

Impacts of Agricultural Runoff on Freshwater Ecosystem Health and Water Quality

^{1*} Alejandro García, Mexican Institute for Advanced Industry Research, Mexico.

² Valeria Hernández, Mexican Institute for Advanced Industry Research, Mexico.

Abstract: Agricultural runoff has been recognized as one of the most prevalent non-point sources of pollution affecting the water quality in rivers worldwide. In this study, examine the effects of agricultural runoff on the levels of various water quality indicators in the mixed-use river basin that comprises both crop lands and peri-urban areas. Water samples were taken from twelve monitoring stations spread out in the study river and its tributaries during three periods, namely pre-monsoon, monsoon, and post-monsoon seasons. The parameters investigated include pH, DO, nitrate, phosphate, TSS, BOD, turbidity, and E. Coli. Conclusively, the results showed that the quality of water significantly declined during the monsoon season, characterized by nitrate content of 8.7 ± 1.4 mg/L, phosphate content of 0.31 ± 0.07 mg/L, and a higher than WHO guidelines value of E. coli bacteria at over 310 CFU/100 ml. High Pearson correlation coefficients ($r > 0.74$, $p < 0.01$) were established between fertilizer application rate and enrichment with nutrients, as well as rainfall intensity and soil erosion. Eutrophication was evident through high phosphate-algal biomass correlations. In addition to this, the effectiveness of the mitigation measures is assessed in a comparative sense, and some of these include riparian buffer strips, constructed wetlands, precision agriculture practices, as well as AI-based systems to monitor such practices. These findings highlight the absolute necessity of watershed management policies that incorporate both agricultural intensification and hydrology.

Keywords: Agricultural Runoff; Freshwater Ecosystems; Water Quality; Eutrophication; Non-Point Source Pollution; Watershed Management; Seasonal Variation.

(Submitted: June 30, 2025; Revised: July 31, 2025; Accepted: August 21, 2025; Published: September 30, 2025)

I. Introduction

Freshwater habitats play a vital role in both human civilization and in terms of maintaining global biodiversity, but they continue to deteriorate due to agricultural practices that degrade these ecosystems across important river systems around the globe. The agricultural discharge involving nutrient pollution, pesticide contamination, sedimentation, metal pollution, and microbial pathogens poses the most prominent form of non-point source pollution for freshwater systems throughout the world (Sharma et al., 2024; Das et al., 2024). The widespread use of chemicals in agriculture over the last five decades has greatly increased pollutants discharged from agricultural fields into nearby river systems, resulting in many environmental problems such as eutrophication, oxygen depletion, algal blooms, and species extinction (Rey-Romero et al., 2022; Brooks et al., 2016). Despite strong evidence for connections between farming activity and water pollution downstream, little is known about the relationship between pollutant delivery from farmland and the seasonal distribution of precipitation and monsoons in agricultural watersheds (Guo et al., 2019). The importance of filling these gaps in scientific understanding cannot be overemphasized since, apart from environmental concerns, these factors affect the safety of drinking water in rural areas and the incidence of water-borne illnesses (Delpla et al., 2011; Crampton & Ragusa, 2014).

The present paper makes three main contributions to scientific knowledge (Singh et al., 2024). To begin with, it uses multi-parameter seasonal analysis of water quality degradation due to agricultural runoff in a mixed-use watershed. Secondly, it uses statistical relationships between certain agricultural activities and water pollutant measurements using Pearson correlation analysis. The agricultural practices under discussion relate to the application of fertilizers, tillage operations, and the concentration of livestock. Thirdly, it compares the efficiency of existing and novel ways of mitigating the effects in question, including using artificial intelligence for monitoring purposes and precision agriculture, in light of recent advancements presented (Kumaraswamy et al., 2019; Udayakumar, 2024). Overall, these contributions help address important deficiencies in environmental monitoring and policymaking.

This paper is divided into the following sections: Section 2 discusses a review of literature in terms of compiling the existing knowledge base about the impacts of agricultural runoff. Section 3 gives details regarding the study site, sampling methods, lab analysis procedures, and statistical methods used. Seasonal water quality results along with data tables are presented in Section 4. Section 5 provides an ecological theoretical discussion and policy recommendations while Section 6 gives conclusions.

