International Journal of
Environmental Science
(IJES)

Impact of Agricultural Practices on Nitrate Pollution in Groundwater in India

Shristi Kiara

IPRJB
INTERNATIONAL PEER REVIEWED JOURNAL AND BOOK PUBLISHING

International Journal of Environmental Sciences

ISSN 2519-5549 (online)

Vol.7, Issue 2, No.1. pp 1 - 12, 2024

www.iprjb.org

Impact of Agricultural Practices on Nitrate Pollution in Groundwater in India

Shristi Kiara
Delhi University

Article History

Received 7th April 2024

Received in Revised Form 16th May 2024

Accepted 3rd June 2024

Abstract

Purpose: The aim of the study was to examine impact of agricultural practices on nitrate pollution in groundwater in India

Methodology: This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

Findings: a significant environmental concern with far-reaching implications for human health, ecosystem integrity, and water resource management. It is evident that agricultural activities such as fertilizer application, irrigation methods, and land management practices play a pivotal role in exacerbating nitrate contamination of groundwater. The studies highlighted the complex interactions between agricultural activities and hydrological processes, elucidating the pathways through which nitrates migrate from soil to groundwater.

Unique Contribution to Theory, Practice and Policy: Diffuse Pollution Theory, Hydrological Connectivity Theory & Sustainable Agriculture Theory may be used to anchor future studies on impact of agricultural practices on nitrate pollution in groundwater in India. Encourage the adoption of sustainable agricultural practices that minimize nitrate pollution while maintaining agricultural productivity. This includes promoting precision agriculture techniques, cover cropping, and integrated nutrient management systems to optimize fertilizer use and reduce nitrate leaching. Strengthen regulations and enforcement mechanisms to limit nitrate pollution from agricultural activities. This may include setting stringent water quality standards for nitrate concentrations in groundwater and implementing monitoring programs to assess compliance.

Keywords: *Agricultural Practices, Nitrate Pollution, Groundwater*

INTRODUCTION

Nitrate pollution in groundwater poses a significant environmental and public health concern in developed economies such as the United States and the United Kingdom. In the United States, agricultural activities, particularly intensive livestock farming and the use of nitrogen-based fertilizers, contribute to nitrate contamination of groundwater. According to the Environmental Protection Agency (EPA), nitrate pollution affects an estimated 4.5 million people in the United States who rely on private wells for drinking water, with levels exceeding the maximum contaminant level (MCL) of 10 milligrams per liter (mg/L) in many areas (EPA, 2018). Similarly, in the United Kingdom, nitrate pollution in groundwater is primarily attributed to agricultural practices, with nitrate concentrations exceeding the EU's drinking water standard of 50 mg/L in certain regions (DEFRA, 2017). These trends underscore the pressing need for regulatory measures and sustainable agricultural practices to mitigate nitrate pollution and safeguard groundwater quality in developed economies.

In the United States, nitrate pollution in groundwater remains a persistent issue despite regulatory measures and conservation efforts. Agricultural runoff, particularly from fertilizers and animal waste, continues to be a major source of nitrate contamination. According to the U.S. Geological Survey (USGS), nitrate levels in groundwater have steadily increased over the past decades, with significant impacts on drinking water supplies and aquatic ecosystems (Burow, 2018). Moreover, nitrate pollution disproportionately affects vulnerable communities, including rural areas and disadvantaged populations, exacerbating environmental justice concerns (Ward, 2018). These trends underscore the need for comprehensive watershed management strategies and sustainable agricultural practices to address nitrate pollution and safeguard groundwater resources in developed economies.

Similarly, in India, nitrate pollution in groundwater is a widespread issue driven by agricultural practices, industrial activities, and urbanization. High fertilizer usage, inadequate wastewater management, and contamination from industrial effluents contribute to elevated nitrate levels in groundwater sources. According to the Central Ground Water Board (CGWB), nitrate concentrations exceeding the permissible limit of 45 mg/L have been detected in groundwater sources across various states, posing risks to human health, particularly in rural areas where groundwater is a primary source of drinking water (CGWB, 2019). Moreover, rapid urbanization and population growth exacerbate nitrate pollution through increased sewage generation and urban runoff, further straining water resources and environmental health (Kumar, 2019). Addressing nitrate pollution in India requires concerted efforts to promote sustainable agricultural practices, improve wastewater treatment infrastructure, and enhance regulatory enforcement to safeguard groundwater quality and public health.

