Assessing Nitrate and Phosphate Contaminants in Agricultural Soils and Groundwater: Implications for MLGU Restoration and Eutrophication Management

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Abstract

Effective crop production depends on a sufficient supply of nutrients through fertilizer application to achieve optimal yield. However, farmers must properly manage soil nutrients to meet the fertility needs of crops without negatively impacting the quality of precious water resources. This study evaluated nitrate and phosphate levels in water and soil in Barangays Mangayang and Gabut, Dupax del Sur, Nueva Vizcaya, to understand the impact of fertilizer and agrochemical use in agriculture. The study revealed that nitrate concentrations in irrigation water were low, with mean values of 0.20275 mg/L in Mangayang and 0.41250 mg/L in Gabut, both within the acceptable limit of 7 mg/L, and showed no significant differences ($p > 0.05$). Soil nitrate levels were also low, with mean values of 0.57640 mg/kg in Mangayang and 0.31300 mg/kg in Gabut, falling below the recommended range of 10-50 mg/kg. Phosphate concentrations in water exceeded acceptable limits, with mean values of 1.5830 mg/L in Mangayang and 1.5415 mg/L in Gabut. In contrast, soil phosphate levels were low, with mean values of 6.1660 mg/kg in Mangayang and 1.6000 mg/kg in Gabut, with no significant differences ($p > 0.05$). In conclusion, nitrate levels were within safe limits, but elevated phosphate concentrations risk water quality and ecosystems. The findings suggest that improved fertilizer management practices, including precision agriculture and reduced nutrient runoff, are essential to mitigate environmental impact and ensure sustainable agricultural practices. Regular monitoring and farmer education are crucial to balancing crop production and environmental protection.

Keywords: agrochemicals, biogeological processes, fertilizer application, leaching events, sustainable farming

1. Introduction

Nueva Vizcaya is recognized as Cagayan Valley's vegetable capital and is poised to become the country's next "salad bowl" (Department of Agriculture, 2011). Dupax del Sur stands out as a leading producer of vegetables, with many families relying on rice farming, onion planting, and vegetable cultivation for their income. Consequently, farmers often resort to fertilizers to enhance crop yields. However, the continuous use of inorganic fertilizers has led to significant soil and water pollution. Excessive fertilizer application can contaminate groundwater, with farmlands being a primary source of pollutants like nitrates and phosphates that accumulate in the soil and water systems (Lemma *et al*., 2017). These surplus nutrients are not fully utilized by plants, leading to runoff that carries them into nearby water sources (Gächter *et al*., 2004). Mussa *et al*. (2009) noted that such nutrient excesses from fertilizers and household waste disrupt biogeochemical cycles, contributing to soil contamination and increasing the risk of eutrophication, which threatens aquatic ecosystems. The environmental impact of chemical fertilizers is profound; they degrade soil fertility and impair water quality, posing risks to both human health and the environment (Patey *et al*., 2008). Nitrates and phosphates are among the most pervasive freshwater pollutants globally (Khan and Ghouri, 2011), originating from various sources including agricultural runoff, wastewater, and septic systems. While organic fertilizers are increasingly used to boost crop yields, their application can also lead to serious environmental issues like leaching and eutrophication (Esteller *et al*., 2009; Guo *et al*., 2010). Eutrophication occurs when water bodies receive excessive nutrients, leading to algal blooms that block sunlight and deplete oxygen as they decay, ultimately causing harm to aquatic life (Ghosh, 2021). Studies in various countries have highlighted the global nature of nitrate and phosphate pollution, emphasizing the need for awareness and collective action (Fried *et al*., 2003). In the Philippines, research on nitrate pollution is limited. Bednarek *et al*. (2014) found high nitrite concentrations in water sources in Laguna due to factors like defective sewage systems and poorly constructed wells. This contamination poses significant risks to communities reliant on these water sources. Similarly, Bernal and Plata (2022) reported high levels of ammonia and inorganic phosphate in Laguna Lake due to aquaculture activities.