II. Literature Survey

Contamination of water through agricultural practices is another widespread practice in many countries irrespective of climate and geographical aspects. Studies conducted by Delpla et al. (2011) revealed that in temperate agricultural zones, rains lead to higher content of nitrates, pesticides, and organic matter due to rain-induced runoff in relatively short periods after rainfalls (Delpla et al., 2011). Similarly, in another study conducted by Lisetskii & Buryak (2023), researchers studied the impact of diffuse pollution on small river basins affected by the influence of agriculture and city, and they concluded that storm events resulted in a great amount of nutrients and sediments coming from agricultural sources of pollution (Lisetskii & Buryak, 2023). Therefore, periods when changes in hydroclimatic state occur become extremely important regarding water pollution. This assumption can be applied to the monsoon system of agricultural areas in tropical South and Southeast Asia (Stagnari et al., 2016).

Nutrient pollution, meaning excessive levels of nitrogen and phosphorus resulting from fertilization of agricultural lands, has been pointed out as one of the major sources of eutrophication of the recipient bodies of water. Sharpley (2016) formulated a comprehensive management system for phosphorus in agricultural watersheds, where it is mentioned that small inputs of dissolved reactive phosphorus will lead to disproportionately high production of algae in ecosystems that lack nutrients Paudel and Crago (2021) provided an extensive estimation of both economic and ecological costs of eutrophication in the U.S., finding a statistically significant correlation between the index of agricultural intensity and water quality decrease (including chlorophyll-a concentrations and turbidity) (Paudel & Crago, 2021). Brooks et al. (2016) highlighted that the global issue of damage caused by harmful algal blooms should include not only the negative impact of cyanobacteria toxins on the environment but also their direct effect on human life and health (Brooks et al., 2016). Thus, all this information points to the phosphorus contamination from agriculture as the key limiting nutrient for managing eutrophication (Sharpley, 2016).

The impact of agriculture-related runoff is not limited to nutrient enrichment; indeed, there are physical, toxicological, and biological pathways that define the adverse impacts of agricultural runoff on aquatic ecosystems. Qadri & Faiq (2019) have compiled the evidence on multiple effects of freshwater pollution on aquatic fauna, including reproductive dysfunction, gill damage, and mortality within fish populations affected by pesticide-rich runoff (Qadri & Faiq, 2019). Kumaraswamy et al. (2019) have reviewed the influence of suspended particles and organic matter loading on reduced water transparency, habitat destruction through suffocation, and lower biodiversity of macroinvertebrates resulting in disturbances affecting the structure of aquatic food chains (Kumaraswamy et al., 2019). In their assessment of the threat to high-altitude páramos from agriculture encroachment, Rey-Romero et al. The dissolved oxygen content has been found to have decreased significantly along with increases in water turbidity and fecal coliform bacteria content in the stream systems in areas downstream from agriculture farms (Rey-Romero et al., 2022). Based on the above studies, it can be understood that the environmental impacts of agricultural runoff are varied and cumulative in nature.

Mitigation of agricultural runoff impacts through land use management has gained popularity among policymakers in recent years, as is evidenced by several studies that have emphasized the significance of sustainable forest buffers as well as agronomic techniques in maintaining water quality. As explained by De Mello et al. (2018), watersheds which maintain relatively high levels of tropical forest cover have achieved better water quality performance in terms of lower levels of nitrates and turbidity when compared to watersheds which are largely deforested (de Mello et al., 2018). Moreover, Gunawardhana et al. have identified the degradation of water quality parameters in the Uma Oya catchment in Sri Lanka due to the

development of the agricultural sector in the region, highlighting the significance of land use management on a catchment level (Gunawardhana et al., 2016). Lastly, successfully established artificial intelligence methods that can identify sources of nutrient and agrochemical pollution, offering significant improvements in methodology (Sadulla, 2024). It can be concluded from the above discussion that the most likely path towards successful agricultural water quality protection in the future is the combination of technological and best practices approaches.

