ISSN: 2688-8645

Identification and Control of Agricultural Non-Point Source Pollution in the Intensive Farming Area of the Guanzhong Plain, China: A Review

Xinkun Song [1, 2, 3], Zhaoxin Zhang [1, 2, 3]

[1] Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi'an, Shaanxi, China

[2] Key Laboratory of Cultivated Land Quality Monitoring and Conservation, Ministry of Agriculture and Rural Affair, Xi'an, Shaanxi, China

[3] Shaanxi Provincial Land Consolidation Engineering Technology Research Center, Xi'an, Shaanxi, China

Abstract

The Guanzhong Plain, one of China's major grain production bases, faces severe agricultural non-point source (NPS) pollution due to intensive high-input farming practices. Excessive fertilizer application and frequent irrigation have led to substantial nitrogen (N) and phosphorus (P) losses, threatening the water quality of the Weihe River system. This paper reviews research progress on NPS pollution identification methods and control technologies in this region. Identification methods—including field monitoring, export coefficient models, mechanistic models such as SWAT, and stable isotope tracing—are systematically compared in terms of applicability and limitations. Control technologies across the "source reduction–process interception–end-of-pipe purification" chain, including formula fertilization, controlled-release fertilizers, biochar amendment, ecological ditches, and riparian buffer strips, are evaluated for their reduction effectiveness. Current research gaps are identified: insufficient long-term monitoring data, inadequate model localization for irrigation districts, low integration of individual technologies, and weak economic feasibility assessment. Future research should prioritize establishing regional monitoring networks, developing irrigation-specific simulation models, promoting multi-technology synergistic optimization, and building long-term policy incentive mechanisms. This review provides a scientific reference for sustainable agricultural NPS pollution management in the Guanzhong Plain and similar intensive farming regions.

Keywords

Non-point Source Pollution; Guanzhong Plain; Intensive Agriculture; Critical Source Area Identification; Control Technologies; Review.

1. Introduction

Agricultural non-point source (NPS) pollution refers to the diffuse migration of nutrients, primarily nitrogen (N) and phosphorus (P), from farmlands to water bodies through surface runoff, interflow, and groundwater leaching. This process is a leading cause of surface water eutrophication and groundwater nitrate contamination worldwide (Carpenter et al., 1998) [1]. Unlike point source pollution, NPS pollution is characterized by dispersed discharge pathways, temporal randomness, and strong spatial heterogeneity, making its monitoring, modeling, and control considerably more challenging (Ongley et al., 2010) [8].

ISSN: 2688-8645

The Guanzhong Plain, located in the central part of Shaanxi Province, China, is a representative intensive agricultural region supporting a winter wheat–summer maize double-cropping system. The area has a warm-temperate semi-humid continental monsoon climate with a mean annual temperature of approximately 13 °C and annual precipitation of 500–600 mm, over 60% of which falls between July and September. Soils are predominantly calcareous loessal soils with silt loam texture. Agricultural intensification has resulted in fertilizer application rates far exceeding crop requirements; national-scale assessments indicate that excessive nitrogen inputs remain a major challenge for water quality improvement in China (Yu et al., 2019) [11]. The flat terrain, combined with well-developed irrigation and drainage systems, creates conditions where high-intensity irrigation and concentrated summer rainfall readily generate surface runoff and deep percolation, accelerating nutrient migration into the Weihe River—the largest tributary of the Yellow River in this region.

In recent years, substantial research has addressed NPS pollution identification and control in this region. However, findings remain fragmented, and comprehensive technology integration is lacking. This paper provides a systematic review of identification methods and control technologies, identifies current challenges, and proposes future research directions.

2. NPS Pollution Identification Methods

Accurate pollution identification underpins effective control strategies. Three methodological categories—load estimation, critical source area (CSA) identification, and source apportionment—are reviewed below.

2.1. Pollution Load Estimation

Field monitoring represents the most direct approach. Runoff plots and automatic water samplers at field outlets or small watersheds provide reliable, event-based measurements. However, field methods are labor-intensive, site-specific, and cannot be directly extrapolated to regional scales (Shen et al., 2012) [9].

