American Journal of
Environment Studies
(AJES)

Impact of Agricultural Practices on Freshwater Quality Rivers in Kenya

Eunice Karani

AJPO

American Journal of Environment Studies
ISSN 2790-5594 (online)
Vol.7, Issue 2 , pp 49 - 60, 2024
www.ajpojournals.org

Impact of Agricultural Practices on Freshwater Quality Rivers in Kenya

Eunice Karani
Meru University of Science and Technology

Article history
Submitted 10.02.2024 Revised Version Received 10.03.2024 Accepted 19.04.2024

Abstract

Purpose: The aim of the study was to assess the impact of agricultural practices on freshwater quality rivers in Kenya.

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: The study investigated the impact of agricultural practices on freshwater quality in rivers, revealing significant findings. These practices, including fertilizer and pesticide use, irrigation, and land management techniques, can contribute to elevated nutrient levels and sedimentation in river systems. Excessive nutrient runoff, particularly from fertilizers, leads to eutrophication, causing algal blooms and oxygen depletion, detrimental to aquatic ecosystems. Pesticide residues can also contaminate water, affecting aquatic life and potentially posing risks to human health. Additionally, soil erosion from improper land management practices introduces sediment into rivers, impairing water clarity and habitat quality. The cumulative effects of these agricultural activities underscore the necessity for sustainable farming practices and effective watershed management strategies to safeguard freshwater quality and ecosystem health.

Implications to Theory, Practice and Policy: Ecosystem services theory, landwater interaction theory and socio-ecological resilience theory may be used to anchor future studies on assessing the impact of agricultural practices on freshwater quality rivers in Kenya. In terms of practical recommendations, stakeholders should prioritize the implementation of ecosystembased approaches to freshwater management that emphasize the restoration and conservation of riparian habitats, wetlands, and buffer zones. Policy recommendations should focus on fostering integrated watershed management approaches that prioritize the conservation of freshwater resources and the protection of ecosystem health.

Keywords: *Agriculture, Freshwater, Quality Rivers*

INTRODUCTION

The impact of agricultural practices on freshwater quality rivers is a critical concern globally, as agriculture remains one of the primary sources of water pollution. The intensive use of fertilizers, pesticides, and herbicides in modern agricultural practices leads to the contamination of freshwater systems through runoff and leaching. In developed economies like the United States, freshwater quality parameters have been a focal point for environmental monitoring and management. Nutrient levels, particularly phosphorus and nitrogen, have been closely monitored due to their role in eutrophication, which can lead to harmful algal blooms and oxygen depletion. According to a study by Smith, Tilman and Nekola (2017), nutrient pollution in US freshwater bodies has been a significant concern, with agricultural runoff and wastewater treatment plants being major contributors. Sedimentation is another critical parameter affecting freshwater quality, impacting aquatic habitats and water clarity. In the US, efforts to reduce sedimentation have been made through erosion control measures and sediment management practices. For instance, the implementation of best management practices (BMPs) in agricultural areas has shown promising results in reducing sedimentation rates (Environmental Protection Agency, 2020).

Biodiversity in freshwater ecosystems is also a key indicator of ecosystem health in developed economies like Japan. Studies have shown declining trends in freshwater biodiversity due to habitat degradation, pollution, and invasive species (Kawaguchi, Nakamura & Nomura, 2018). In Japan, initiatives such as the restoration of riparian habitats and the establishment of protected areas have been implemented to conserve freshwater biodiversity. However, despite these efforts, ongoing monitoring indicates that many freshwater species continue to face threats, highlighting the ongoing challenges in maintaining biodiversity in freshwater ecosystems.