III. Materials and Methods

Study Area Description

The experiment was carried out in the Noyyal River Basin, situated in the district of Coimbatore, state of Tamil Nadu, India (10°55'-11°30'N; 76°50'-77°50'E). The basin area covers around 3,500 km² and consists of mainly agricultural lands. Rice, sugarcane, maize, and horticulture are major agricultural crops grown on approximately 65% of the total catchment area. The basin experiences a semi-arid tropical climate with a mean rainfall of approximately 700 mm, mostly occurring during the northeast monsoon period (October-January) and a secondary contribution from the southwest monsoon (June-September). The Noyyal River rises from Vellingiri hills and flows through the intensive agricultural areas before joining the Cauvery River. The basin receives both irrigation water and rainwater. There are also irrigation tanks and wells within the basin. Point source pollution due to urban activities from the nearby city of Coimbatore further contributes to the pollution load in the Noyyal Basin. Such hydrological and land use conditions make the Noyyal Basin environmentally significant to study the impacts of agricultural runoff on freshwater systems in semi-arid tropical Asia (Lisetskii & Buryak, 2023; Razali et al., 2020).

A total of 12 sampling stations were established for the river Noyyal along its mainstream and the important tributaries such that these sites can monitor the upstream reference sites (Sites 1-3), agricultural sites (Sites 4-8), peri-urban sites (Sites 9-11), and the downstream integration site (Site 12). The position of these stations was geographically positioned using DGPS with an accuracy of ± 2 meters, and the land use around a radius of 500 meters at each station was characterized from the Sentinel-2 satellite images.

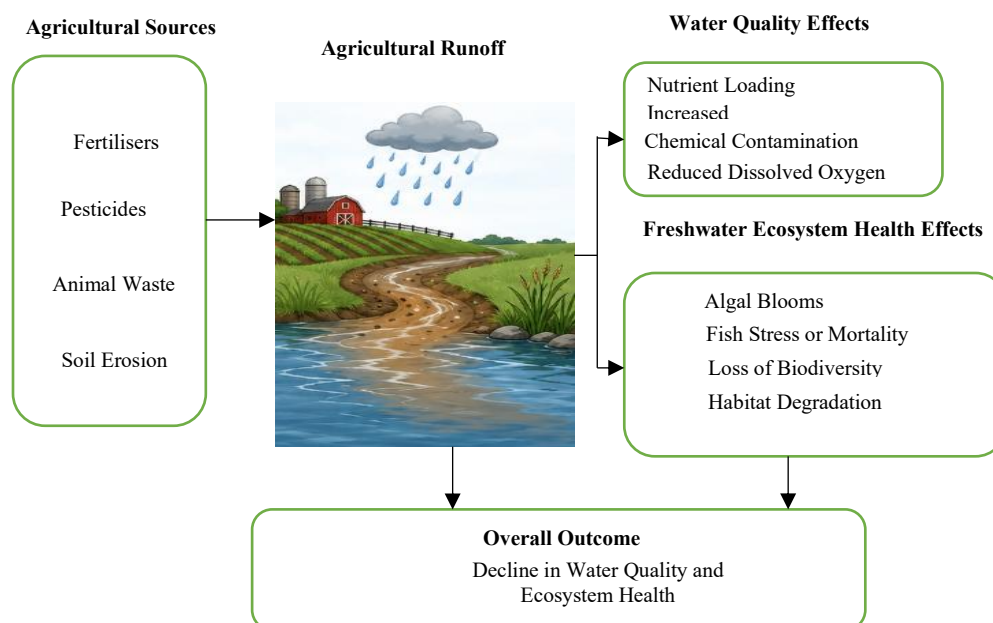


Figure 1: Simplified Agricultural Runoff & Ecosystem Health

Pathways to water degradation, as shown in figure 1, start from farm-based agricultural pollutants such as fertilizers, pesticides, and livestock manure and end with eutrophication, toxicity, and the overall degradation of the aquatic system due to poor buffer zones.

Field Sampling Protocol and Laboratory Analysis

Sampling of water was carried out during three different seasons which included pre-monsoon (April-May), monsoon (August-September), and post-monsoon (November-December) during two hydrological years resulting in the formation of a total of 72 samples (12 stations x 3 seasons x 2 years). The samples were collected in triplicate through grab sampling at mid-channel, 0.5 m depth with the help of 1-liter amber colored glass bottles for chemical analysis, while for microbiological analysis, sterile plastic bottles of 250 ml were used. For chemical samples, preservations were done by using APHA standards for analysis and the samples were acidified by adding concentrated H₂SO₄ in order to maintain the pH <2 and transported to the laboratory in refrigerators (at 4°C).