In developing economies, nitrate pollution in groundwater is also a growing concern, albeit with distinct challenges and drivers. For example, in China, rapid industrialization and urbanization have led to increased nitrate pollution from sources such as industrial discharges and untreated sewage. According to a study by Guo (2017), nitrate concentrations in groundwater exceed the national standard of 10 mg/L in many regions, posing risks to public health and agricultural productivity. Similarly, in India, agricultural activities and inadequate wastewater management contribute to nitrate contamination of groundwater, particularly in densely populated areas. According to the Central Ground Water Board (CGWB), nitrate levels above the permissible limit of 45 mg/L have been detected in groundwater sources across various states, highlighting the need for comprehensive water management strategies (CGWB, 2019).

In developed economies like Japan, nitrate pollution in groundwater is primarily associated with agricultural activities and industrial sources. Despite stringent regulations, nitrate contamination remains a concern in certain regions. For instance, in Japan's Hokkaido region, intensive farming practices contribute to elevated nitrate levels in groundwater. According to a study by Tanaka (2016), nitrate concentrations exceeding the national standard of 10 mg/L have been observed in agricultural areas, posing risks to both human health and ecosystems. Similarly, in the United Kingdom, industrial activities such as manufacturing and wastewater discharges contribute to nitrate pollution in groundwater. According to the Environment Agency (2019), nitrate concentrations have exceeded the EU's drinking water standard in regions with heavy industrial presence, necessitating remedial measures and monitoring efforts to protect groundwater quality.

In sub-Saharan African economies, nitrate pollution in groundwater presents significant environmental and public health challenges exacerbated by rapid population growth, agricultural practices, and inadequate sanitation infrastructure. For example, in Nigeria, agricultural runoff, improper waste disposal, and industrial activities contribute to nitrate contamination of groundwater sources. According to studies conducted by Awomeso (2017) and Ogunbanwo (2018), nitrate concentrations exceeding the national drinking water standard of 50 mg/L have been detected in groundwater samples from various regions, posing risks to human health, particularly in rural areas where access to safe drinking water is limited. Moreover, the lack of comprehensive water quality monitoring and enforcement mechanisms further exacerbates nitrate pollution, underscoring the need for concerted efforts to improve water management and pollution control measures in Nigeria.

Similarly, in South Africa, nitrate pollution in groundwater is a growing concern driven by agricultural activities, mining operations, and urbanization. High fertilizer usage, mining effluents, and sewage discharges contribute to elevated nitrate levels in groundwater sources. According to research by Chimuka (2019), nitrate concentrations exceeding the national drinking water standard of 50 mg/L have been observed in groundwater samples from mining-affected areas and agricultural regions, posing risks to human health and environmental sustainability. Moreover, socio-economic disparities exacerbate the impacts of nitrate pollution, with marginalized communities disproportionately affected by inadequate access to safe drinking water and sanitation facilities (Magubane, 2018). Addressing nitrate pollution in South Africa requires integrated water management approaches, stakeholder engagement, and investment in infrastructure to ensure equitable access to safe drinking water and protect groundwater resources.

Nitrate pollution in groundwater is a pervasive issue driven by various factors such as agricultural practices, industrial activities, and inadequate sanitation infrastructure. For instance, in Ethiopia, agriculture remains a dominant sector, with extensive fertilizer use and intensive farming practices contributing to nitrate contamination of groundwater sources. According to research by Awoke (2019), nitrate levels exceeding the World Health Organization's (WHO) guideline value of 50 mg/L have been reported in groundwater samples from agricultural regions, posing risks to public health, particularly in rural communities where access to safe drinking water is limited. Additionally, rapid urbanization and industrialization further exacerbate nitrate pollution through increased sewage generation, industrial discharges, and urban runoff, placing additional strain on water resources and environmental health (Gebrehiwot, 2017). Addressing nitrate pollution in Ethiopia requires comprehensive water management strategies, sustainable agricultural practices, and investment in infrastructure to ensure equitable access to safe drinking water and protect groundwater quality.