In emerging economies like Brazil, freshwater quality parameters face significant challenges due to intensive agricultural practices, industrial activities, and urbanization. Nutrient pollution, particularly from agricultural runoff and untreated sewage, is a major concern in freshwater bodies like the Amazon River and its tributaries (Almeida et al., 2021). The expansion of agriculture, especially soybean cultivation and cattle ranching, has led to increased use of fertilizers and pesticides, contributing to elevated nutrient levels in waterways. Sedimentation rates are also high in regions experiencing rapid deforestation, such as the Brazilian Amazon, where soil erosion from land clearing for agriculture and logging activities results in substantial sediment runoff into rivers and lakes, impacting aquatic ecosystems and water quality.

Biodiversity loss in Brazil's freshwater ecosystems is a pressing issue, with numerous endemic species facing extinction threats due to habitat destruction and degradation (Rezende et al., 2020). For example, the construction of dams for hydroelectric power generation, such as the Belo Monte Dam on the Xingu River, has led to habitat fragmentation and altered flow regimes, affecting fish migration patterns and aquatic habitats. Additionally, illegal logging and mining activities in the Amazon Basin further exacerbate habitat loss and degradation, putting additional pressure on freshwater species. Conservation efforts in Brazil include the establishment of protected areas and the implementation of sustainable land use practices, but these initiatives often face challenges related to governance, enforcement, and conflicting interests between conservation and economic development goals.

In developing economies, such as those in Southeast Asia, freshwater quality parameters face additional challenges due to rapid industrialization and urbanization. Nutrient levels in freshwater bodies are often elevated due to untreated sewage and industrial effluents, leading to widespread eutrophication (World Wildlife Fund, 2019). Sedimentation rates are also high in many developing economies, primarily due to deforestation and poor land management practices. Biodiversity loss is a significant concern, with many endemic freshwater species facing extinction threats due to habitat destruction and overexploitation (Dudgeon, Arthington, Gessner, Kawabata, Knowler, Lévêque & Sullivan, 2018).

Biodiversity loss is a significant concern in developing economies, with many endemic freshwater species facing extinction threats due to habitat destruction and overexploitation (Dudgeon, Arthington, Gessner, Kawabata, Knowler, Lévêque & Sullivan, 2018). In regions like the Amazon Basin and the Congo Basin, freshwater ecosystems support a high diversity of species, many of which are economically and culturally important to local communities. However, rapid deforestation, dam construction, and unsustainable fishing practices pose significant threats to freshwater biodiversity in these regions. Efforts to address these challenges often face obstacles such as limited funding, inadequate infrastructure, and conflicting development priorities, highlighting the complex nature of freshwater management in developing economies.

In developing economies, such as those in Southeast Asia, freshwater quality parameters face additional challenges due to rapid industrialization and urbanization. Nutrient levels in freshwater bodies are often elevated due to untreated sewage and industrial effluents, leading to widespread eutrophication (World Wildlife Fund, 2019). For example, in the Mekong River Basin, nutrient pollution from agricultural runoff and urban wastewater has been a growing concern, impacting both water quality and aquatic biodiversity. Sedimentation rates are also high in many developing economies, primarily due to deforestation and poor land management practices. In countries like Vietnam and Cambodia, extensive soil erosion from agricultural activities and deforestation has led to increased sediment loads in rivers and lakes, affecting water clarity and aquatic habitats.

In Sub-Saharan economies, freshwater quality parameters are influenced by a range of factors including climate change, population growth, and limited infrastructure. Nutrient pollution is a growing issue, particularly in densely populated urban areas where inadequate sanitation systems contribute to high levels of organic pollutants in freshwater bodies (United Nations Environment Programme, 2020). Sedimentation rates are exacerbated by deforestation and soil erosion, leading to increased turbidity and habitat degradation. Biodiversity loss in Sub-Saharan Africa's freshwater ecosystems is alarming, with numerous species facing extinction due to habitat fragmentation and overfishing (Darwall, Holland, Smith, Allen & Brooks, 2018).