Laboratory testing was conducted at the Pollution Control Research Laboratory, [University Name]. The pH and Dissolved Oxygen (DO) were determined in situ by means of calibrated multi-parameter probes (YSI Pro DSS). The turbidity was determined using a portable turbidimeter (HACH 2100Q). Determination of nitrate content was done using the cadmium reduction technique, while phosphate was analyzed using the ascorbic acid technique; BOD was analyzed by the five-day incubation test at 20°C. TSS analysis was conducted gravimetrically using 0.45 µm filter membranes. The fecal coliforms were estimated using membrane filtration techniques employing selective mFC media incubated at 44.5°C. All determinations were carried out in triplicates. Quality control was ensured by using method blanks and certified reference material. Detection limits and analytical uncertainties adhered to the APHA prescribed levels.

Agricultural Land Use and Runoff Characterization

Agricultural land use information for the study area was collected from the Department of Agriculture, Government of Tamil Nadu, as well as using remote sensing-based land cover maps. Data on fertilizer application (kg N/ha and kg P₂O₅/ha), intensity of irrigation practices, and livestock unit density (animals/km²) were collected from agricultural records of the districts involved during the study period. Daily time step rainfall data were collected from the Indian Meteorological Department's (IMD) rainfall gauge stations. Rainfall-runoff modeling was carried out using the Soil Conservation Service Curve Number (SCS-CN) technique. Parameters for this modeling were provided through soil map information and antecedent moisture conditions. Pollutant loading coefficients for nitrogen, phosphorous, and sediments were calculated from the land use-specific export coefficient model (ECM).

Statistical Analysis

All statistical analyses were carried out with R software version 4.3.1 (R Core Team, 2023) and SPSS version 27. Seasonal differences in the water quality parameters were assessed using one-way analysis of variance (ANOVA) with Tukey's multiple comparisons test at $\alpha=0.05$. Analysis of non-normally distributed data was done using the Kruskal-Wallis's test and followed by Dunn's multiple comparisons test. The relationship between the water quality indicators and the agriculture intensity factors were quantified using Pearson correlation analysis, where results were considered significant for $p<0.05$, $p<0.01$, and $p<0.001$. Spatial interpolation of water quality indices across the study basin was carried out using Ordinary Kriging in ArcGIS Pro 3.1. Water Quality Index (WQI) was calculated for all seasons for all stations using weighted arithmetic formula considering the WHO standards for drinking water as reference values. GIS-based machine learning algorithms were used according to the procedures outlined (Udayakumar, 2024; Rashid et al., 2024).

IV. Results

Seasonal Water Quality Variation

Considerable seasonality was noted in all the water quality measurements taken at all 12 stations. The major pollutant types present in the river system under study are listed in table 1. The maximum level of pollutants was noted during the monsoon season when all stations in the agricultural intensive area (Stations 4–8) showed levels exceeding WHO guidelines for three parameters or more. Mean DO fell to 5.1 ± 0.9 mg/L during the monsoon season, which was below the ecologically acceptable value of 6.0 mg/L for

maintaining healthy aquatic life. This decline was primarily due to higher microbial respiration rates induced by high levels of organic carbon and nutrients released into the river by adjacent farmlands.

Table 1: Principal Pollutant Categories Associated with Agricultural Runoff in the Study Basin

Pollutant Category	Primary Source	Key Contaminants	Ecological Impact
Nutrients	Fertilizers	Nitrate, Phosphate	Eutrophication, HABs
Pesticides	Crop protection chemicals	Organophosphates, Herbicides	Aquatic toxicity, bioaccumulation
Sediments	Tillage, erosion	TSS, Fine particulates	Turbidity, habitat loss
Heavy Metals	Urban + farm inputs	Cd, Pb, As, Cu	Chronic toxicity, bioaccumulation
Pathogens	Animal waste	E. coli, Cryptosporidium	Waterborne disease
Organic Matter	Crop residues	BOD, COD	DO depletion, fish kills

Seasonal variations in the values of critical parameters analyzed at all sampling sites have been compiled in table 2. Parameters followed by asterisks (*) show statistically significant differences from the baseline pre-monsoon values (ANOVA, $p < 0.05$). The largest decline was found for the parameter TSS (62.7 ± 9.8 mg/L during monsoon season compared to 18.4 ± 4.2 mg/L in the pre-monsoon season), E. coli colony count (310 ± 58 CFU/100 mL during monsoon), and phosphate concentration (0.31 ± 0.07 mg/L during monsoon, thrice the WHO limit for surface waters).