Export coefficient models estimate regional loads using empirical relationships between land use types and pollutant export intensities. These models require minimal data and are computationally efficient (Johnes, 1996) [3]. In the Guanzhong Plain, land use change has been shown to significantly influence non-point source pollution loads, with cropland expansion and intensification contributing to increased nutrient export. The main limitation of export coefficient approaches is the assumption of spatial homogeneity, which ignores variations in topography, soil properties, management practices, and interannual rainfall fluctuations.

Mechanistic models, particularly the Soil and Water Assessment Tool (SWAT), simulate coupled hydrological, soil erosion, and nutrient cycling processes with high spatiotemporal resolution (Gassman et al., 2007) [2]. SWAT has been widely applied to simulate NPS pollution in Chinese watersheds, including the Weihe River basin, demonstrating satisfactory capability in capturing spatial and temporal variability of nutrient loads (Shen et al., 2012) [9]. A key limitation of SWAT is its relatively weak representation of artificial irrigation management, which is critical for irrigation districts like the Guanzhong Plain. The integration of field monitoring data for model calibration with simulation outputs for spatial source attribution—forming a "monitoring–simulation–statistical" framework—is an increasingly recommended approach (Shen et al., 2012) [9].

2.2. Critical Source Area Identification

CSAs are localized zones where high pollutant export intensity coincides with strong hydrological connectivity to receiving waters. Two main approaches exist. Model-based threshold discrimination uses SWAT outputs combined with topographic indices to classify risk zones. Multi-indicator comprehensive evaluation integrates soil nutrient levels, fertilization

ISSN: 2688-8645

intensity, soil erodibility, slope, and proximity to water bodies into a GIS-based risk index. While flexible in incorporating multiple factors, this method relies on subjective expert-based weight assignments (Shen et al., 2012) [9].

2.3. Source Apportionment

Stable isotope techniques have emerged as powerful tools for N source tracing. Different N sources exhibit distinct $\delta^{15}N$ and $\delta^{18}O$ signatures, enabling quantitative source apportionment (Kendall et al., 2007) [4]. In the Weihe River basin, dual-isotope approaches have been applied to differentiate fertilizer-derived nitrate from soil organic nitrogen and sewage sources, providing critical evidence for targeted management.

3. NPS Pollution Control Technologies

3.1. Source Reduction Technologies

Formula fertilization based on soil testing reduces nutrient surplus through science-based rate recommendations. National-scale analyses have emphasized that optimizing nitrogen management is essential for restoring water quality in China (Yu et al., 2019) [11]. Controlled-release fertilizers synchronize nutrient release with crop uptake patterns. Biochar amendment improves soil nutrient retention through adsorption and enhanced soil structure. Meta-analyses have demonstrated that biochar can increase crop productivity under certain conditions (Liu et al., 2013) [6] and exhibits high stability in soil, contributing to long-term carbon sequestration (Wang et al., 2016) [10].

3.2. Process Interception Technologies

Ecological ditches transform conventional drainage channels into vegetated purification systems. [5] Kumwimba et al. (2018) reviewed the design, mechanisms, and management strategies of vegetated drainage ditches for removing pollutants from agricultural runoff, emphasizing their effectiveness for nutrient retention. Riparian buffer strips slow overland flow, promoting sedimentation of particulate P and biological uptake of dissolved nutrients (Mayer et al., 2007) [7]. Buffer width optimization is critical in land-scarce intensive farming areas.

3.3. Technology Integration

Individual technologies often exhibit variable performance depending on meteorological and site conditions. Integrated approaches combining source reduction and process interception—such as optimized fertilization combined with ecological ditches and buffer strips—have shown greater potential for achieving consistent and synergistic pollution reduction (Yu et al., 2019). Such combinations address multiple pathways of nutrient loss and enhance system resilience.

4. Challenges and Future Directions

Major challenges include: (1) sparse long-term monitoring infrastructure insufficient for robust model calibration; (2) inadequate representation of irrigation scheduling in SWAT and similar models; (3) limited evaluation of synergistic effects among combined technologies; (4) insufficient cost-benefit analysis and farmer adoption research hindering technology transfer.

Future directions should prioritize: (1) establishing permanent monitoring networks with IoT-based real-time systems in representative irrigation districts of the Guanzhong Plain; (2) improving irrigation modules in mechanistic models for small-scale distributed simulation; (3) optimizing multi-technology combinations through field experiments and long-term scenario modeling; (4) integrating remote sensing, machine learning, and isotope data for high-

resolution dynamic CSA mapping; (5) developing economic incentive mechanisms informed by farmer behavior research.

