



Effects of Rice Farming Practices and Fertilizer Application on Water Quality of the Mahayahay-Kitcharao Small Reservoir Irrigation Project

Emmalyn E. Montiza^{1*}; Romell A. Seronay²

¹Graduate School, Caraga State University, Ampayon, Butuan City, Philippines

²Center for Research in Environmental Management and Eco-Governance, Caraga State University, 8600, Butuan City, Agusan del Norte, Philippines

*Corresponding Author

Received:- 18 April 2026/ Revised:- 29 April 2026/ Accepted:- 05 May 2026/ Published: 15-05-2026

Copyright © 2026 International Journal of Environmental and Agriculture Research

This is an Open-Access article distributed under the terms of the Creative Commons Attribution

Non-Commercial License (<https://creativecommons.org/licenses/by-nc/4.0>) which permits unrestricted

Non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract— This study examined fertilizer application practices and their association with nutrient concentrations in irrigation water of the Mahayahay–Kitcharao Small Reservoir Irrigation Project (KSRIP) in Agusan del Norte, Philippines, during the dry season. Nitrogen (N), phosphorus (P), and potassium (K) levels were assessed across upstream, midstream, and downstream locations using a descriptive-comparative design integrating survey data from 64 rice farmers and laboratory water analysis. Survey results showed 78.1% of farmers were ≥ 50 years old (mean 56.4 years), with average farming experience of 22.3 years; 79.7% were tenants, and 93.8% used only inorganic fertilizers, applied twice per season via broadcast method. Laboratory analysis revealed N concentrations of 0.0075 mg/L (upstream and midstream) and 0.3317 mg/L (downstream). P ranged from 0.1567 to 0.2800 mg/L, and K from 0.7833 to 0.8167 mg/L. Kruskal–Wallis tests showed no significant differences in N, P, or K among sites ($p > 0.05$). All N and P values were within DENR allowable limits for irrigation water (N: 14 mg/L; P: 1 mg/L). Potassium has no established regulatory standard. Despite intensive uniform fertilizer use, dry-season nutrient concentrations remained within regulatory thresholds without significant spatial variation. Continued monitoring and improved fertilizer management are recommended.

Keywords— irrigation water quality, nutrient accumulation, rice farming practices, fertilizer management, agricultural sustainability.

I. INTRODUCTION

Irrigation development is critical for increasing agricultural productivity and food security in developing countries [1]. In the Philippines, small reservoir irrigation systems stabilize crop production during dry seasons, but their long-term sustainability depends on responsible nutrient management [2]. Excessive or poorly timed fertilizer application can lead to nutrient losses through runoff and leaching, accumulating within irrigation systems [3]. Nitrogen, phosphorus, and potassium—the primary macronutrients in rice cultivation—are particularly concerning when applied in conventional flood-irrigated systems [4].

In Agusan del Norte, the Kitcharao Small Reservoir Irrigation Project (KSRIP) supplies irrigation water to approximately 550 hectares of farmland. As fertilizer use intensifies to meet production targets, assessing whether nutrient concentrations remain within regulatory limits (DENR Administrative Order 2016-08 and 2021-19 for Class C fresh surface waters) becomes essential. Dry-season conditions with reduced water volume may concentrate nutrients, potentially creating spatial differences among upstream, midstream, and downstream sections.

This study examines fertilizer application practices and their relationship to N, P, and K concentrations in irrigation water within the Mahayahay-KSRIP during the dry season, comparing spatial patterns and assessing compliance with national

standards. It was hypothesized that nutrient concentrations would increase progressively from upstream to downstream locations due to cumulative fertilizer inputs.

II. MATERIALS AND METHODS

2.1 Research Design and Locale:

A descriptive-comparative design was employed. The study was conducted in Kitcharao, Agusan del Norte, Philippines (fourth-class municipality, agriculture-dependent economy), focusing on the Mahayahay-KSRIP during the dry season.

