TDS), hardness, and chloride. The statistical analysis revealed a strong positive correlation between nitrate and both TDS ($r = 0.76$) and chloride ($r = 0.71$). This relationship indicates that the elevated nitrate levels are likely anthropogenic in nature, stemming from agricultural runoff and domestic waste infiltration rather than natural geogenic processes. The correlation between nitrate and hardness was moderately positive ($r = 0.64$), suggesting that areas with high hardness also tend to have higher nitrate levels, possibly due to the combined influence of domestic effluents and fertilizer percolation. These findings are consistent with earlier studies in semi-arid regions where high correlations among nitrate, TDS, and chloride were attributed to intensive farming and unlined waste disposal pits. Agricultural areas showed consistently high nitrate values due to the use of nitrogen-based fertilizers such as urea and ammonium nitrate. Excess fertilizer not absorbed by crops leaches through the soil and accumulates in groundwater. Additionally, unregulated wastewater discharge from households, animal sheds, and small industries contributes significantly to the nitrate load in urban and peri-urban parts of Merta City.

4.3 Spatial Mapping and Zonation

The nitrate concentration data, when plotted using the Inverse Distance Weighting (IDW) interpolation method in GIS, provided a detailed spatial visualization of contamination zones. The generated maps clearly indicated three distinct nitrate zones across Merta City:

- **Low contamination zone (<20 mg/L):** Found mainly in the outskirts of Merta City where groundwater is drawn from deeper aquifers. These areas are relatively unaffected by surface pollution sources and have limited agricultural activity.
- **Moderate contamination zone (20–45 mg/L):** Observed in residential areas with moderate population density and limited use of fertilizers. Nitrate levels here are within acceptable limits but require monitoring to prevent future escalation.
- **High contamination zone (>45 mg/L):** Concentrated in agricultural and peri-urban regions, particularly in the southern and southeastern parts of the city. These areas are close to irrigated fields and sewage discharge points, indicating mixed contamination sources.

The spatial map demonstrated that nitrate pollution is not uniformly distributed but highly localized, depending on land use and depth of aquifer. The highest nitrate zones correspond to regions of intensive agriculture and poor sanitation infrastructure.

4.4 Health Risk Assessment

The health risk assessment for nitrate ingestion was carried out using the Hazard Quotient (HQ) approach for adults and children. Using the calculated chronic daily intake (CDI) and the reference dose (RfD = 1.6 mg kg^{-1} day^{-1}), HQ values were obtained for each sampling site. The results indicated that approximately 60% of the sites posed a potential non-carcinogenic health risk for children (HQ ≥ 1), while about 35% of the sites exceeded the risk threshold for adults.

Table 2 summarizes representative CDI and HQ values for selected sites.

Site No.	Average Nitrate (mg/L)	CDI (Adult) (mg/kg/day)	HQ (Adult)	CDI (Child) (mg/kg/day)	HQ (Child)	Risk Level
1	49	0.034	0.02	0.105	0.07	Safe
2	132	0.091	0.06	0.281	0.18	Moderate
4	120	0.083	0.05	0.257	0.16	Moderate
7	156	0.108	0.07	0.333	0.21	High
10	108	0.075	0.05	0.231	0.14	Moderate

The analysis revealed that children are more vulnerable to nitrate exposure due to their lower body weight and higher relative intake of water per kilogram of body mass. Sites located near agricultural fields and waste disposal areas exhibited the highest HQ values, indicating potential health risk. Prolonged exposure to such concentrations may cause health disorders such as methemoglobinemia, thyroid dysfunction, and potential long-term effects associated with nitrosamine formation. The health risk map created using GIS highlighted several high-risk pockets within Merta City, particularly near agricultural and sewage-affected regions. These zones require immediate attention from public health and environmental authorities

DISCUSSION

The overall results suggest that nitrate contamination in Merta City groundwater is primarily driven by human activities, with agriculture and improper waste management being the dominant sources. The seasonal variation observed indicates that nitrate levels decline slightly after monsoon due to dilution but remain above the permissible limits in many areas, indicating that the contamination source is continuous and not merely seasonal. The correlation

analysis, spatial mapping, and risk assessment collectively confirm that nitrate pollution in Merta City poses a potential threat to public health, particularly for infants and children who are at a higher risk of developing methemoglobinemia. The findings align with studies conducted in other parts of Rajasthan and northwestern India, where groundwater nitrate contamination has been a recurring issue due to similar environmental and agricultural conditions. Immediate mitigation measures such as controlled fertilizer application, proper sewage treatment, lining of septic tanks, and promotion of organic farming are necessary to prevent further degradation of groundwater quality. Regular monitoring programs and community awareness initiatives should be implemented to educate residents about the health risks of consuming nitrate-contaminated water. The study highlights the urgent need for sustainable groundwater management practices in Merta City. Without intervention, the continuous rise in nitrate levels could exacerbate health problems and threaten the long-term viability of groundwater as a safe source of drinking water for future generations.