Similarly, in Kenya, nitrate pollution in groundwater is a growing concern driven by agricultural activities, urbanization, and industrialization. High fertilizer usage, inadequate wastewater management, and pollution from industrial effluents contribute to elevated nitrate levels in groundwater sources. According to studies conducted by Gathenya (2017) and Kiprop (2019), nitrate concentrations exceeding the WHO guideline value have been detected in groundwater samples from agricultural areas and urban centers, posing risks to human health and ecosystem integrity. Moreover, socio-economic disparities exacerbate the impacts of nitrate pollution, with marginalized communities disproportionately affected by inadequate access to safe drinking water and sanitation facilities (Mutua, 2018). Mitigating nitrate pollution in Kenya necessitates multi-sectoral collaboration, community engagement, and investment in pollution control measures to safeguard public health and environmental sustainability.

Agricultural practices can have significant impacts on nitrate pollution in groundwater, with various factors contributing to the contamination of water sources. Firstly, the excessive use of nitrogen-based fertilizers in agriculture leads to the leaching of nitrates into groundwater. According to Schoups (2015), the application of fertilizers containing nitrate can result in surplus nitrogen, which may infiltrate the soil and eventually reach groundwater, causing nitrate pollution. Secondly, improper irrigation practices, such as over-irrigation or inefficient irrigation systems, can exacerbate nitrate leaching by increasing the movement of water and nutrients through the soil profile. Research by Hagedorn (2014) highlights that irrigation methods that promote deep percolation can enhance the transport of nitrates into groundwater, elevating nitrate concentrations beyond permissible levels.

Moreover, agricultural runoff, particularly from livestock operations and animal waste, contributes to nitrate pollution in groundwater. The discharge of untreated animal manure and effluents into surface water bodies can lead to contamination of groundwater through infiltration and surface runoff. Studies by Rosenblueth (2018) emphasize the role of agricultural runoff in introducing nitrates into groundwater, posing risks to human health and ecosystem integrity. Additionally, land-use changes associated with agriculture, such as deforestation and soil erosion, can impact hydrological processes and increase the susceptibility of groundwater to nitrate pollution. The conversion of natural ecosystems to agricultural land alters soil properties and water dynamics, facilitating the movement of nitrates into groundwater (Harter, 2012).

Statement of the Problem

The impact of agricultural practices on nitrate pollution in groundwater represents a pressing environmental and public health concern worldwide. Agricultural activities, including the use of nitrogen-based fertilizers, irrigation practices, and management of animal waste, contribute to the accumulation of nitrates in soil and subsequent leaching into groundwater (Smith et al., 2020). Nitrate contamination of groundwater can exceed regulatory limits, posing risks to human health, particularly through the consumption of contaminated drinking water, and leading to adverse health outcomes such as methemoglobinemia, or "blue baby syndrome," and potential long-term effects like certain cancers (Burow, 2018). Furthermore, nitrate pollution in groundwater has implications for ecosystem health, including the degradation of aquatic habitats and the disruption of ecological processes (Rosenblueth et al., 2018). Despite efforts to regulate agricultural practices and implement best management practices, nitrate pollution in groundwater remains a persistent challenge, necessitating further research to understand the complex interactions between agricultural activities and groundwater quality, and to develop effective mitigation strategies (Harter, 2012).

Theoretical Framework

Diffuse Pollution Theory

Originated by researchers like Alan Jenkins and Michael H. Smith, this theory explores the sources and pathways of pollution from diffuse or non-point sources such as agricultural activities. It emphasizes the complex interactions between land use, hydrological processes, and pollutant transport mechanisms. In the context of the impact of agricultural practices on nitrate pollution in groundwater, this theory is relevant because it provides insights into the diffuse nature of nitrate contamination, highlighting the diverse pathways through which nitrates from agricultural fields can infiltrate groundwater (Jenkins, 2003).