Despite existing studies elsewhere, there is a notable lack of research on nitrate accumulation in Dupax del Sur's farmlands and its environmental implications. Eutrophication and soil degradation are pressing issues in the area, as evidenced by the nutrient status map for nitrate and phosphates illustrated by the Department of Agriculture (2017a). These issues are primarily driven by leachate leakage, agricultural runoff, and urbanization. These challenges underscore the need for targeted studies, such as this one, to identify contamination pathways and provide actionable insights for environmental restoration and eutrophication control. The insufficient monitoring of nitrate and phosphate pollution in the Philippines is concerning, emphasizing the need for comprehensive data to inform sustainable environmental management practices (Oremo *et al*., 2021).

The findings of this study are expected to bring significant environmental and community benefits by highlighting the risks associated with prolonged use of inorganic fertilizers and encouraging farmers to adopt sustainable alternatives. Local governments can utilize these insights to raise awareness about nutrient pollution, implement restoration efforts, and establish eutrophication control programs. Furthermore, the study lays a foundation for future research on nitrate and phosphate accumulation in soil and water reservoirs, enhancing the understanding of nutrient pollution. This aligns with Saint Mary's University's Project WEALTH VERSION 2.0, which focuses on risk reduction and mitigation, promoting sustainable farming and environmental conservation. The study also supports key United Nations Sustainable Development Goals (SDGs): SDG 2 (Zero Hunger), by promoting food security and sustainable agriculture; SDG 6 (Clean Water and Sanitation), by ensuring sustainable water management; SDG 12 (Responsible Consumption and Production), by fostering responsible resource use; and SDG 13 (Climate Action), by addressing climate change impacts (United Nations, 2023).

The study, conducted in Dupax del Sur, Nueva Vizcaya, aimed to assess nitrate and phosphate concentrations in farm soil and irrigation water. It sought to address critical research questions, including the levels of these nutrients in groundwater and farmland soil across various study sites, and whether significant differences exist in nutrient levels among the sampled locations. The research aimed to propose actionable recommendations for community-specific restoration efforts and eutrophication control programs. Assessing nutrient concentrations in soil and water is essential for understanding the environmental implications of current agricultural practices in the region. By addressing nutrient pollution, the study provides strategic insights into sustainable resource management, supporting the long-term health of local ecosystems and communities.

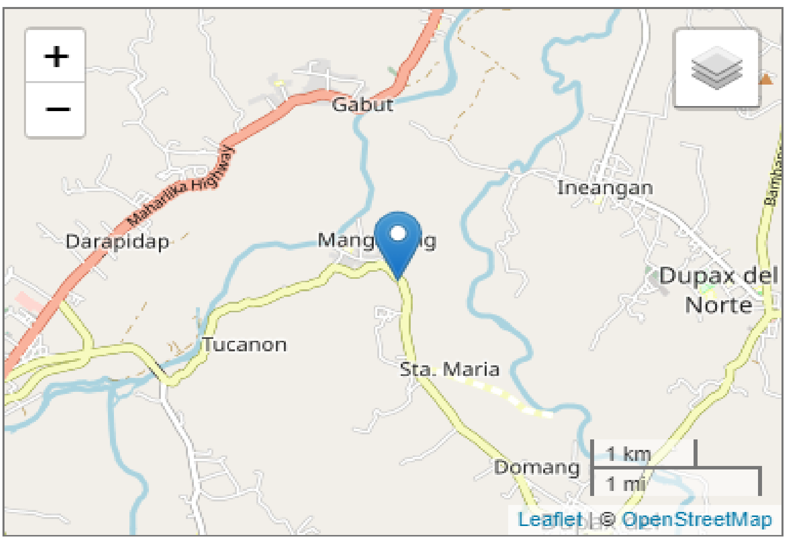
2. Methodology

2.1 Research Design

The study utilized a quasi-experimental research design to assess and compare the nitrate and phosphate concentrations in farmland soil and groundwater in two selected barangays in Dupax del Sur, Nueva Vizcaya.