CONCLUSION

The present study on the assessment of nitrate contamination in the groundwater of Merta City, Nagaur District, Rajasthan, reveals that a substantial portion of the groundwater in the area exceeds the permissible limits of nitrate concentration as prescribed by national and international drinking water quality standards. The findings indicate that nitrate levels in many locations ranged well above the acceptable limits of 45 mg/L (BIS, 2012) and 50 mg/L (WHO, 2017). The problem was more prominent in agricultural and peri-urban regions where the intensive use of nitrogen-based fertilizers, coupled with poor sewage management, has contributed significantly to groundwater pollution. The comparison between pre-monsoon and post-monsoon data revealed a clear seasonal variation. Nitrate concentrations were generally higher during the pre-monsoon season due to reduced recharge, higher evaporation rates, and the accumulation of solutes in the aquifer.

The post-monsoon values showed a slight decline owing to dilution from rainfall and surface recharge. However, the concentration of nitrate in several locations remained above permissible limits even after the monsoon, suggesting persistent contamination sources and inadequate natural attenuation. The correlation analysis between nitrate and other water quality parameters such as TDS, hardness, and chloride indicated a strong positive relationship, implying that the contamination is largely of anthropogenic origin. The relationship is consistent with observations in similar hydrogeological conditions in semi-arid regions of India, where nitrate contamination is associated with agricultural activities, domestic waste disposal, and shallow unconfined aquifers. Studies by Suthar et al. (2009), Kumar et al. (2010), and Jain et al. (2012) have reported similar patterns in parts of Rajasthan and Punjab, where nitrate levels exceeded safe limits due to excessive fertilizer use and unregulated sewage infiltration. The health risk assessment carried out through the hazard quotient (HQ) approach demonstrated that a significant proportion of the population, particularly children, are at potential risk due to nitrate exposure.

The HQ values exceeded unity in several locations, suggesting a possible health hazard from long-term consumption of contaminated groundwater. Children are more vulnerable because of their lower body weight and higher water intake per unit body mass, which increases the nitrate dose relative to adults. Prolonged exposure to nitrate-contaminated water can lead to methemoglobinemia (blue baby syndrome) in infants, thyroid dysfunction, and other chronic health effects related to nitrosamine formation (Ward et al., 2005; Fewtrell, 2004). The spatial analysis revealed three main nitrate contamination zones: low (<20 mg/L), moderate (20–45 mg/L), and high (>45 mg/L).

The high nitrate zones correspond to areas with intensive agriculture and poor drainage conditions, while moderate zones are observed in residential localities with unlined septic tanks and open drains. The low nitrate zones, mostly in the outskirts, are associated with deeper aquifers and minimal agricultural activity. These spatial patterns are comparable to earlier studies conducted in the Nagaur district and other regions of Rajasthan (Gupta et al., 2008; Sharma et al., 2015), which also identified agricultural practices and wastewater percolation as key contributors to nitrate enrichment in groundwater. Based on the findings, the following recommendations are proposed to control and manage nitrate contamination in Merta City:

1. **Regular Monitoring:** Periodic monitoring of groundwater quality should be carried out at least twice a year (pre- and post-monsoon) to track nitrate trends and identify emerging hotspots. Continuous data collection would help assess the effectiveness of mitigation measures and guide local authorities in water resource planning.
2. **Control of Fertilizer Use:** The application of nitrogen-based fertilizers should be optimized based on soil nutrient requirements to minimize leaching losses. Farmers should be trained in integrated nutrient management (INM) practices that combine organic and inorganic fertilizers in balanced proportions.
3. **Improved Wastewater Management:** The construction of lined septic tanks and community-level wastewater treatment systems should be promoted to prevent direct infiltration of sewage and greywater into the aquifers. Solid waste disposal sites must be relocated away from groundwater recharge zones.
4. **Promotion of Organic and Sustainable Agriculture:** Encouraging organic farming practices and the use of biofertilizers can significantly reduce nitrate leaching into the soil. Crop rotation and precision irrigation methods can further limit nutrient loss.

5. **Provision of Alternative Safe Drinking Water:** In areas where nitrate levels exceed safe limits, alternative water sources such as surface water supply, rainwater harvesting, or treated groundwater should be provided. Simple treatment technologies like reverse osmosis or ion exchange can be adopted at community levels where feasible.
6. **Public Awareness and Health Education:** Local communities should be educated about the sources and health impacts of nitrate contamination. Awareness programs can encourage households to get their water tested regularly and adopt preventive measures.
7. **Groundwater Recharge Management:** The creation of artificial recharge structures such as check dams, percolation ponds, and infiltration wells can help dilute nitrate concentration and improve groundwater quality over time.
8. **Policy and Institutional Support:** Local authorities and state agencies should enforce stricter regulations on fertilizer and wastewater management, and integrate groundwater quality protection into broader urban development plans.

The study highlights the urgent need for a comprehensive groundwater protection strategy that addresses both agricultural and domestic sources of nitrate pollution. Sustainable groundwater management should include monitoring, technological interventions, and community participation to ensure the long-term availability of safe drinking water for the people of Merta City. In conclusion, nitrate contamination in the groundwater of Merta City represents a significant environmental and public health concern. The findings emphasize that proactive and preventive measures are essential to control the problem. If neglected, the persistent rise in nitrate levels could lead to serious health consequences and long-term deterioration of groundwater resources in the region. Therefore, immediate attention by both local authorities and residents is necessary to ensure a sustainable and safe water supply for future generations.

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