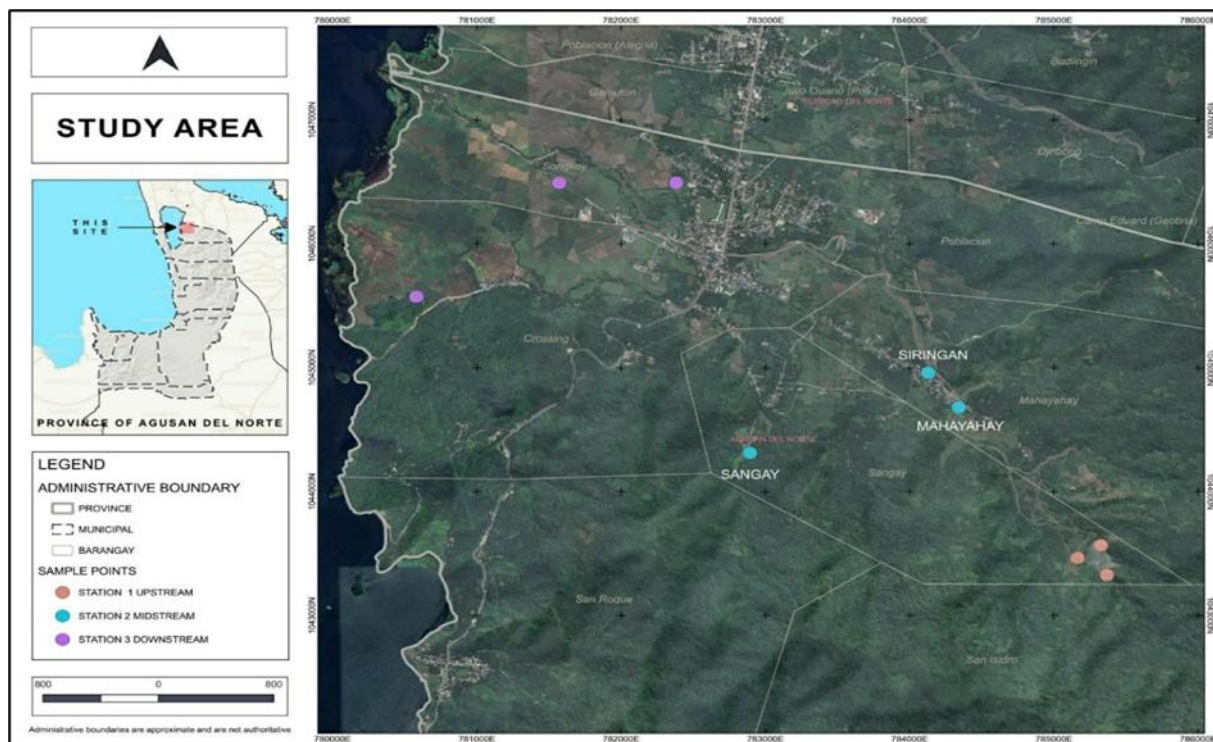


FIGURE 1: Location map of the study area

2.2 Participants and Sampling:

Sixty-four rice farmers actively cultivating within the irrigation service area were selected via convenience sampling. Inclusion criteria: residing within 2 km of the reservoir and farming with any fertilizer type.

2.3 Survey Instrument:

A structured questionnaire (face-to-face interviews, KoBoCollect mobile app) collected: (a) demographics (age, sex, education, land ownership, farm size, experience, location); (b) fertilizer practices (type, frequency, method, water source); (c) perceptions of water quality (5-point Likert scales). The questionnaire was validated by experts and pilot-tested (n=10).

2.4 Water Sampling and Laboratory Analysis:

Water samples were collected from three stations (upstream, midstream, downstream; ~1 km apart) during the dry season. Three replicate samples per station were taken every 2 hours, stored in insulated containers with ice, and transported to an accredited laboratory. Analytical methods: Nitrogen (Devarda Alloy Method), Phosphorus (Vanadomolybdate Method), Potassium (ICP-OES). Detection limits: N=0.015 mg/L; P=0.01–0.017 mg/L. Values below detection limit (BDL) were substituted with half the limit [5].

2.5 Data Analysis:

Descriptive statistics (frequencies, means, SD) characterized demographics and fertilizer practices. Chi-square tests (or Fisher's exact) assessed associations between location and fertilizer practices ($\alpha=0.05$). Kruskal–Wallis test compared nutrient concentrations across locations due to non-normal distribution and small sample size. Effect sizes: Cramér's V (chi-square) and eta-squared (η^2). Analyses used SPSS.

2.6 Regulatory Benchmark:

Measured concentrations were compared with DENR DAO 2016-08/2021-19 Class C standards for irrigation water: Nitrate (as NO₃-N) ≤14 mg/L; Phosphate (as PO₄) ≤1 mg/L; no standard for potassium.

III. RESULTS

3.1 Demographic Characteristics of Rice Farmers:

The demographic profile of rice farmers within the Mahayahay–Kitcharao Small Reservoir Irrigation Project (KSRIP) reveals a predominantly aging farming population. As shown in Table 1, 78.1% of respondents were 50 years of age or older, with a mean age of 56.4 years (SD = 8.7). Only 4.7% belonged to the 30–39 age cohort, indicating limited participation by younger generations in rice farming activities. This age distribution is consistent with national trends in Philippine agriculture, where outmigration of youth to urban centers has left an aging workforce in rural areas [6]. The near-equal sex distribution (51.6% male, 48.4% female) highlights the significant but often underrecognized role of women in rice production, particularly in labor-intensive activities such as transplanting, weeding, and fertilizer application [7].

Educational attainment among respondents was generally low: 42.2% completed only elementary education, 48.4% reached high school, and only 7.8% attended college. Limited formal education may influence farmers' decision-making processes regarding fertilizer selection, dosage, and timing, often leading to reliance on traditional practices or imitating neighbors rather than evidence-based nutrient management [8].