2.2 Study Site and Sample Collection

Soil and water samples were collected from four farms: three located in Barangay Mangayang and one in Barangay Gabut, as shown in Figure 1. These two neighboring barangays are separated by the Magat River, which flows between them and is surrounded by hectares of farmland owned by the residents of both barangays. Farming is the primary livelihood for most families, with rice being the main crop. The selected barangays were specifically chosen for their proximity to rice fields, ensuring that the agro-ecosystems in these areas were relevant to the study.



Barangay Mangayang
Coordinates:
16.3089, 121.0731 (16° 19' North, 121° 4' East)
Estimated elevation above sea level:
376.9 meters (1,236.5 feet)

Barangay Gabut
Coordinates:
16.3252, 121.0660 (16° 20' North, 121° 4' East)
Estimated elevation above sea level
365.1 meters (1,197.8 feet)

Figure 1. Location of the study sites

2.2.1 Mangayang and Gabut Farmers’ Profile

The farmers from Mangayang and Gabut are members of the Mangayang-Iñeangan-Duppes Irrigation Association, Inc. and Gabut Farmers Rice and Onion Growers Association, respectively. The farmlands cover an area ranging from 0.8 hectares (8,000 sq. meters) to 1.5 hectares (15,000 sq. meters). In Mangayang, the common crop planted is sweet potato, locally known as camote, alongside rice on two farms and corn on one farm. The only farm visited in Gabut is planted with squash and red onions. To enhance plant growth, all sampled farmers commonly use urea fertilizer, recognized as one of the most widely used chemical nitrogen fertilizers (Zhengzhou, 2019). Another growth booster employed is Triple 14 fertilizer, which contains an equal NPK ratio of 14% nitrogen, 14% phosphorus, and 14% potassium, with the remaining percentage comprising other essential nutrients for plant growth (WhyFarmit, 2023). On average, six to seven bags of fertilizer are applied per hectare of farmland.

The plant growers are hesitant to use organic fertilizers, particularly the vermicompost provided free by the Department of Agriculture. Vermicompost is the product of the decomposition process using various species of earthworms, which creates a mixture of decomposing vegetable or food waste, bedding materials, and vermicast (Kaur, 2020). Based on the farmers' past experiences, the earthworms, which excrete the vermicast, eventually destroyed their crops. Throughout the year, the farmers have two cropping seasons or cycles, allowing time for the soil to sustain or restore its productivity. To supplement their farm produce, one farmer operates a piggery, while another takes care of ducks.

2.2.2 Water Sample Collection

In this study, six groundwater samples were collected—four from Barangay Mangayang and two from Barangay Gabut—following rigorous sampling protocols to ensure data integrity. Each borehole was pumped for three minutes to purge stagnant water, and sample bottles were rinsed three times with well water to eliminate potential contaminants. The samples were stored in clean polyethylene bottles and preserved with 1 mL of 96% sulfuric acid per 500 mL to stabilize nitrate-nitrogen levels. They were then transported in an icebox maintained at approximately 4°C to minimize biological activity and chemical changes (US Environmental Protection Agency, 2016).

2.2.3 Farm Soil Sample Collection

Soil samples were collected using a manual collection method designed to obtain representative surface and shallow subsurface samples from the study sites. Initially, the surface layer was removed from the sampling plot to expose the underlying soil. A V-shaped cut was then made to a depth of 15 cm using a spade, allowing for the collection of thick slices of soil from the exposed face of the cut. These slices were placed in a clean container, where they were thoroughly mixed to ensure homogeneity. Any foreign materials, such as roots, stones, pebbles, and gravel, were carefully removed to prevent contamination. To reduce the bulk of the sample to approximately one kilogram, quartering was employed: the mixed sample was divided into four equal parts, with two opposite quarters discarded and the remaining two quarters remixed. This process was repeated until the desired sample size was achieved. Finally, the collected samples were placed in clean polyethylene bags, which were labeled with essential information, including the sampling location and collection date, ensuring proper identification and traceability for subsequent analysis (Acharya, 2018).