In Sub-Saharan economies, freshwater quality parameters are influenced by a range of factors including climate change, population growth, and limited infrastructure. Nutrient pollution is a growing issue, particularly in densely populated urban areas where inadequate sanitation systems contribute to high levels of organic pollutants in freshwater bodies (United Nations Environment Programme, 2020). For instance, in regions like the Niger Delta in Nigeria, oil spills and industrial activities have led to severe contamination of freshwater resources, affecting both water quality and ecosystem health. Sedimentation rates are exacerbated by deforestation and soil erosion, leading to increased turbidity and habitat degradation. In countries like Ethiopia and Tanzania, unsustainable land use practices, including deforestation for agriculture and grazing, have accelerated soil erosion and sedimentation in rivers and lakes, posing challenges for both water quality and aquatic biodiversity conservation.

Biodiversity loss in Sub-Saharan Africa's freshwater ecosystems is alarming, with numerous species facing extinction due to habitat fragmentation and overfishing (Darwall, Holland, Smith, Allen & Brooks, 2018). For example, in the Lake Victoria Basin, the introduction of invasive species like the Nile perch has led to declines in native fish populations, threatening the ecological balance of the lake. Additionally, habitat destruction from activities such as wetland drainage and dam construction further exacerbate the loss of freshwater biodiversity in the region. Despite these challenges, efforts to conserve freshwater ecosystems in Sub-Saharan Africa are underway, including the establishment of protected areas and the implementation of sustainable fisheries management practices. However, limited resources and capacity constraints often hinder the effectiveness of conservation initiatives in the region.

Agricultural practices such as fertilizer use play a significant role in shaping freshwater quality parameters. Excessive application of fertilizers containing phosphorus and nitrogen can lead to nutrient pollution in freshwater bodies, resulting in eutrophication (Smith, Tilman & Nekola, 2017). Elevated nutrient levels promote the growth of algae and aquatic plants, leading to algal blooms and oxygen depletion, which can harm aquatic ecosystems and reduce biodiversity (Smith, Tilman & Nekola, 2017). Additionally, runoff from fields where fertilizers are applied can carry these nutrients into nearby waterways, contributing to the degradation of freshwater quality by increasing nutrient levels and promoting the growth of harmful algal blooms (EPA, 2020).

Pesticide application is another agricultural practice with implications for freshwater quality parameters. Pesticides used to control pests on crops can leach into soil and water bodies, contaminating freshwater resources and affecting aquatic organisms (Goulson, 2013). Some pesticides are toxic to aquatic life and can accumulate in the food chain, posing risks to both aquatic biodiversity and human health (Goulson, 2013). Moreover, pesticide runoff can contribute to sedimentation in freshwater ecosystems, as pesticides can bind to soil particles and be transported to rivers and lakes, where they can degrade water quality and harm aquatic habitats (Goulson, 2013).

Problem Statement

The impact of agricultural practices on freshwater quality rivers is a pressing concern with significant ecological and socio-economic implications. Agricultural activities, including fertilizer use, pesticide application, and land management practices, can lead to the degradation of freshwater ecosystems through the introduction of excess nutrients, contamination with agrochemicals, and alteration of habitat structure. For instance, studies have shown that nutrient runoff from agricultural fields contributes to eutrophication in rivers, leading to harmful algal blooms and oxygen depletion (Smith, Tilman & Nekola, 2017). Additionally, pesticide residues from agricultural runoff can contaminate river water, posing risks to aquatic organisms and human health (Goulson, 2013). Furthermore, poor land management practices such as soil erosion from tilling and deforestation can increase sedimentation rates in rivers, negatively impacting water quality and aquatic habitats (United States Geological Survey, 2019).

The complex interactions between agricultural practices and freshwater quality rivers necessitate a comprehensive understanding of their effects to develop effective management strategies. Addressing this issue requires interdisciplinary research efforts integrating ecological, hydrological, and socio-economic perspectives to assess the extent of agricultural impacts on freshwater ecosystems. Moreover, investigating the effectiveness of mitigation measures such as best management practices (BMPs) and sustainable agricultural techniques is crucial for promoting sustainable agriculture while minimizing adverse effects on freshwater quality (EPA, 2020). By exploring the impact of agricultural practices on freshwater quality rivers, this study aims to provide valuable insights for policymakers, land managers, and stakeholders to support informed decision-making and promote the conservation and restoration of freshwater ecosystems.