Land tenure status further contextualizes farming behavior. The majority of farmers (79.7%) were either tenants (42.2%) or renters (37.5%), with only 20.3% owning the land they cultivated. This predominance of tenancy arrangements may discourage long-term investments in soil and nutrient management, as the benefits of such investments often accrue to landowners rather than to tenants. Consequently, tenant farmers may prioritize short-term yield gains through intensive inorganic fertilizer use rather than adopting more sustainable but potentially costlier practices [9].

Farm size averaged 1.2 hectares (SD = 0.9), ranging from 0.25 to 5 hectares, confirming that farming operations are small-scale—typical of irrigated rice systems in the Philippines [10]. Mean farming experience was 22.3 years (SD = 10.2), with nearly 80% of respondents having more than a decade of experience. Such extensive experience suggests that current farming practices are deeply entrenched and may be resistant to change, even when alternative nutrient management strategies offer environmental benefits [11]. In terms of spatial distribution within the irrigation system, 48.4% of farms were located downstream, 31.3% midstream, and 20.3% upstream. This downstream concentration is particularly relevant because downstream sections of irrigation networks typically receive cumulative agricultural runoff and drainage from upstream areas, potentially influencing observed nutrient patterns [12].

TABLE 1
DEMOGRAPHIC PROFILE OF THE RESPONDENTS

Variable	Category	Frequency	Percentage (%)
Age (years)	30–39	3	4.7
	40–49	11	17.2
	50–59	26	40.6
	60 and above	24	37.5
	Total	64	100
Sex	Male	33	51.6
	Female	31	48.4
	Total	64	100
Educational Level	Elementary	27	42.2
	High School	31	48.4
	College	5	7.8
	Post-Baccalaureate	1	1.6
Total		64	100

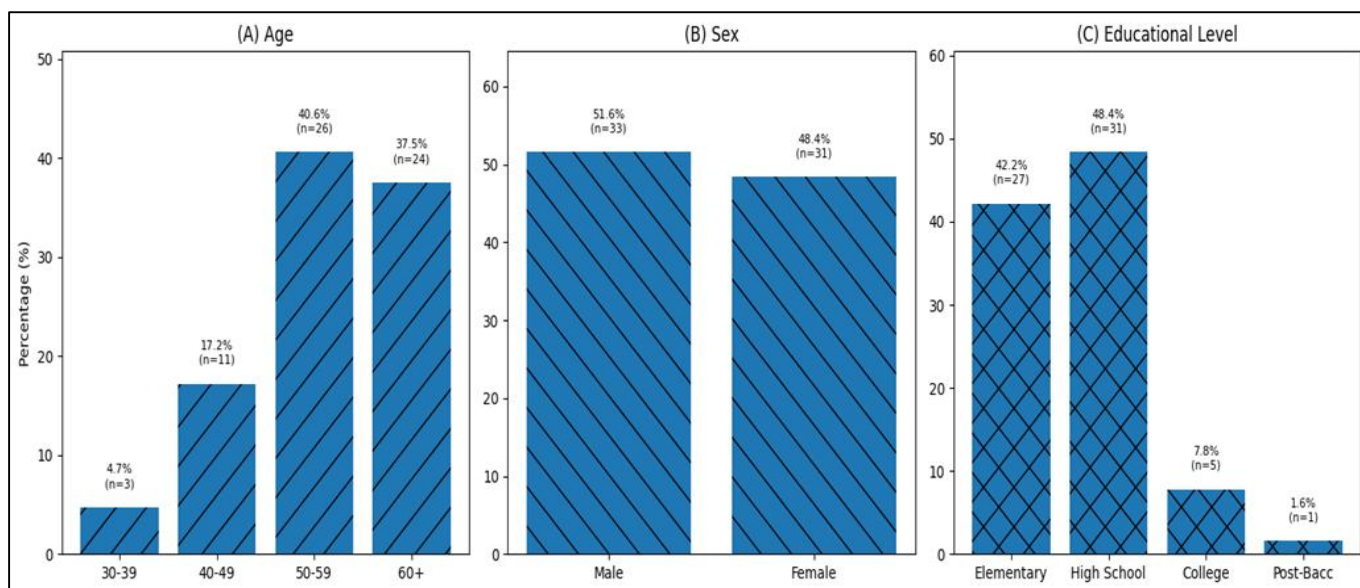


FIGURE 2: Distribution of respondents' demographic profile in terms of age, sex, and educational level

3.2 Fertilizer Application Practices:

Fertilizer application practices were remarkably uniform across all three spatial locations, indicating a standardized approach to nutrient management among farmers in the irrigation service area. Table 2 summarizes these practices. The vast majority of respondents (93.8%) relied exclusively on inorganic (chemical) fertilizers, with only 1.6% using organic fertilizers alone and 4.7% employing a combination of organic and inorganic inputs. The minimal adoption of organic or integrated nutrient management reflects a strong preference for readily available, fast-acting chemical fertilizers that provide immediate visual yield responses [8,11]. Statistical analysis using the chi-square test revealed no significant association between farm location and fertilizer type ($\chi^2 = 3.669$, $df = 4$, $p = 0.453$), confirming that fertilizer choice is spatially homogeneous throughout the irrigation system. This uniformity implies that any observed spatial variation in nutrient concentrations is unlikely to be driven by differences in fertilizer type and must instead be explained by hydrological transport processes or other environmental factors [13].