2.2.4 Calibration of Standard Curve

To prepare the calibration curve for nitrate concentration, a stock nitrate solution was made by dissolving 0.7218 g of potassium nitrate (dried at 105°C for 24 hours) in 1 L of distilled water, yielding a concentration of 100 mg NO3-N/L (1 mL contains 100 µg of NO3-N). Standards ranging from 0 to 7 mg NO3-N/L were created through appropriate dilutions of the stock solution and analyzed alongside the samples to establish a linear calibration curve relating absorbance to nitrate concentration. The absorbance readings at 220 nm and 275 nm were recorded in triplicates and averaged to calculate the corrected absorbance reading by finding the difference between the two readings (Parvez *et al*., 2014).

For phosphate analysis, a 300 mg/L stock solution of potassium phosphate monobasic (KH2PO4) was prepared by dissolving 0.220 g in a 500 mL volumetric flask with distilled water. From this stock, 10 mL was diluted in various flasks (200 mL, 250 mL, 500 mL, and 1 L) to create standard solutions of 15 mg/L, 12 mg/L, 6 mg/L, and 3 mg/L, respectively. Additionally, 15 mL of the stock solution was diluted to obtain a 4.5 mg/L standard. A standard curve was constructed based on the absorbance readings of the phosphate standards. The equation of the trendline was used in determining the phosphate concentration of unknown samples. These standards facilitated accurate quantification of phosphate concentrations in the samples (Parvez *et al.*, 2014).

2.3. Data Gathering Procedure

2.3.1 Nitrate Assessment of Water and Farm Soil Samples

Nitrate concentration ([NO3-N mg/L]) was determined using the ultraviolet spectrophotometric method (Eaton *et al.*, 2005), employing a UV-VIS Spectrophotometer (Biobase Bk-UV1000) at wavelengths of 220 nm and 275 nm. Measurements at these wavelengths correct for interference from dissolved organic matter, which absorbs at both wavelengths, while nitrate is primarily absorbed at 220 nm. The nitrate concentration was calculated by subtracting the absorbance at 275 nm from that at 220 nm, and the corrected absorbance was compared to a calibration curve established with known nitrate standards. Prior to analysis, 50 mL of field samples were filtered, and 1 mL of 1N HCl was added to reduce interference from organic matter. Each sample was analyzed in triplicate, and the average absorbance was recorded for accuracy.

2.3.2 Phosphate Assessment of Water and Farm Soil Samples

The analysis of phosphate concentrations in water and soil samples involved the preparation of ammonium sulfate and molybdate solutions, ensuring accurate results. An ammonium sulfate solution was created by dissolving 0.75 g in 50 mL of distilled water and adding 5 mL of concentrated sulfuric acid, allowing it to cool before diluting to 250 mL. For water samples, 10 mL of each sample was combined with 200 mL of the ammonium sulfate solution in an Erlenmeyer flask and shaken for over 30 minutes to extract phosphates, followed by filtration to remove particulates. In the case of soil samples, dried soil (10 g) was treated similarly with the ammonium sulfate solution after being oven-dried at 50°C. A molybdate reagent was prepared by dissolving 5 g of ammonium molybdate in 100 mL of distilled water, then slowly adding 160 mL of concentrated sulfuric acid and diluting to 500 mL. For phosphate detection, 10 mL of each standard phosphate solution was mixed with 20 mL of distilled water, 2 mL of the molybdate solution, and ascorbic acid in a 150 mL Erlenmeyer flask. The mixture was heated until boiling, resulting in a blue or green color, and absorbance was measured at 650 nm using a UV-Vis spectrophotometer (University of Canterbury, 2011).