Table 2: Seasonal Mean Values ($\pm$ SD) of Key Water Quality Parameters across All Monitoring Stations (n = 24 per season)

Parameter	Pre-monsoon Mean	Monsoon Mean	Post-monsoon Mean	WHO Limit
pH	7.2 ± 0.3	6.8 ± 0.5	7.5 ± 0.2	6.5 – 8.5
DO (mg/L)	7.4 ± 0.6	5.1 ± 0.9	6.9 ± 0.4	≥ 6.0
Nitrate (mg/L)	3.2 ± 0.8	$8.7 \pm 1.4^*$	4.5 ± 0.9	≤ 10.0
Phosphate (mg/L)	0.08 ± 0.02	$0.31 \pm 0.07^*$	0.14 ± 0.03	≤ 0.10
TSS (mg/L)	18.4 ± 4.2	$62.7 \pm 9.8^*$	25.3 ± 5.1	≤ 25.0
BOD (mg/L)	1.9 ± 0.4	$4.8 \pm 1.1^*$	2.4 ± 0.5	≤ 3.0
E. coli (CFU/100mL)	42 ± 12	$310 \pm 58^*$	88 ± 19	0 (drinking)
Turbidity (NTU)	6.2 ± 1.1	$28.4 \pm 6.3^*$	9.7 ± 2.0	≤ 5.0 (drinking)

Agricultural Driver–Pollutant Correlations

Correlation coefficients between various agricultural intensity factors and water quality parameters are provided in table 3. The highest positive correlation was observed between fertilizer application and nitrate concentrations ($r = 0.87$, $p < 0.001$), similar to results obtained by Paudel and Crago (2021; Paudel & Crago, 2021). Turbidity and TSS correlated best among all water quality parameters, ($r = 0.91$, $p < 0.001$), confirming sediment resuspension as the key physical process connecting rainfall with water quality deterioration. Finally, DO and BOD were strongly negatively correlated ($r = -0.82$, $p < 0.001$), which confirmed the influence of biological oxygen consumption on low oxygen concentrations. Stronger correlation between livestock and E. coli abundance ($r = 0.68$, $p < 0.01$) suggested the importance of animal waste as one of the major sources of microbiological pollution.

Table 3: Pearson Correlation Coefficients between Agricultural Intensity Variables and Water Quality Parameters

Parameter Pair	Pearson r	p-value
Nitrate vs. Fertilizer Use	0.87	< 0.001
TSS vs. Rainfall Intensity	0.79	< 0.001
DO vs. BOD	-0.82	< 0.001
Phosphate vs. Algal Biomass	0.74	< 0.01
Turbidity vs. TSS	0.91	< 0.001
E. coli vs. Livestock Density	0.68	< 0.01
pH vs. Nitrate Load	-0.55	< 0.05

Mitigation Strategy Effectiveness

The relative effectiveness of common recommendations for mitigation along with some new strategies is shown in figure 2 below. Among the traditional options, the use of constructed wetlands proved the most effective approach (removal efficiency 50-85%) for removal of combined nitrogen, phosphorus, pathogens, and biological oxygen demand. Riparian buffer strips were able to provide a reduction of 40-70% for nutrients and sediments in cases where their widths exceeded 15 m next to stream edges. In the case of intensive crop production systems, application of advanced fertilizer application techniques showed an efficiency of 25-45%. AI-powered real-time monitoring systems, although not being able to reduce pollutants directly, added great value in terms of detecting exceedances and dynamic priority setting, as was mentioned by authors in (Sadulla, 2024; Guo et al., 2019).