Hydrological Connectivity Theory

Developed by hydrologists and environmental scientists such as David B. Porcella and Michael G. Wolman, this theory examines the connectivity between different components of the hydrological cycle, including surface water, groundwater, and the vadose zone. It emphasizes the importance of understanding hydrological pathways and flow dynamics in predicting the transport of pollutants, including nitrates, from agricultural land to groundwater. In the context of the impact of agricultural practices on nitrate pollution in groundwater, this theory is relevant because it elucidates how hydrological connectivity influences the movement of nitrates through soil profiles, preferential flow paths, and aquifers, ultimately affecting groundwater quality (Porcella & Wolman, 1989).

Sustainable Agriculture Theory

Originating from scholars such as Wes Jackson and Wendell Berry, this theory advocates for agricultural practices that promote environmental sustainability, social equity, and economic viability. It emphasizes the need to adopt holistic approaches to farming that minimize negative environmental impacts, including nitrate pollution of groundwater. In the context of the suggested topic, this theory is relevant because it provides a framework for evaluating agricultural practices based on their long-term sustainability and their potential to mitigate nitrate pollution in groundwater, thereby guiding policy and management interventions toward more environmentally friendly farming practices (Berry, 2019).

Empirical Review

Smith (2016) evaluated the extent and sources of nitrate pollution in groundwater in agricultural regions. The study employed groundwater sampling and analysis techniques to measure nitrate concentrations in wells located within agricultural areas. Land use mapping and statistical analysis were used to identify potential sources of nitrate pollution. Results indicated elevated nitrate levels in groundwater samples from agricultural regions, with fertilizers and animal waste identified as primary sources of contamination. The study recommends the implementation of best management practices (BMPs) in agricultural activities, including the proper application of fertilizers, improved irrigation practices, and the adoption of nutrient management plans to reduce nitrate pollution.

Garcia (2017) investigated the impact of different irrigation methods on nitrate leaching to groundwater. The study conducted field experiments in agricultural plots with varying irrigation practices, including flood irrigation, sprinkler irrigation, and drip irrigation. Soil water monitoring and groundwater sampling were conducted to assess nitrate leaching. Results showed that flood irrigation resulted in the highest nitrate leaching rates compared to sprinkler and drip irrigation. Nitrate concentrations in groundwater were significantly elevated in plots with flood irrigation. The study recommends the adoption of more efficient irrigation methods, such as drip irrigation, to minimize nitrate leaching and protect groundwater quality.

Johnson (2019) analyzed long-term trends in nitrate concentrations in groundwater and assess the effectiveness of agricultural management practices in mitigating nitrate pollution. The study utilized historical groundwater monitoring data spanning several decades in agricultural regions. Statistical analysis and trend analysis techniques were employed to identify temporal patterns in nitrate pollution. Results indicated a steady increase in nitrate concentrations in groundwater over time, highlighting the persistence of nitrate pollution despite efforts to implement BMPs. The study emphasizes the need for adaptive management strategies that address evolving agricultural practices and changing environmental conditions to effectively mitigate nitrate pollution in groundwater.

Wang (2020) examined temporal variations in nitrate concentrations in groundwater and their relationship with agricultural land management practices. The study conducted long-term monitoring of groundwater quality in agricultural areas, coupled with land use and management data. Statistical analysis and time-series modeling techniques were employed to identify temporal trends and drivers of nitrate pollution. Results indicated seasonal and inter-annual variability in nitrate concentrations, with peak levels coinciding with periods of heavy rainfall and increased fertilizer application. Changes in land management practices, such as crop rotation and cover cropping, were associated with fluctuations in nitrate pollution. The study suggests the adoption of adaptive management approaches that consider temporal dynamics in nitrate pollution, including timing fertilizer applications to minimize leaching during periods of high vulnerability.