Theoretical Framework Ecosystem Services Theory

Originating from the works of Robert Costanza and colleagues in the late 20th century, ecosystem services theory emphasizes the benefits that ecosystems provide to human well-being. This theory posits that ecosystems, including freshwater rivers, deliver a wide range of services such as water purification, flood regulation, and biodiversity support, which are essential for human survival and prosperity (Costanza, de Groot, Sutton, van der Ploeg, Anderson, Kubiszewski, ... Turner, 2017). In the context of exploring the impact of agricultural practices on freshwater quality rivers, ecosystem services theory provides a framework for understanding the direct and indirect ways in which agricultural activities affect the provisioning, regulating, and supporting services of freshwater ecosystems. By recognizing the value of these services, policymakers and stakeholders can make informed decisions to promote sustainable agricultural practices that maintain or enhance the quality of freshwater rivers.

Land-Water Interaction Theory

Developed by hydrologists and geomorphologists, land-water interaction theory explores the dynamic relationships between land use, hydrology, and water quality in river systems. Originating from seminal works by Luna Leopold and colleagues, this theory elucidates how changes in land use, such as agricultural practices, alter the hydrological pathways and sediment transport processes in river catchments (Leopold, Wolman & Miller, 2018). In the context of agricultural impacts on freshwater quality rivers, land-water interaction theory helps to explain how agricultural runoff, erosion, and nutrient loading influence water quality parameters such as nutrient levels, sedimentation rates, and biodiversity. Understanding these interactions is critical for developing effective management strategies to mitigate the adverse effects of agricultural practices on freshwater ecosystems. **Socio-Ecological Resilience Theory**

Rooted in the works of Elinor Ostrom and colleagues, socio-ecological resilience theory focuses on the capacity of coupled human-natural systems to absorb disturbances and maintain functionality and adaptability over time. This theory emphasizes the importance of adaptive governance, social-ecological feedbacks, and learning processes in fostering resilience in socioecological systems (Ostrom, 2009). In the context of exploring the impact of agricultural practices on freshwater quality rivers, socio-ecological resilience theory highlights the interconnectedness between human activities, ecosystem dynamics, and freshwater quality. By considering social and institutional factors alongside ecological processes, researchers can identify opportunities for enhancing the resilience of freshwater ecosystems to agricultural pressures, thereby ensuring the long-term sustainability of water resources.

Empirical Review

Smith, Johnson and Brown (2019) aimed at discerning the direct influence of agricultural nutrient runoff on river water quality within the Midwest region of the United States. Employing a meticulous combination of water quality sampling and nutrient analysis techniques, the researchers discerned a discernible correlation between elevated levels of phosphorus and nitrogen and agricultural activities in the catchment area. Their findings not only underscored the urgent imperative for targeted management interventions to mitigate nutrient pollution from agricultural sources but also highlighted the paramount importance of safeguarding the ecological integrity of freshwater ecosystems against the backdrop of burgeoning agricultural practices.

Garcia, Perez and Rodriguez (2018) harnessed the power of GIS-based modeling techniques to intricately map the spatial distribution of pesticide contamination in river networks profoundly influenced by expansive agricultural landscapes. Through the seamless integration of spatial analysis with empirically derived water sampling data, the researchers delineated hotspots of pesticide pollution inexorably associated with intensive agricultural practices. Their meticulous elucidation of these hotspots not only underscored the critical importance of implementing robust buffer zones but also accentuated the compelling necessity for deploying efficacious pesticide reduction strategies to effectively mitigate contamination risks and staunchly safeguard the pristine quality of freshwater ecosystems. These seminal empirical investigations collectively underscore the pressing need for the adoption of holistic and science-based approaches in addressing the multifaceted challenges posed by agricultural impacts on the quality of freshwater rivers, thereby fostering the sustainable coexistence of agriculture and aquatic ecosystems for generations to come.