Using the standard curve obtained from the absorbance readings of standard phosphate at known concentrations, an equation was derived from the equation of its trendline using Microsoft Excel data processing software. The equation of the trendline is presented in Equation 1.

$$y=mx+b \tag{1}$$

where y is the absorbance of the sample and x is the phosphate concentration of the sample. The measured absorbance readings of each sample were substituted into the equation, and the phosphate concentration was obtained by solving for x.

2.4. Treatment of Data

Mean and standard deviation were used to determine the nitrate and phosphate content of the samples tested in three replicates. The data were tested using a t-test to determine whether significant differences in the nitrate-nitrogen and phosphate concentrations of the farmland soils and groundwater sources at different study sites were present. The groundwater quality criteria used for interpreting the results were obtained from the Department of Environment and Natural Resources ([DENR], 2016) Administrative Order No. 2016-08 for Class C waters and Nutrient Status Maps (2016) for both nitrogen and phosphorus content as of June 2017 in Nueva Vizcaya from the Department of Agriculture - Bureau of Soils and Water Management (2017a; 2017b).

2.5 Ethical Considerations

This study, approved by the Saint Mary's University Research Ethics Board (SMUREB 1st sem 2023 201), analyzed nitrate and phosphate levels in farm soil and irrigation water without involving human or animal participants. Researchers followed strict safety protocols due to the hazardous nature of the chemicals used, which could pose environmental and health risks. All procedures generating potential aerosols were conducted in safe laboratory environments.

3. Results and Discussion

3.1 Nitrate Concentrations in Water Samples

The average freshwater nitrate concentrations (in mg/L) at various locations within the two barangays were calculated. The statistical analysis produced a p-value greater than 0.05, showing that dissolved nitrate levels in field irrigation water do not differ significantly between the two barangays. Furthermore, the mean nitrate concentrations in both barangays are less than seven mg/L, which is within the permissible limits set by DENR Administrative Order No. 2016-08. The low nitrate concentrations reported in irrigation freshwater, as shown in Table 1, are most likely caused by surface water bodies such as neighboring irrigation canals, rivers, or creeks.

Table 1. Statistical comparison of nitrate concentrations (mg/L) in freshwater samples from Barangays Mangayang and Gabut

Site	N	Mean (mg/L)	Std. deviation	t	df	Sig. (2-tailed)
Mangayang	4	.20275	.064412	-1.237	1.076	.422
Gabut	2	.41250	.235467			

3.2 Nitrate Concentration in Soil Samples

The average soil nitrate concentrations (in mg/kg) at various places in the two barangays were calculated. The statistical analysis yielded a p-value greater than 0.05, indicating that there is no significant difference in accessible nitrate levels in the farming soils between the two barangays. Furthermore, as shown in Table 2, the mean accessible soil nitrate concentrations are less than 10 mg/kg, which is significantly below the acceptable range of 10-50 mg/kg set by Australia's Department of Employment, Economic Development, and Innovation (2010).

Table 2. Statistical comparison of nitrate concentrations (mg/L) in soil samples from Barangays Mangayang and Gabut

Site	N	Mean (mg/kg)	Std. Deviation	t (df = 5)	Sig. (2-tailed)
Mangayang	5	.57640	.480772	.731	.498
Gabut	2	.31300	.057983		

Available soil nitrate levels can fluctuate primarily due to leaching into groundwater, as nitrates are highly soluble in water (Li *et al.*, 2023). The loss of available nitrates from the farmland due to leaching may have led to deficient nitrate concentrations in the soil, with the available soil nitrates accumulating in the groundwater. To address this, supplementing elemental nitrogen through ammonia-based and nitrate-based fertilizers, as well as adopting practices to reduce nitrate loss, are recommended.