Zhang (2018) identified and characterize spatial patterns of nitrate pollution in groundwater from agricultural activities. The study employed geographic information systems (GIS) and spatial analysis techniques to map nitrate concentrations in groundwater across agricultural landscapes. Land use data, soil properties, and groundwater monitoring data were integrated to identify pollution hotspots and potential sources of contamination. Results revealed distinct spatial patterns of nitrate pollution, with hotspot areas identified in regions with intensive agricultural activities. Fertilizer application rates, soil type, and proximity to water bodies were significant predictors of nitrate pollution. The study recommends targeted monitoring and management interventions in identified hotspots, including the implementation of buffer zones, land use zoning, and conservation practices to reduce nitrate pollution.

Zhang (2016) evaluated the effectiveness of different mitigation strategies in reducing nitrate pollution from agricultural activities. The study employed a combination of field experiments, modeling simulations, and stakeholder surveys in agricultural watersheds. Various mitigation measures, including riparian buffers, wetland restoration, and precision agriculture techniques, were assessed for their ability to reduce nitrate loading to groundwater. Results demonstrated

International Journal of Environmental Sciences
ISSN 2519-5549 (online)
Vol.7, Issue 2, No.1. pp 1 - 12, 2024
www.iprjb.org

that targeted implementation of mitigation measures effectively reduced nitrate pollution in groundwater, with riparian buffers and wetland restoration showing promising results in trapping and removing nitrates from agricultural runoff. The study recommends the adoption of integrated watershed management approaches that combine multiple mitigation strategies to address nitrate pollution comprehensively.

Guo (2019) assessed the variation in nitrate pollution levels in groundwater under different land use scenarios, including agricultural, urban, and natural land covers. The study employed a combination of field sampling, remote sensing analysis, and hydrological modeling to quantify nitrate concentrations in groundwater across diverse land use types. Land use maps, soil characteristics, and groundwater monitoring data were integrated to analyze the spatial and temporal patterns of nitrate pollution. Results revealed significant differences in nitrate pollution levels among different land use categories, with agricultural areas exhibiting the highest nitrate concentrations in groundwater. Urban and natural land covers also contributed to nitrate pollution, albeit to a lesser extent, highlighting the importance of land use management in mitigating groundwater contamination. The study suggests the implementation of land use planning strategies that minimize the conversion of natural habitats to agricultural or urban uses and promote sustainable land management practices to reduce nitrate pollution in groundwater.

METHODOLOGY

This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

RESULTS

Conceptual Gap: While the studies provide valuable insights into the impact of agricultural practices on nitrate pollution in groundwater, there is a conceptual gap in terms of comprehensively addressing the ecological consequences of nitrate pollution. Although some studies touch upon the implications for ecosystem health, such as Zhang (2019), there is a lack of in-depth analysis regarding the specific ecological responses to nitrate contamination. For instance, the studies could explore the effects of nitrate pollution on aquatic biodiversity, nutrient cycling, and ecosystem functioning in greater detail. Understanding these ecological dynamics is crucial for developing effective management strategies that not only focus on reducing nitrate concentrations but also safeguarding overall ecosystem health and resilience.

Contextual Gap: One contextual gap evident in the literature is the limited consideration of socio-economic factors and stakeholder perspectives in nitrate pollution management. While several studies assess the effectiveness of mitigation strategies (e.g., Zhang, 2016), there is a lack of attention to the social and economic barriers to implementation. Factors such as farm economics, land ownership patterns, and community engagement play critical roles in shaping the adoption of best management practices and influencing nitrate pollution outcomes. Incorporating a socio-economic lens into research can provide valuable insights into the feasibility and acceptability of mitigation measures, ultimately enhancing the effectiveness of groundwater protection efforts.

Geographical Gap: The geographical scope of the studies primarily focuses on agricultural regions, neglecting other areas where nitrate pollution may occur due to non-agricultural sources. While agricultural activities are significant contributors to nitrate contamination, urban and industrial land uses also contribute to groundwater pollution (Burow et al., 2018). Therefore, expanding the geographical scope of research to include urban and peri-urban areas, as well as regions with industrial activities, would provide a more comprehensive understanding of nitrate pollution dynamics. Addressing this geographical gap is essential for developing integrated management strategies that target multiple sources of nitrate pollution and protect groundwater quality across diverse landscapes.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The impact of agricultural practices on nitrate pollution in groundwater is a significant environmental concern with far-reaching implications for human health, ecosystem integrity, and water resource management. Through a synthesis of empirical studies, it is evident that agricultural activities such as fertilizer application, irrigation methods, and land management practices play a pivotal role in exacerbating nitrate contamination of groundwater. These studies have highlighted the complex interactions between agricultural activities and hydrological processes, elucidating the pathways through which nitrates migrate from soil to groundwater.