5. Conclusion

Agricultural NPS pollution in the Guanzhong Plain exhibits high loads and pronounced spatiotemporal variability. Identification methods have progressed from single approaches to multi-technique integration encompassing monitoring, modeling, and isotope tracing. Control technologies are evolving from isolated measures toward full-chain "source–process–end-of-pipe" coordination. Priority actions include establishing regional monitoring networks, localizing mechanistic models, and optimizing integrated technology packages. Balancing emission reduction with agricultural productivity will enable sustainable, replicable NPS pollution management for the Guanzhong Plain and comparable intensive agricultural regions in northern China.

Acknowledgments

This work was financially supported by the Shaanxi Youth Science and Technology Nova Program (Grant No. 2025ZC-KJXX-149).

References

[1] Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications, 8(3), 559–568. https://doi.org/10.1890/1051-0761(1998)008[0559:NPOSWW]2.0.CO;2.

[2] Gassman, P. W., Reyes, M. R., Green, C. H., & Arnold, J. G. (2007). The Soil and Water Assessment Tool: Historical development, applications, and future research directions. Transactions of the ASABE, 50(4), 1211–1250. https://doi.org/10.13031/2013.23637.

[3] Johnes, P. J. (1996). Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to surface waters: The export coefficient modelling approach. Journal of Hydrology, 183(3–4), 323–349.

[4] Kendall, C., Elliott, E. M., & Wankel, S. D. (2007). Tracing anthropogenic inputs of nitrogen to ecosystems. In R. Michener & K. Lajtha (Eds.), Stable Isotopes in Ecology and Environmental Science (2nd ed., pp. 375–449). Blackwell Publishing. https://doi.org/10.1002/9780470691854.ch12.

[5] Kumwimba, M. N., Meng, F., Iseyemi, O., Moore, M. T., Zhu, B., Tao, W., Liang, T. J., & Ilunga, L. (2018). Removal of non-point source pollutants from domestic sewage and agricultural runoff by vegetated drainage ditches (VDDs): Design, mechanism, management strategies, and future directions. Science of the Total Environment, 639, 742–759. https://doi.org/10.1016/j.scitotenv.2018.05.184.

[6] Liu, X., Zhang, A., Ji, C., Joseph, S., Bian, R., Li, L., Pan, G., & Paz-Ferreiro, J. (2013). Biochar's effect on crop productivity and the dependence on experimental conditions—a meta-analysis of literature data. Plant and Soil, 373(1–2), 583–594. https://doi.org/10.1007/s11104-013-1806-x.

[7] Mayer, P. M., Reynolds, S. K., McCutchen, M. D., & Canfield, T. J. (2007). Meta-analysis of nitrogen removal in riparian buffers. Journal of Environmental Quality, 36(4), 1172–1180. https://doi.org/10.2134/jeq2006.0462.

[8] Ongley, E. D., Zhang, X., & Yu, T. (2010). Current status of agricultural and rural non-point source pollution assessment in China. Environmental Pollution, 158(5), 1159–1168. https://doi.org/10.1016/j.envpol.2009.10.047.

[9] Shen, Z., Liao, Q., Hong, Q., & Gong, Y. (2012). An overview of research on agricultural non-point source pollution modelling in China. Separation and Purification Technology, 84, 104–111. https://doi.org/10.1016/j.seppur.2011.01.018.

[10] Wang, J., Xiong, Z., & Kuzyakov, Y. (2016). Biochar stability in soil: Meta-analysis of decomposition and priming effects. GCB Bioenergy, 8(3), 512–523. https://doi.org/10.1111/gcbb.12266.

ISSN: 2688-8645

[11] Yu, C., Huang, X., Chen, H., Godfray, H. C. J., Wright, J. S., Hall, J. W., Gong, P., Ni, S., Qiao, S., Huang, G., Xiao, Y., Zhang, J., Feng, Z., Ju, X., Ciais, P., Stenseth, N. C., Hessen, D. O., Sun, Z., Yu, L., & Taylor, J. (2019). Managing nitrogen to restore water quality in China. Nature, 567(7749), 516–520. https://doi.org/10.1038/s41586-019-1001-1.