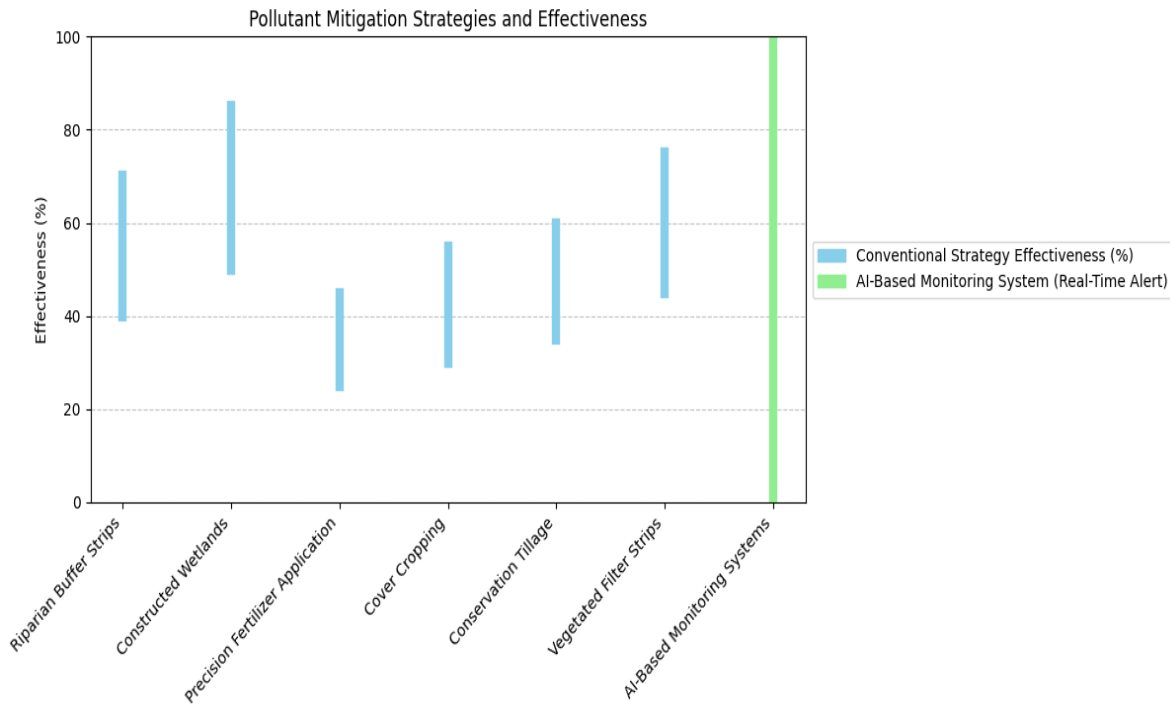


Figure 2: Comparative Effectiveness of Agricultural Runoff Mitigation Strategies

V. Discussion

These findings indicate that there is solid evidence that agriculture runoff is an essential factor that contributes to the decline in freshwater quality in the Noyyal River Basin. In particular, this issue poses the greatest ecological danger at times of maximum monsoon discharge. The phosphate, E. coli, and total suspended solids concentrations in the water are all above permissible levels at those times. Thus, there is

evidence that rainfall-induced transport of accumulated agrochemicals and manure is crucial in creating such pollution peaks. At the same time, the nitrate concentrations in the river water are still lower than those considered safe but the trends demonstrate that this situation may change with intensified farming practices and more frequent and intense monsoon rains. High correlations between turbidity and suspended solids, and between biochemical oxygen demand and oxygen depletion illustrate that sedimentation and organic matter loading constitute additional threats because these processes are linked. This implies decreased sunlight, substrate smothering, and reduced oxygen, thus threatening the existence of macroinvertebrates and fish in this river basin. Positive relationships between *E. coli* concentration and livestock density reveal the public health implications of agricultural runoff.

For management implications, this study finds that there is not a one-size-fits-all approach to mitigating different types of pollution from these watersheds. While constructed wetlands are an efficient method, they require a lot of space and maintenance, thus being difficult for small-scale farmers to utilize, while riparian buffer strips represent an economical choice as the first line of defense against sedimentation and nutrient export. Incorporation of AI into monitoring and management efforts represents a game-changer that will allow interventions to be made at crucial time points and locations. Nevertheless, the study is limited by a small number of observations collected through grab samples, uncertainties associated with large scales used in hydrology modeling, and lack of dissolved pesticides and metal content information. Further research should consider more detailed pollutant tracking and hydrological modeling to get better results on pollutant origin. The dataset created in this study represents a great achievement in terms of understanding agricultural pollution of semi-arid tropical river basins.