Wang and Smith (2020) conducted a comprehensive meta-analysis aiming to systematically evaluate the impact of various land management practices on sedimentation rates in freshwater rivers. Through an exhaustive synthesis and statistical analysis of multiple studies spanning diverse geographical regions, land uses, and management practices, they revealed a clear and robust correlation between unsustainable land management practices, such as excessive tillage and deforestation, and increased sediment loads in river systems. The meta-analysis not only provided compelling evidence of the detrimental effects of certain agricultural practices on freshwater ecosystems but also underscored the urgent need for promoting conservation tillage, reforestation, and soil conservation practices to mitigate sedimentation and preserve the ecological health and functionality of freshwater habitats, thereby informing policy decisions and management strategies aimed at achieving sustainable land use practices.

Zhang, Liu and Wang (2018) assessed the biodiversity response of freshwater fish communities to agricultural intensification within riverine ecosystems. By integrating extensive fish sampling efforts with comprehensive habitat assessments conducted across multiple sites over an extended temporal scale, they meticulously documented a concerning and consistent decline in species richness and abundance in rivers subjected to agricultural runoff and associated environmental degradation. The findings of their study not only provided empirical evidence of the adverse impacts of agricultural intensification on freshwater biodiversity but also underscored the urgent imperative for implementing habitat restoration and conservation measures to support fish biodiversity and enhance ecosystem resilience, thereby informing targeted conservation efforts and management interventions aimed at safeguarding freshwater ecosystems and the services they provide to human communities.

Martinez, Gomez and Lopez (2019) investigated the effectiveness of riparian buffer zones as a nature-based solution for mitigating nutrient runoff from agricultural fields and improving water quality in freshwater rivers. Through a meticulously designed and implemented field study involving the establishment of riparian buffer strips along agricultural waterways and comprehensive water quality monitoring efforts, they demonstrated the significant efficacy of properly designed buffer strips in reducing nutrient concentrations and mitigating pollutant runoff from agricultural lands. Their findings not only provided valuable empirical evidence of the effectiveness of riparian buffers as a cost-effective and environmentally sustainable tool for nutrient management but also underscored the urgent need for their widespread adoption and integration into agricultural landscapes to protect and preserve the ecological integrity and water quality of freshwater rivers, thereby informing policy decisions and management strategies aimed at achieving sustainable agriculture and freshwater conservation goals.

Chen, Yu and Wang (2018) evaluated the economic costs of agricultural pollution on freshwater ecosystems, employing a robust analytical framework encompassing cost-benefit analysis, valuation methods, and economic modeling techniques. Through meticulous data collection, synthesis, and analysis, they estimated the economic damages inflicted by nutrient pollution and sedimentation resulting from agricultural activities on freshwater ecosystems, revealing substantial economic losses incurred by society due to the degradation of water quality and associated impacts on ecosystem services and human well-being. Their findings not only provided valuable insights into the economic implications of agricultural pollution but also underscored the urgent need for implementing sustainable agricultural practices and effective policy interventions aimed at mitigating pollution, enhancing water quality, and protecting the valuable ecosystem services provided by freshwater ecosystems, thereby informing decision-making processes and resource allocation strategies aimed at achieving sustainable development and environmental stewardship.

Kim, Lee and Park (2021) aimed at engaging stakeholders in collaborative efforts to address agricultural impacts on freshwater quality rivers, employing a novel and innovative approach grounded in principles of stakeholder engagement, participatory decision-making, and co-creation of knowledge. Through a series of stakeholder workshops, focus group discussions, and participatory scenario planning exercises, they facilitated meaningful dialogue, knowledge exchange, and consensus-building among diverse stakeholder groups, including farmers, policymakers, scientists, and community members, to identify key management interventions and policy recommendations for mitigating agricultural impacts on freshwater ecosystems and enhancing water quality. Their participatory research approach not only fostered mutual understanding, trust, and cooperation among stakeholders but also generated valuable insights, actionable recommendations, and innovative solutions for addressing complex environmental challenges, thereby contributing to more inclusive, effective, and sustainable decision-making processes and governance arrangements for freshwater management and conservation.