3.3 Phosphate Concentration in Water Samples

Statistical analysis shows a p-value greater than 0.05, indicating no significant difference in the dissolved phosphate levels in the freshwater used for field irrigation between the two barangays. Additionally, Table 3 reveals that the mean phosphate concentrations in both barangays exceed 0.025 mg/L, surpassing the acceptable limits outlined in the Water Quality Guidelines of DENR Administrative Order No. 2016-08 and the revised guidelines in DENR AO No. 2021-19 (DENR, 2021). This indicates the need for further measures to reduce phosphate concentrations in the freshwater used for irrigation in the barangays. The average freshwater phosphate concentrations (in mg/L) from several locations within the two barangays are shown in Table 3.

Table 3. Statistical comparison of phosphate concentrations (mg/L) in freshwater samples from Barangays Mangayang and Gabut

Site	N	Mean (mg/L)	Std. Deviation	t	df	Sig. (2-tailed)
Mangayang	4	1.5830	.24548	.185	4	.862
Gabut	2	1.5415	.29486			

3.4 Phosphate Concentration in Soil Samples

The statistical analysis indicates a p-value of 0.230, which is greater than the 0.05 threshold, suggesting no significant difference in the available phosphate levels in the soil between the farming sites of Barangays Mangayang and Gabut (Table 4). Specific recommended phosphate levels cannot be established due to the varying requirements of different crops, as each crop demands unique amounts of available phosphate for optimal growth.

The results align with findings from Chakraborty *et al*. (2020) and Mussa *et al*. (2009), who noted that phosphate from fertilizers often accumulates in surface water through runoff, even when soil phosphate concentrations remain low. Similarly, Swistock (2022) highlighted that fertilizer or manure runoff is a likely contributor to the dissolved phosphate concentrations observed in the irrigation water of the two barangays.

Given these findings, monitoring phosphate levels in both soil and freshwater is critical to achieving several objectives: optimizing crop yields, avoiding nutrient antagonism caused by excess phosphorus, and maintaining water quality. Effective monitoring can help prevent eutrophication and other forms of water degradation caused by nutrient pollution.

Table 4. Statistical comparison of phosphate concentrations (mg/L) in soil samples from Barangays Mangayang and Gabut

Site	N	Mean (mg/kg)	Std. Deviation	t (df = 5)	Sig. (2-tailed)
Mangayang	5	6.1660	4.41296	1.365	.230
Gabut	2	1.6000	1.41421		

The nutrient status map from the Bureau of Soils and Water Management (2017b) confirms the study's findings on nitrate and phosphate levels in Dupax del Sur. It indicates that while nitrate levels in the sites are generally low, phosphate levels are more variable, with some areas experiencing higher levels in water due to surface runoff, which aligns with the observed results. This further suggests that applying fertilizers, especially in the context of crop cultivation in Dupax del Sur, may lead to nutrient imbalances in both soil and water, which can have significant environmental impacts, including water contamination and the potential for eutrophication. Although nitrates are more soluble in water and can leach towards groundwater or irrigation water, the low levels of dissolvable nitrate and clay-loam soil in Dupax del Sur limit the amount of leached nitrates in irrigation water, which mainly consist of dissolved nitrates from organic matter that were minimized during analysis (Geisseler and Horwath, 2016).

4. Conclusion and Recommendation

It can be concluded that nitrates from the soil obtained from the two communities are nearly depleted, and low amounts of nitrate can be leached through various water sources, leading to low concentrations of dissolved nitrate in the irrigation water. The differences in soil and water phosphate concentrations may be due to a separate irrigation source experiencing multiple runoff and leaching events, increasing its dissolved phosphate. This discrepancy indicates that fertilizer or manure runoff likely contributes to elevated water phosphate levels.

To address these issues, the study emphasizes the importance of regularly monitoring soil and water nutrients, alongside adopting sustainable practices such as optimized fertilizer application and runoff management, to improve nutrient availability, prevent eutrophication, and ensure environmental sustainability. Additionally, it recommends collaborating with the Provincial Department of Agriculture to develop comprehensive Information, Education, and Communication (IEC) materials that promote customized sustainable soil and water management practices and farming techniques, focusing on effective soil and water amendments and restoration methods.

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