Regarding application frequency, 89.1% of farmers applied fertilizers twice per cropping season, 9.4% applied once, and only 1.6% applied more than twice. The mean number of applications per season was 1.92. This twice-per-season schedule aligns with recommended nutrient management guidelines for irrigated rice during the dry season, where split applications are designed to synchronize nutrient availability with critical crop growth stages—typically at transplanting or early tillering and again at panicle initiation [11]. However, the slight variation observed in the downstream section (16.1% applying once per season, 80.7% twice, and 3.2% more than twice) was not statistically significant ($\chi^2 = 4.959$, $df = 4$, $p = 0.292$). Nevertheless, even small differences in application timing can influence downstream nutrient transport in gravity-fed irrigation networks, as water flowing from upstream to downstream fields may carry dissolved or suspended nutrients from earlier applications [13].

All farmers (100%) reported using the broadcast method for fertilizer application, where granules are manually scattered over the flooded rice field surface. While broadcast application is labor-efficient and requires no specialized equipment, it is associated with lower nutrient use efficiency compared to deep placement or split-band methods. In flooded rice systems, broadcast-applied nitrogen, particularly urea, is susceptible to volatilization losses, while phosphorus may be fixed in soil or lost with surface runoff [14]. Furthermore, all farmers depended exclusively on the small reservoir (dam) as their sole source of irrigation water. This reliance means that water is recirculated within the system, and any nutrients not taken up by crops can remain in the irrigation network and be transported downstream. The combination of broadcast application, exclusive reservoir water use, and gravity-fed flow creates conditions conducive to the redistribution of nutrients within the irrigation system, making spatial monitoring particularly important.

TABLE 2
FERTILIZER TYPE USAGE BY LOCATION IN THE IRRIGATION SYSTEM

Location	Inorganic Only	Organic Only	Combination	Total
Upstream	13 (100.0%)	0 (0.0%)	0 (0.0%)	13
Midstream	18 (90.0%)	1 (5.0%)	1 (5.0%)	20
Downstream	29 (93.5%)	0 (0.0%)	2 (6.5%)	31
Total	60 (93.8%)	1 (1.6%)	3 (4.7%)	64