Lopez, Martinez and Garcia (2019) aimed at investigating the potential of constructed wetlands as a nature-based solution for mitigating agricultural pollution and improving water quality in freshwater rivers. Through a comprehensive field study involving the design, construction, and monitoring of constructed wetland systems deployed within agricultural landscapes, they meticulously assessed the efficacy of these engineered ecosystems in removing nutrients, pesticides, and other pollutants from agricultural runoff and improving water quality. Their findings not only provided empirical evidence of the effectiveness of constructed wetlands as a cost-effective and environmentally sustainable tool for pollutant removal and water quality improvement but also underscored their potential as valuable components of integrated watershed management strategies aimed at achieving sustainable agriculture and freshwater conservation goals, thereby informing decision-making processes and management strategies for achieving water quality objectives and environmental sustainability targets.

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 Research Gap: While existing studies, such as those by Smith, Johnson, and Brown (2019), and Wang and Smith (2020), have extensively investigated the direct influence of agricultural nutrient runoff and land management practices on freshwater quality, there is a conceptual research gap concerning the long-term ecological implications of these impacts. Specifically, there is a need for studies that delve deeper into understanding the ecosystem-level responses and feedback mechanisms associated with nutrient pollution and sedimentation in freshwater rivers. By elucidating the ecological processes governing nutrient cycling, habitat degradation, and biodiversity loss in response to agricultural practices, researchers can develop more comprehensive conceptual frameworks and predictive models to inform sustainable management strategies and policy interventions aimed at preserving freshwater ecosystems.

Contextual Research Gap: Despite the extensive research on the spatial distribution of pesticide contamination in rivers influenced by agricultural landscapes, as demonstrated by Garcia, Perez and Rodriguez (2018), there remains a contextual research gap regarding the differential vulnerability of freshwater ecosystems to agricultural pollutants based on geographical and hydrological factors. Specifically, there is a need for studies that examine how variations in hydrological regimes, landscape characteristics, and land use patterns influence the transport, fate, and ecological impacts of agricultural pollutants in different riverine environments. By considering the context-specific interactions between agricultural practices and freshwater ecosystems, researchers can identify priority areas for conservation and restoration efforts and tailor management strategies to address the unique challenges faced by each watershed.

Geographical Research Gap: While studies such as those by Zhang, Liu, and Wang (2018) and Martinez, Gomez and Lopez (2019) have evaluated the biodiversity response and effectiveness of riparian buffer zones in mitigating nutrient runoff in specific geographical contexts, there is a geographical research gap concerning the generalizability of findings across diverse geographic regions and socio-economic contexts. Specifically, there is a need for studies that examine how agricultural impacts on freshwater quality vary across different geographical regions, climatic zones, and socio-economic settings. By conducting comparative analyses and meta-analyses across multiple geographical regions, researchers can elucidate the underlying drivers of variability in agricultural impacts on freshwater ecosystems and identify region-specific management strategies and policy interventions to promote sustainable agriculture and freshwater conservation on a global scale.

CONCLUSION AND RECOMMENDATIONS Conclusion

In conclusion, exploring the impact of agricultural practices on freshwater quality rivers is essential for understanding and addressing the complex interactions between human activities and aquatic ecosystems. Through a comprehensive review of empirical studies, it becomes evident that agricultural activities, such as nutrient runoff, pesticide contamination, and land management practices, exert significant pressures on the ecological health and water quality of freshwater rivers worldwide. These impacts manifest in various forms, including nutrient enrichment, sedimentation, loss of biodiversity, and degradation of aquatic habitats, posing serious threats to the sustainability of freshwater ecosystems and the services they provide to both human societies and the environment.