VI. Conclusion

In conclusion, this study has proven that the agricultural runoff significantly impacts the environmental condition of freshwater ecosystems in the Noyyal River Basin, Tamil Nadu, India. The most important findings of the study can be described as follows: (i) The monsoon runoff season is associated with statistically significant impairment of water quality in terms of all assessed indices, with the most notable exceedances of WHO limits occurring for phosphate, TSS, BOD, and *E. coli*; (ii) The Pearson's correlation revealed strong and statistically significant relationships between indicators of the intensity of agricultural activities and pollution levels, especially between fertilizers utilization and nitrates ($r = 0.87$, $p < 0.001$), precipitation intensity and TSS concentration ($r = 0.79$, $p < 0.001$), as well as BOD and DO depletion ($r = -0.82$, $p < 0.001$); (iii) The use of constructed wetlands and buffer strips appears to be the most versatile structural means of mitigation, whereas the artificial intelligence-based real-time monitoring represents the most promising technology. (iv) No single measure is capable of mitigating the impact of all forms of agricultural pollution, thus highlighting the necessity for comprehensive approaches.

The above results have immediate policy implications on how agricultural watersheds should be managed within semi-arid tropical environments. There is a need to enhance and enforce regulatory measures controlling the use of fertilizers, development of buffer zones, and proper management of animal waste, especially within watersheds supplying water used by rural populations. Investments in training farmers in precision agriculture methods would be a worthwhile venture.

Future studies must consider: (i) the use of event-based sampling to understand the dynamics of the first flush phenomena during the beginning of the monsoon runoff periods; (ii) the inclusion of dissolved pesticides and metals in water quality sampling schemes; (iii) the implementation of distributed hydrological models at very high resolutions in order to identify pollutants' sources within smaller sub-catchments; (iv) the evaluation of the effectiveness of AI-driven management tools under operational field conditions; and (v) the socio-economic analysis of the willingness to pay for watershed management and protection services. Filling these knowledge gaps will be critical in order to tackle the growing problem of agricultural pollution using regionally-tailored solutions.

Declarations

Conflict of Interest: The authors declare no conflict of interest.

Funding: This research received no external funding.

Dataset Description: The dataset supporting the findings of this study comprises seasonal water quality measurements (pH, DO, nitrate, phosphate, TSS, BOD, turbidity, E. coli) collected from 12 monitoring stations across the Noyyal River Basin, Tamil Nadu, India, during pre-monsoon, monsoon, and post-monsoon periods over two consecutive hydrological years.