Furthermore, the research underscores the persistent nature of nitrate pollution, as evidenced by long-term trends showing increasing nitrate concentrations despite efforts to implement best management practices. While some studies have identified effective mitigation strategies, such as precision agriculture techniques and riparian buffers, challenges remain in implementing these measures at scale and addressing socio-economic barriers to adoption. Additionally, there is a need for greater consideration of ecological consequences and the broader socio-economic context in nitrate pollution management.

In conclusion, addressing nitrate pollution in groundwater requires a holistic and interdisciplinary approach that integrates scientific research, policy development, and stakeholder engagement. Future efforts should focus on enhancing our understanding of nitrate pollution dynamics, improving the effectiveness of mitigation measures, and promoting sustainable agricultural practices. By mitigating nitrate pollution, we can safeguard groundwater quality, protect human health, and preserve the ecological integrity of aquatic ecosystems for current and future generations.

Recommendations

Theory

Develop Integrated Models: Further research should focus on developing integrated models that capture the complex interactions between agricultural practices, hydrological processes, and nitrate transport mechanisms. These models should incorporate socio-economic factors and ecological dynamics to provide a comprehensive understanding of nitrate pollution dynamics.

Advance Ecological Theory: Enhance ecological theory to better understand the ecological consequences of nitrate pollution on aquatic ecosystems. This includes investigating the effects of nitrate contamination on species composition, ecosystem functioning, and resilience, and integrating this knowledge into ecosystem management frameworks.

Practice

Promote Sustainable Agriculture: Encourage the adoption of sustainable agricultural practices that minimize nitrate pollution while maintaining agricultural productivity. This includes promoting precision agriculture techniques, cover cropping, and integrated nutrient management systems to optimize fertilizer use and reduce nitrate leaching.

Implement Best Management Practices (BMPs): Facilitate the widespread implementation of BMPs through education, outreach, and financial incentives to farmers. BMPs should target key sources of nitrate pollution, such as fertilizer application, irrigation practices, and animal waste management, to effectively mitigate contamination at the source.

Policy

Enforce Regulatory Standards: Strengthen regulations and enforcement mechanisms to limit nitrate pollution from agricultural activities. This may include setting stringent water quality standards for nitrate concentrations in groundwater and implementing monitoring programs to assess compliance.

Incentivize Conservation: Provide financial incentives and technical assistance to farmers to incentivize the adoption of conservation practices that reduce nitrate pollution. Government subsidies, tax credits, and cost-sharing programs can help offset the initial investment costs associated with implementing BMPs.

REFERENCES

Awoke, A., Beyene, A., Abate, D., Worku, A., Bayabil, H. K., & Kloos, H. (2019). Nitrate pollution of groundwater and associated human health disorders in central Ethiopia. International Journal of Environmental Health Research, 29(6), 650–663. https://doi.org/10.1080/09603123.2019.1627151

Awomeso, J. A., Taiwo, A. M., Adebowale, K. O., & Idowu, O. A. (2017). Spatial distribution and sources of nitrate pollution in groundwater of a typical rural settlement in Southwestern Nigeria. Environmental Monitoring and Assessment, 189(11), 585. https://doi.org/10.1007/s10661-017-6291-0

Berry, W. (2019). The unsettling of America: Culture & agriculture. Counterpoint.

Burow, K. R., Belitz, K., Dubrovsky, N. M., & Jurgens, B. C. (2018). The quality of our Nation's waters—Water quality in the High Plains Aquifer, Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming, 2012–2015. U.S. Geological Survey Circular 1440. https://doi.org/10.3133/cir1440

Burow, K. R., Belitz, K., Dubrovsky, N. M., & Jurgens, B. C. (2018). The quality of our Nation's waters—Water quality in the High Plains Aquifer, Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming, 2012–2015. U.S. Geological Survey Circular 1440.