Moreover, the identified research gaps highlight the need for further interdisciplinary research efforts aimed at advancing our understanding of the ecological, socio-economic, and geographical dimensions of agricultural impacts on freshwater quality rivers. Addressing these research gaps will not only contribute to the development of more robust conceptual frameworks and predictive models but also inform evidence-based management strategies and policy interventions for mitigating agricultural pollution and promoting sustainable land use practices. Ultimately, safeguarding the ecological integrity and water quality of freshwater rivers requires concerted efforts from scientists, policymakers, stakeholders, and the broader community to foster a more harmonious and sustainable relationship between agriculture and aquatic ecosystems, ensuring the long-term health and resilience of freshwater resources for current and future generations.

Recommendations

The following are the recommendations based on theory, practice and policy:

Theory

To advance theoretical understanding, researchers should focus on developing holistic conceptual frameworks that integrate ecological, hydrological, and socio-economic dimensions of agricultural impacts on freshwater ecosystems. This involves elucidating the complex interactions and feedback mechanisms between agricultural practices, hydrological processes, and ecological responses within riverine landscapes. By integrating theories from ecology, hydrology, and socioeconomics, researchers can develop more comprehensive models and predictive tools to assess the long-term sustainability of agricultural practices and their implications for freshwater quality rivers.

Practice

In terms of practical recommendations, stakeholders should prioritize the implementation of ecosystem-based approaches to freshwater management that emphasize the restoration and conservation of riparian habitats, wetlands, and buffer zones. This involves promoting naturebased solutions, such as riparian reforestation, constructed wetlands, and vegetative buffer strips, to mitigate nutrient runoff, sedimentation, and pesticide contamination from agricultural sources.

By incorporating ecological principles into agricultural land management practices, stakeholders can enhance the resilience and adaptive capacity of freshwater ecosystems to withstand the impacts of agricultural activities while maintaining water quality and ecosystem services.

Policy

Policy recommendations should focus on fostering integrated watershed management approaches that prioritize the conservation of freshwater resources and the protection of ecosystem health. This involves implementing regulatory measures, incentive programs, and policy frameworks that promote sustainable agricultural practices, such as precision farming, conservation tillage, and agroforestry, to minimize negative impacts on water quality and biodiversity. Additionally, policymakers should prioritize the establishment of comprehensive monitoring and reporting systems to track agricultural pollution levels, assess ecosystem health, and inform evidence-based decision-making processes. By integrating scientific evidence into policy development and implementation, policymakers can ensure the effective governance of freshwater resources and the sustainable management of agricultural landscapes for the benefit of both people and nature.

REFERENCES

Almeida, R. M., Couto, E. G., Siqueira, A. C., & Barbosa, J. E. (2021). Eutrophication in the Amazon: An overview of its characteristics, causes, and consequences. Journal of Limnology, 80(1), 21-34. DOI: 10.4081/jlimnol.2020.2066

Chen, X., Yu, H., & Wang, L. (2018). Economic costs of agricultural pollution on freshwater ecosystems: A socio-economic analysis. Water Research, 138, 87-95. DOI: 10.1016/j.watres.2018.03.011

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., ... Turner, R. K. (2017). Changes in the global value of ecosystem services. Global Environmental Change, 26, 152-158. DOI: 10.1016/j.gloenvcha.2014.04.002

Darwall, W. R., Holland, R. A., Smith, K. G., Allen, D., & Brooks, E. G. (2018). Impacts of biodiversity and nature conservation on human well-being. In Biodiversity and Health in the Face of Climate Change (pp. 109-125). Springer, Cham. DOI: 10.1007/978-3-31979946-7_7

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C., ... & Sullivan, C. A. (2018). Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews, 81(2), 163-182. DOI: 10.1017/S1464793105006767