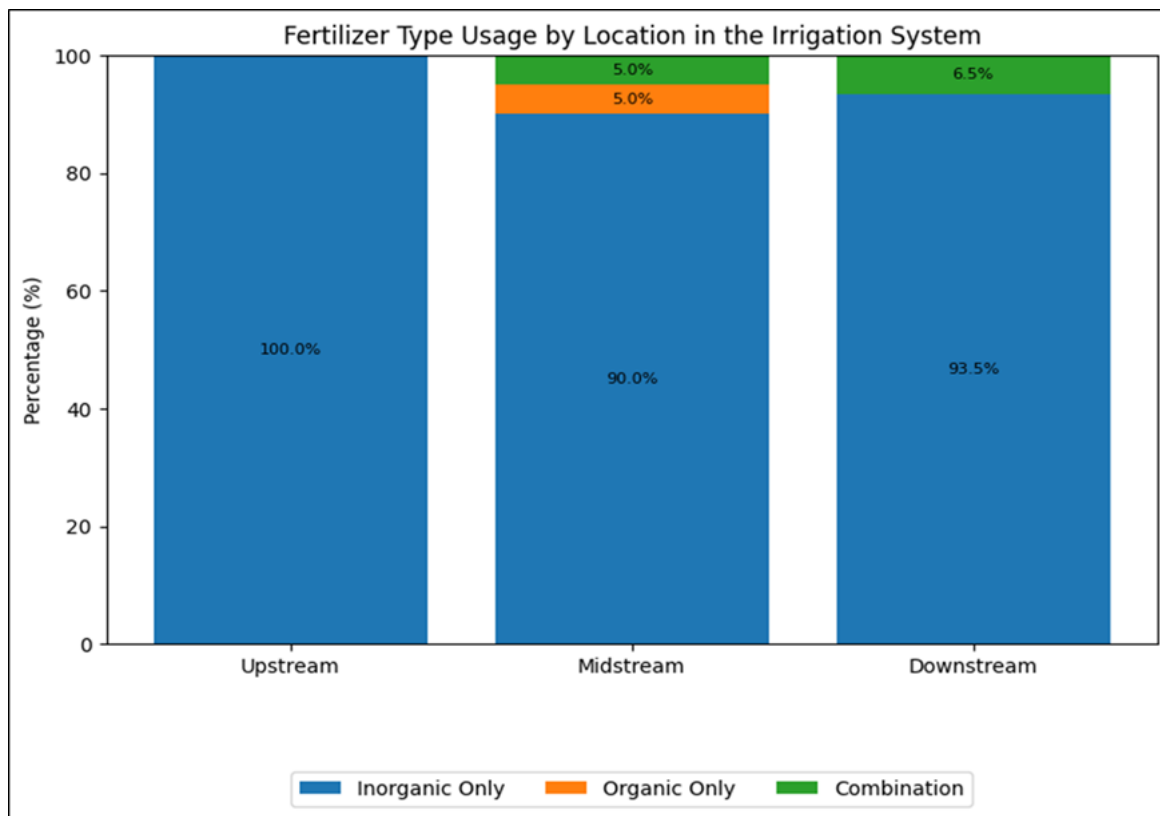


FIGURE 3: Distribution of fertilizer type usage across irrigation system locations

3.3 Nutrient Concentrations Across Locations:

Table 3 presents the mean concentrations of nitrogen (N), phosphorus (P), and potassium (K) measured at upstream, midstream, and downstream sampling locations during the dry season. Each location was sampled in triplicate (n = 3 per location). Nitrogen concentrations were identical and minimal at upstream and midstream locations (0.0075 mg/L), which corresponds to half of the laboratory detection limit (BDL substitution). The presence of BDL values upstream and midstream suggests that nitrogen inputs from fertilizer applications in these upper sections were either rapidly taken up by crops, lost to the atmosphere via volatilization, or not yet transported at the time of sampling. In contrast, the downstream location showed a substantially higher mean nitrogen concentration of 0.3317 mg/L, with individual sample values ranging from below detection (0.0075 mg/L) to 0.98 mg/L. This nearly 44-fold increase in mean concentration from upstream to downstream (0.0075 → 0.3317 mg/L) is descriptively notable, suggesting a potential accumulation trend. One possible explanation is that nitrogen—particularly in nitrate form—is highly mobile in water and can be transported from upstream and midstream fields to downstream sections through irrigation flow and field drainage [3,13]. However, the large standard deviation downstream (SD = 0.5615) indicates high variability among replicate samples, which may reflect intermittent transport processes or localized input events.

Phosphorus concentrations showed moderate variability without a consistent spatial trend. The highest mean concentration was observed downstream (0.2800 mg/L), followed by upstream (0.2533 mg/L) and midstream (0.1567 mg/L). The midstream location recorded the lowest minimum value (0.01 mg/L), while both midstream and downstream had maximum values of 0.36 mg/L and 0.82 mg/L, respectively. Phosphorus is generally less mobile than nitrogen in soil-water systems because it tends to adsorb to soil particles and is transported primarily with sediment rather than in dissolved form [13]. Therefore, the presence

of phosphorus in irrigation water may be more closely associated with soil erosion or suspended solids rather than direct leaching. The lack of a clear spatial gradient suggests that phosphorus transport is patchy and influenced by local factors such as field slope, soil texture, and recent tillage or irrigation events.

Potassium concentrations remained relatively stable across all three locations: upstream (0.7833 mg/L), midstream (0.8167 mg/L), and downstream (0.8100 mg/L). The coefficients of variation were moderate upstream (25.1%) and midstream (28.8%) but very low downstream (5.7%), indicating that potassium distribution was most uniform in the lower section of the irrigation system. Potassium is known to be less susceptible to leaching compared to nitrogen because it is retained by cation exchange sites in soil [11]. The stability of potassium concentrations across locations suggests that fertilizer-derived potassium is either efficiently taken up by crops or retained within soil profiles, with minimal transport through irrigation water.

Importantly, when compared with the regulatory standards established by the Philippine Department of Environment and Natural Resources (DENR) for Class C fresh surface waters designated for irrigation (DENR Administrative Order 2016-08 and 2021-19), all measured nutrient concentrations were well within allowable limits. The DENR maximum allowable limit for nitrate (as NO₃-N) is 14 mg/L—approximately 42 times higher than the highest observed nitrogen concentration (0.98 mg/L downstream). Similarly, the DENR limit for phosphate (as PO₄) is 1 mg/L, which exceeds all measured phosphorus values. Potassium has no specific regulatory threshold for irrigation water. Therefore, from a regulatory perspective, the irrigation water quality during the dry-season sampling period remained acceptable for agricultural use.