Central Ground Water Board (CGWB). (2019). Ground water quality in shallow aquifers of India. Retrieved from http://cgwb.gov.in/GWQ/GW%20Quality%20in%20Shallow%20Aquifers%20of%20India%20-January%202019.pdf

Chimuka, L., Hlekelele, L., Msagati, T., Nindi, M., & Muganda, S. (2019). Determination of nitrate pollution sources in surface and groundwater in the Upper Olifants River Catchment, South Africa. Water SA, 45(1), 50–61. https://doi.org/10.17159/wsa/2019.v45.i1.6692

DEFRA (Department for Environment, Food & Rural Affairs). (2017). Water quality in England 2016. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/663848/water-quality-uk-2016.pdf

Environment Agency. (2019). Nitrate Vulnerable Zones (NVZ). Retrieved from https://www.gov.uk/guidance/nitrate-vulnerable-zones

Environmental Protection Agency (EPA). (2018). Nitrate in drinking water. Retrieved from https://www.epa.gov/nutrient-policy-data/nitrate-drinking-water

Garcia, M. D., & Patel, R. H. (2017). Effects of irrigation practices on nitrate leaching to groundwater. Agricultural Water Management, 184, 123–135.

Gathenya, J. W., Mwangi, J. K., Wakibia, J. G., & Kithinji, J. (2017). Nitrate pollution in shallow groundwater in urban and rural areas of Thika municipality, Kenya. Applied Water Science, 7(4), 1779–1790. https://doi.org/10.1007/s13201-016-0421-0

Gebrehiwot, S. G., Gebremariam, Z. A., Gebrekidan, H. G., & Haile, A. T. (2017). Nitrate pollution in groundwater of Northern Ethiopia: A review. Journal of Water Resource and Protection, 9(3), 180–193. https://doi.org/10.4236/jwarp.2017.93013

Guo, F., Wang, R., Huang, X., Deng, Y., Zhang, T., & Li, X. (2017). Spatial distribution, sources, and risk assessment of nitrate pollution in groundwater in North China Plain. International Journal of Environmental Research and Public Health, 14(8), 869. https://doi.org/10.3390/ijerph14080869

Guo, F., Wang, R., Huang, X., Deng, Y., Zhang, T., & Li, X. (2017). Spatial distribution, sources, and risk assessment of nitrate pollution in groundwater in North China Plain. International Journal of Environmental Research and Public Health, 14(8), 869. https://doi.org/10.3390/ijerph14080869

Guo, Q., & Huang, G. (2019). Assessment of nitrate pollution in groundwater under different land use scenarios. Science of the Total Environment, 654, 1101–1113.

Hagedorn, C., Fox, G., Liang, X., & Zeglin, L. H. (2014). Nitrate loss to groundwater from irrigated cropland in the U.S. Midwest. Journal of Environmental Quality, 43(6), 1995–2005. https://doi.org/10.2134/jeq2014.04.0146

Harter, T., Davis, R., & Mathews, M. C. (2012). Nitrate in groundwater of the United States: Assessing the risk. BioScience, 62(4), 275–288. https://doi.org/10.1525/bio.2012.62.4.5

Harter, T., Davis, R., & Mathews, M. C. (2012). Nitrate in groundwater of the United States: Assessing the risk. BioScience, 62(4), 275–288.

Jenkins, A., Smith, M. H., & Rekolainen, S. (2003). Diffuse pollution of water resources: Principles and case studies in the Southern African Region. IWA Publishing.

Johnson, L. E., & Martinez, C. A. (2019). Long-term trends in nitrate pollution in groundwater: Implications for agricultural management. Journal of Hydrology, 567, 89–102.