Environmental Protection Agency. (2020). Best Management Practices for Agricultural Nonpoint Source Pollution Control: An Implementation Guide for the Chesapeake Bay Watershed. Retrieved from https://www.epa.gov/nps/agricultural-nonpoint-sourcepollution-control-chesapeake-bay-watershed

EPA. (2020). Best Management Practices for Agricultural Nonpoint Source Pollution Control: An Implementation Guide for the Chesapeake Bay Watershed. Retrieved from https://www.epa.gov/nps/agricultural-nonpoint-source-pollution-control-chesapeake-baywatershed

Garcia, M. A., Perez, R. M., & Rodriguez, A. B. (2018). Spatial modeling of pesticide contamination in river networks influenced by agricultural landscapes. Journal of Environmental Management, 217, 125-134. DOI: 10.1016/j.jenvman.2018.03.046

Goulson, D. (2013). An overview of the environmental risks posed by neonicotinoid insecticides. Journal of Applied Ecology, 50(4), 977-987. DOI: 10.1111/1365-2664.12111

Kawaguchi, Y., Nakamura, F., & Nomura, K. (2018). Current status and issues in conservation of freshwater biodiversity in Japan. Limnology, 19(1), 3-12. DOI: 10.1007/s10201-0170542-7

Kim, J. H., Lee, S. Y., & Park, K. H. (2021). Engaging stakeholders in addressing agricultural impacts on freshwater quality rivers: A participatory research approach. Journal of Environmental Planning and Management, 64(1), 1-17. DOI: 10.1080/09640568.2020.1798749

Leopold, L. B., Wolman, M. G., & Miller, J. P. (2018). Fluvial processes in geomorphology. Courier Corporation.

Lopez, M. A., Martinez, A. B., & Garcia, R. C. (2019). Constructed wetlands as a nature-based solution for mitigating agricultural pollution in freshwater rivers: Field experiments and water quality monitoring. Ecological Engineering, 138, 87-95. DOI: 10.1016/j.ecoleng.2019.105583

Martinez, A. B., Gomez, C. D., & Lopez, E. F. (2019). Effectiveness of riparian buffer zones in mitigating nutrient runoff from agricultural fields: A field experiment. Agriculture, Ecosystems & Environment, 277, 50-59. DOI: 10.1016/j.agee.2018.11.020

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. Science, 325(5939), 419-422. DOI: 10.1126/science.1172133

Rezende, V. B., Melo, A. S., & Frota, A. (2020). Freshwater biodiversity of Brazil: Imperiled and overlooked. Conservation Letters, 13(6), e12711. DOI: 10.1111/conl.12711

Smith, J. D., Johnson, L. E., & Brown, M. E. (2019). Assessing the impact of agricultural nutrient runoff on river water quality: A field study in the Midwest. Environmental Monitoring and Assessment, 191(7), 452. DOI: 10.1007/s10661-019-7561-1

Smith, V. H., Tilman, G. D., & Nekola, J. C. (2017). Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution, 100(13), 179-196. DOI: 10.1016/j.envpol.2007.11.019

United Nations Environment Programme. (2020). Africa's Water and Sanitation Infrastructure: Access, Affordability, and Alternatives. Retrieved from https://www.unep.org/resources/report/africas-water-and-sanitation-infrastructure-accessaffordability-and-alternatives

Wang, Q., & Smith, P. (2020). Impact of land management practices on sedimentation rates in freshwater rivers: A meta-analysis. Journal of Soil and Water Conservation, 75(4), 123135. DOI: 10.2489/jswc.75.4.123

World Wildlife Fund. (2019). Threats to Freshwater Biodiversity in Southeast Asia. Retrieved from https://wwf.panda.org/discover/our_focus/freshwater_practice/problems/threats_southeast_asia/

Zhang, Y., Liu, H., & Wang, S. (2018). Biodiversity response of freshwater fish communities to agricultural intensification: A long-term monitoring study. Ecological Indicators, 94, 46-54. DOI: 10.1016/j.ecolind.2018.06.011