TABLE 3
DESCRIPTIVE STATISTICS OF NUTRIENT CONCENTRATIONS BY LOCATION (MG/L)

Location	Nutrient	n	Mean	SD	Minimum	Maximum
Upstream	Nitrogen	3	0.0075	0	0.0075	0.0075
	Phosphorus	3	0.2533	0.1361	0.1	0.36
	Potassium	3	0.7833	0.1966	0.56	0.93
Midstream	Nitrogen	3	0.0075	0	0.0075	0.0075
	Phosphorus	3	0.1567	0.1818	0.01	0.36
	Potassium	3	0.8167	0.2354	0.59	1.06
Downstream	Nitrogen	3	0.3317	0.5615	0.0075	0.98
	Phosphorus	3	0.28	0.4677	0.01	0.82
	Potassium	3	0.81	0.0458	0.76	0.85

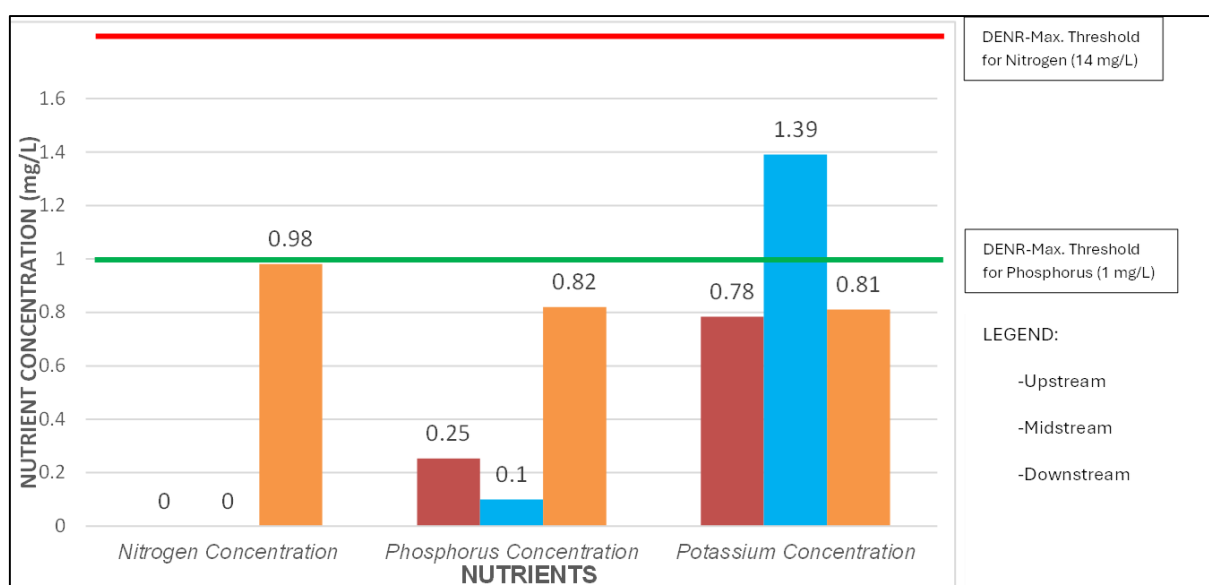


FIGURE 4: Spatial Comparison of N, P, and K Concentrations in Irrigation Water with DENR Regulatory Thresholds

3.4 Statistical Comparison of Nutrient Concentrations:

To determine whether the observed descriptive differences in nutrient concentrations among upstream, midstream, and downstream locations were statistically significant, the Kruskal–Wallis test was employed. This non-parametric test was chosen because of the small sample size ($n = 3$ per location) and the non-normal distribution of nutrient data, as evidenced by the presence of BDL values and high variance in some groups. Table 4 presents the results.

For nitrogen, the Kruskal–Wallis H statistic was 2.000 with 2 degrees of freedom, yielding a p-value of 0.368. Since this p-value exceeds the conventional significance level of $\alpha = 0.05$, the null hypothesis of no difference in nitrogen concentrations among the three locations cannot be rejected. In other words, despite the descriptive 44-fold increase in mean concentration from upstream to downstream, the difference was not statistically significant given the current sample size and data variability. For phosphorus, the H statistic was 0.655 ($df = 2, p = 0.721$), and for potassium, the H statistic was 0.089 ($df = 2, p = 0.957$). Both p-values were substantially above 0.05, indicating no statistically significant differences in phosphorus or potassium concentrations across locations.

The absence of statistical significance does not necessarily mean that no spatial pattern exists. Rather, it suggests that with only three replicate samples per location and the high within-location variability (particularly for nitrogen and phosphorus downstream), the study had limited statistical power to detect small-to-moderate differences. As noted by Egbueri et al. [15], descriptive spatial trends in small irrigation systems may only become statistically detectable after prolonged monitoring or increased sampling frequency. Therefore, while the current results indicate statistical uniformity, the descriptive pattern—especially the downstream nitrogen increase—warrants continued observation with a larger and more temporally replicated sampling design.

Effect sizes were also considered. For the non-significant Kruskal–Wallis tests, eta-squared (η^2) values were small ($\eta^2 < 0.05$ for all nutrients), indicating that location explained very little of the total variance in nutrient concentrations. This reinforces the conclusion that, during the dry-season sampling period, spatial location within the irrigation system was not a meaningful predictor of nutrient levels.