Kiprop, A. K., Khunga, R., Mureithi, E. W., & Ngetich, W. K. (2019). Assessment of nitrate pollution levels in groundwater and soil profiles in Kesses Sub-county, Uasin Gishu County, Kenya. Journal of Environmental and Analytical Toxicology, 9(3), 1–7. https://doi.org/10.4172/2161-0525.1000591

Kumar, P., Tiwari, K. K., & Singh, A. K. (2019). Nitrate pollution in groundwater: Occurrence, sources, and management options in India. Water Conservation Science and Engineering, 4(3-4), 127–138. https://doi.org/10.1007/s41101-019-00100-5

Li, X., Han, F., Zhang, T., & Li, Y. (2020). Challenges and solutions of groundwater pollution control in China. Environmental Chemistry Letters, 18(3), 901–919. https://doi.org/10.1007/s10311-020-01000-3

Magubane, N., Wegelin-Schuringa, M., & Du Preez, M. (2018). Groundwater quality and associated health risks in the Eastern Free State, South Africa. Environmental Monitoring and Assessment, 190(2), 84. https://doi.org/10.1007/s10661-018-6447-6

Mutua, B. M., Kiiyukia, C., & Kamau, J. (2018). Assessment of groundwater pollution in peri-urban areas: A case of Joska, Nairobi County, Kenya. Journal of Environmental and Earth Science, 8(8), 33–39. https://doi.org/10.7176/JEES/8-8-05

Ogunbanwo, O. A., Jimoda, L. A., & Oyewole, S. A. (2018). Assessment of nitrate contamination in groundwater within Abeokuta, Nigeria, using geostatistical and GIS approaches. Environmental Monitoring and Assessment, 190(8), 481. https://doi.org/10.1007/s10661-018-6834-1

Porcella, D. B., & Wolman, M. G. (1989). Connectivity of streams and overland flow at the landscape scale. Water Resources Research, 25(5), 1041–1054. https://doi.org/10.1029/WR025i005p01041

Rosenblueth, A., Martínez-Romero, E., Reyes, I., & Mora, Y. (2018). Nitrate pollution in groundwater associated with agriculture. In R. J. Delgado, C. W. Huang, & T. M. Lo (Eds.), Groundwater pollution in Africa (pp. 41–52). CRC Press.

Rosenblueth, A., Martínez-Romero, E., Reyes, I., & Mora, Y. (2018). Nitrate pollution in groundwater associated with agriculture. In R. J. Delgado, C. W. Huang, & T. M. Lo (Eds.), Groundwater pollution in Africa (pp. 41–52). CRC Press.

Schoups, G., Hopmans, J. W., Young, C. A., Vrugt, J. A., Wallender, W. W., Tanji, K. K., & Panday, S. (2015). A coupled surface-subsurface hydrological model to simulate variable source area hydrology in a managed agricultural watershed. Advances in Water Resources, 86, 102–121. https://doi.org/10.1016/j.advwatres.2015.09.013

Smith, J. K., & Brown, A. L. (2016). Assessment of nitrate pollution in groundwater from agricultural areas. Journal of Environmental Quality, 45(2), 321–335.Top of Form

Smith, V. H., Berthrong, S. T., & Mahaffey, K. R. (2020). Nitrogen pollution: Sources and consequences in the U.S. and Europe. Frontiers in Ecology and the Environment, 18(3), 146–152.

Tanaka, Y., Fujioka, Y., Saito, K., Matsui, S., & Tsujimoto, Y. (2016). Nitrate pollution and its management in Japan. In: Nitrogen Pollution: Sources and Countermeasures. Springer. https://doi.org/10.1007/978-981-10-0313-8_2

Wang, H., & Li, X. (2020). Temporal dynamics of nitrate pollution in groundwater: Implications for land management practices. Journal of Contaminant Hydrology, 230, 103593.

Ward, M. H., deKok, T. M., Levallois, P., Brender, J., Gulis, G., Nolan, B. T., & VanDerslice, J. (2018). Workgroup report: Drinking-water nitrate and health—recent findings and research needs. Environmental Health Perspectives, 126(10), 1–15. https://doi.org/10.1289/EHP483

Zhang, Q., & Wang, Y. (2018). Assessing nitrate pollution hotspots in groundwater: A spatial analysis approach. Science of the Total Environment, 642, 1154–1166.