References

- [1] Lisetskii, F. N., & Buryak, Z. A. (2023). Runoff of water and its quality under the combined impact of agricultural activities and urban development in a small river basin. *Water*, 15(13), 2443. <https://doi.org/10.3390/w15132443>
- [2] Delpla, I., Baurès, E., Jung, A. V., & Thomas, O. (2011). Impacts of rainfall events on runoff water quality in an agricultural environment in temperate areas. *Science of the total environment*, 409(9), 1683-1688. <https://doi.org/10.1016/j.scitotenv.2011.01.033>
- [3] Crampton, A., & Ragusa, A. T. (2014). Perceived agricultural runoff impact on drinking water. *Journal of Water and Health*, 12(3), 484-491. <https://doi.org/10.2166/wh.2014.212>
- [4] Sharma, K., Rajan, S., & Nayak, S. K. (2024). Water pollution: Primary sources and associated human health hazards with special emphasis on rural areas. In *Water resources management for rural development* (pp. 3-14). Elsevier. <https://doi.org/10.1016/B978-0-443-18778-0.00014-3>
- [5] Das, A. K., Gupta, N., Mahmood, T., Tripathy, B. C., Das, R., & Das, S. (2024). Assessing anthropogenic influences on the water quality of Gomati River using an innovative weighted fuzzy soft set-based water pollution rating system. *Discover Water*, 4(1), 73. <https://doi.org/10.1007/s43832-024-00136-3>
- [6] Qadri, R., & Faiq, M. A. (2019). Freshwater pollution: effects on aquatic life and human health. In *Fresh water pollution dynamics and remediation* (pp. 15-26). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-13-8277-2_2
- [7] Rey-Romero, D. C., Domínguez, I., & Oviedo-Ocaña, E. R. (2022). Effect of agricultural activities on surface water quality from páramo ecosystems. *Environmental Science and Pollution Research*, 29(55), 83169-83190. <https://doi.org/10.1007/s11356-022-21709-6>
- [8] Kumaraswamy, T. R., Javeed, S., Javaid, M., & Naika, K. (2019). Impact of pollution on quality of freshwater ecosystems. In *Fresh water pollution dynamics and remediation* (pp. 69-81). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-13-8277-2_5
- [9] Sadulla, S. (2024). State-of-the-art techniques in environmental monitoring and assessment. *Innovative Reviews in Engineering and Science*, 1(1), 25-29. <https://doi.org/10.31838/INES/01.01.06>
- [10] Sharpley, A. (2016). Managing agricultural phosphorus to minimize water quality impacts. *Scientia Agricola*, 73, 1-8. <https://doi.org/10.1590/0103-9016-2015-0107>
- [11] Paudel, J., & Crago, C. L. (2021). Environmental externalities from agriculture: evidence from water quality in the United States. *American Journal of Agricultural Economics*, 103(1), 185-210. <https://doi.org/10.1111/ajae.12130>
- [12] Stagnari, F., Jan, S., Angelica, G., & Michele, P. (2016). Sustainable agricultural practices for water quality protection. *Water stress and crop plants: a sustainable approach*, 1, 75-85. <https://doi.org/10.1002/9781119054450.ch6>
- [13] Razali, A., Syed Ismail, S. N., Awang, S., Praveena, S. M., & Zainal Abidin, E. (2020). The impact of seasonal change on river water quality and dissolved metals in mountainous agricultural areas and risk to human health. *Environmental Forensics*, 21(2), 195-211. <https://doi.org/10.1080/15275922.2020.1728434>

- [14] de Mello, K., Valente, R. A., Randhir, T. O., & Vettorazzi, C. A. (2018). Impacts of tropical forest cover on water quality in agricultural watersheds in southeastern Brazil. *Ecological Indicators*, 93, 1293-1301. <https://doi.org/10.1016/j.ecolind.2018.06.030>
- [15] Brooks, B. W., Lazorchak, J. M., Howard, M. D., Johnson, M. V. V., Morton, S. L., Perkins, D. A., ... & Steevens, J. A. (2016). Are harmful algal blooms becoming the greatest inland water quality threat to public health and aquatic ecosystems?. *Environmental toxicology and chemistry*, 35(1), 6-13. <https://doi.org/10.1002/etc.3220>
- [16] Udayakumar, R. (2024). Machine learning for public wellness: optimizing hygiene practices and pollution monitoring in smart cities. *Hygiene and Sanitation*, 103 (3), 216–222. <https://doi.org/10.47470/0016-9900-2024-103-3-216-222>
- [17] Singh, P. K., Kumar, U., Kumar, I., Dwivedi, A., Singh, P., Mishra, S., ... & Sharma, R. K. (2024). Critical review on toxic contaminants in surface water ecosystem: sources, monitoring, and its impact on human health. *Environmental Science and Pollution Research*, 31(45), 56428-56462. <https://doi.org/10.1007/s11356-024-34932-0>
- [18] Gunawardhana, W. D. T. M., Jayawardhana, J. M. C. K., & Udayakumara, E. P. N. (2016). Impacts of agricultural practices on water quality in Uma Oya catchment area in Sri Lanka. *Procedia food science*, 6, 339-343. <https://doi.org/10.1016/j.profoo.2016.02.068>
- [19] Guo, T., Gill, D., Johengen, T. H., & Cardinale, B. L. (2019). What determines the public's support for water quality regulations to mitigate agricultural runoff?. *Environmental Science & Policy*, 101, 323-330. <https://doi.org/10.1016/j.envsci.2019.09.008>
- [20] Rashid, M. K., Salman, I. R., Obaid, A. L., Hassan, S. A. D. H., Al-Musawi, M. R., & Al-Saady, M. (2024). Application of machine learning in predicting sources of water pollution in the Euphrates and Tigris rivers in Iraq. *International Journal of Aquatic Biology*, 12(6), 581-589. <https://doi.org/10.22034/ijab.v12i6.2421>