TABLE 4
KRUSKAL–WALLIS TEST RESULTS FOR NUTRIENT CONCENTRATIONS BY LOCATION

Nutrient	H Statistic	df	p-value	Decision
Nitrogen	2	2	0.368	Not Significant
Phosphorus	0.655	2	0.721	Not Significant
Potassium	0.089	2	0.957	Not Significant

3.5 Farmers' Perceptions of Water Quality:

Farmers' perceptions of irrigation water quality were assessed using a five-point Likert scale, with results summarized in Table 5. The overall mean perception score was 3.81 ($SD = 0.42$), corresponding to a verbal interpretation of "Good" and a qualitative rating of "High" (based on the scale where 3.41–4.20 = Good/High). This indicates that, on average, farmers considered the irrigation water suitable for agricultural purposes.

When asked specifically about observable changes in water quality associated with fertilizer use, the mean score was 3.72, suggesting that farmers do recognize some degree of water quality alteration linked to their nutrient management practices. Commonly cited observations included occasional greenish coloration of water (suggesting possible algal growth), turbidity after heavy irrigation events, and a perceived "fertilizer smell" in drainage canals. However, these perceptions were not uniform across all respondents; downstream farmers were more likely to report visible changes than upstream farmers, which aligns with the descriptive increase in nitrogen concentration observed downstream.

Regarding the statement "Fertilizer application has affected the quality of irrigation water," the mean score was 3.68, reflecting moderate agreement. This suggests that while farmers acknowledge a connection between their practices and water quality,

they do not perceive the impact as severe. Importantly, when asked whether water quality changes have affected crop health or yield, the mean score dropped to 3.45, indicating that farmers believe any water quality alterations have had only minor or inconsistent effects on their agricultural productivity.

The convergence between farmers' perceptions (generally good water quality) and laboratory measurements (nutrient levels within regulatory limits) is notable. However, perceptual data should be interpreted with caution, as farmers may not detect subtle nutrient increases that do not produce visible symptoms such as algal blooms, fish kills, or crop damage [16]. Furthermore, the "shifting baseline syndrome" [17] may operate in this community: farmers who have used the irrigation system for decades may perceive current water quality as normal compared to past conditions, even if gradual nutrient enrichment has occurred. Therefore, while perception data provide valuable contextual insight, they should complement rather than replace empirical monitoring.

TABLE 5
FARMERS' FERTILIZER USAGE PRACTICES

Statement	Mean	Interpretation
Regular use of chemical fertilizers	3.98	High
Preference for organic fertilizers	3.16	Moderate
Application follows guidelines	4	High
Mixing fertilizers for yield	3.94	High
Training on fertilizer application	3.95	High
Overall Mean	3.81	High

IV. DISCUSSION

The demographic profile of farmers (aging, low formal education, predominantly tenants) aligns with national trends in Philippine agriculture [6,7] and may influence fertilizer decisions, favoring conventional inorganic inputs over integrated nutrient management [8]. The near-universal reliance on inorganic fertilizers (93.8%) and broadcast application, combined with sole dependence on reservoir irrigation, creates conditions where unabsorbed nutrients can be transported within the irrigation network [3,9].

Despite intensive and uniform fertilizer practices, nutrient concentrations did not differ significantly across upstream, midstream, and downstream locations. This spatial uniformity may be attributed to: (a) relatively short distance between sampling points (~2 km total), limiting cumulative nutrient enrichment; (b) dry-season water management practices that may reduce runoff connectivity; (c) the small reservoir acting as a buffer or mixing zone. However, the descriptive increase in downstream nitrogen (0.0075 → 0.3317 mg/L), though not statistically significant with current sample size (n=3 per location), suggests a potential accumulation trend that warrants further investigation with larger replication [10].

All measured N and P concentrations were well within DENR Class C standards for irrigation water (N: 14 mg/L; P: 1 mg/L), indicating that current fertilizer practices, as of the dry-season sampling, have not caused regulatory exceedances. Potassium levels, for which no standard exists, were stable. These findings are consistent with studies in other irrigated rice systems where nutrient concentrations remained below thresholds under moderate fertilizer inputs [11,12].

Farmers' perception that water quality is "Good" (mean 3.81/5) aligns with laboratory results, though perceptual data should be interpreted cautiously as farmers may not detect subtle nutrient changes [13]. The contrast between observed downstream nitrogen increase (descriptive) and non-significant statistical difference highlights the need for larger sample sizes and seasonal monitoring to detect emerging trends.

V. CONCLUSION

Rice farming in the Mahayahay-KSRIP is characterized by experienced, older, smallholder tenants who rely uniformly on inorganic fertilizers applied twice per season via broadcast method. During the dry-season sampling period, nitrogen, phosphorus, and potassium concentrations did not differ significantly among upstream, midstream, and downstream locations,

and all measured N and P levels complied with DENR irrigation water standards. Therefore, the null hypothesis of no significant difference in nutrient concentrations across locations could not be rejected for any of the three nutrients. Although a descriptive increase in downstream nitrogen was observed, it was not statistically significant. The absence of spatial differentiation suggests that current fertilizer practices have not led to measurable nutrient accumulation within the irrigation network under dry-season conditions. However, continued monitoring is essential to detect potential long-term changes. Current fertilizer practices, under dry-season conditions, do not appear to cause regulatory exceedances, but continued monitoring is warranted.

VI. RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed.

First, regular seasonal monitoring of nitrogen, phosphorus, and potassium should be conducted during both dry and wet seasons to capture temporal variations in nutrient concentrations, as the current study was limited to dry-season sampling only.

Second, the sampling design should be strengthened by increasing the number of replicates and sampling sites to improve statistical power and enable detection of subtle but meaningful spatial differences in nutrient distribution.

Third, agricultural extension services should promote efficient fertilizer management practices among farmers, particularly split-timed application and avoidance of broadcast application before heavy irrigation events, to reduce nutrient runoff while maintaining crop yields.

Fourth, farmers should be encouraged to adopt integrated nutrient management approaches that combine inorganic fertilizers with organic amendments such as compost or rice straw, as this can improve soil nutrient retention and reduce reliance on chemical inputs.

Fifth, continuous farmer education programs should be implemented to raise awareness of DENR water quality standards and the environmental consequences of excessive fertilizer use, using participatory methods tailored to farmers' low formal education levels.

Sixth, collaboration among farmers, the National Irrigation Administration, and the municipal government should be formalized to establish a community-based water quality monitoring program, ensuring sustained data collection and shared accountability.

Finally, further research should examine nutrient dynamics across multiple cropping seasons and include additional water quality parameters such as dissolved oxygen and turbidity to provide a more comprehensive environmental assessment.

ACKNOWLEDGMENT

The author thanks the panel members for their critiques, Mr. Michael John Asis for statistical assistance, and the rice farmers of Kitcharao for their participation.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this research paper.

REFERENCES

- [1] Shah, S. S., Van Dam, J., Singh, A., & [Additional authors if available]. (2024). Impact of irrigation, fertilizer, and pesticide management practices on groundwater and soil health in the rice–wheat cropping system—A comparison of conventional, resource conservation technologies and conservation agriculture. *Environmental Science and Pollution Research*. <https://doi.org/10.1007/s11356-024-35661-0>
- [2] Dong, Z., Liu, Y., Li, M., & [Additional authors if available]. (2023). Effect of different NPK fertilization timing sequences management on soil-petiole system nutrient uptake and fertilizer utilization efficiency of drip irrigation cotton. *Scientific Reports*, 13(1). <https://doi.org/10.1038/s41598-023-40620-9>
- [3] Santiago-Arenas, R., Dhakal, S., Ullah, H., Agarwal, A., & Datta, A. (2021). Seeding, nitrogen and irrigation management optimize rice water and nitrogen use efficiency. *Nutrient Cycling in Agroecosystems*, 120(3), 325–341. <https://doi.org/10.1007/s10705-021-10153-6>
- [4] Mahajan, M., Singh, A., Singh, R. P., & [Additional authors if available]. (2023). Understanding the benefits and implications of irrigation water and fertilizer use on plant health. *Environment, Development and Sustainability*, 26(8), 20561–20582. <https://doi.org/10.1007/s10668-023-03490-9>
- [5] United States Environmental Protection Agency. (2006). *Data quality assessment: Statistical methods for practitioners* (EPA QA/G-9S). USEPA.

- [6] Moya, P., Kajisa, K., Barker, R., & [Additional authors if available]. (2015). Changes in rice farming in the Philippines: Insights from five decades of a household-level survey. *Philippine Journal of Crop Science*, 40(2), 1–14.
- [7] Paris, T. R., Singh, A., Luis, J., & Hossain, M. (2009). Labour outmigration, livelihood of rice farming households and women left behind: A case study in Eastern Uttar Pradesh. *Economic and Political Weekly*, 44(13), 61–67.
- [8] Awotoye, O. O. (2017). Effects of agricultural runoff on water quality. *Applied Water Science*, 7(2), 837–846. <https://doi.org/10.1007/s13201-015-0327-1>
- [9] 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.
- [10] Egbueri, J. C., Ezugwu, C. K., Ameh, P. D., & Unigwe, C. O. (2020). Seasonal influence on nutrient concentration in agricultural water sources. *Environmental Earth Sciences*, 79(9), 1–13. <https://doi.org/10.1007/s12665-020-09005-4>
- [11] Cruz, R. V. O., Santos, J. A., & Delos Reyes, R. A. (2020). Spatial variability of nutrient concentrations in irrigation canals of Mindanao, Philippines. *Asian Journal of Water, Environment and Pollution*, 17(2), 21–30.
- [12] Castillo, G. T., Palao, L. K., & Flores, M. J. (2016). Agricultural nutrient runoff and water quality in irrigated rice areas of Central Luzon, Philippines. *Philippine Journal of Science*, 145(4), 387–398.
- [13] Whyte, K. P. (2013). On the role of traditional ecological knowledge as a collaborative concept: A philosophical study. *Ecological Processes*, 2(7), 1–12. <https://doi.org/10.1186/2192-1709-2-7>.