Water Quality Effects of Backyard Pig Farms on Doline Ponds of Tabok Peninsula, Isabel, Leyte, Philippines

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Abstract

Backyard pig farms on the Tabok Peninsula, Northwestern Leyte, Philippines, pose risks to the sustainability of the region's doline ponds, which are essential for aquifer recharge. These ponds receive pig slurry from the said farms, yet the impact of this wastes on pond water quality is poorly understood due to a lack of monitoring. This study investigates the physicochemical properties of doline pond waters in the villages of Antipolo and Cantuhaon to establish baseline water quality and assess pig slurry's impact. A two-group experimental design was used with five replications for the unslurried (USG) control and slurried (SG) treatment groups. Composite and grab samples from each pond were analyzed for nine physicochemical parameters. Bootstrap hypothesis testing showed no significant differences in temperature, pH, COD, and NO_3-N between the groups. Turbidity was marginally significant, and total P was below the reporting limit. However, EC, TDS, and alkalinity were significantly higher in SG ponds, likely due to inorganic salts and lime-like substances that waste decomposition releases. The contradiction between this evidence of decomposition and the COD and NO_3-N results is attributed to the significantly higher macrophyte density in SG ponds, likely removing excess nutrients and organic material through phytoassimilation. Overall, the findings indicate that current backyard pig farming practices in the area have not yet negatively impacted pond water quality. However, indirect evidence of increased nutrient release and utilization in SG ponds supports prioritizing the peninsula's doline ponds in the LDWQS Programs of Isabel and Palompon, especially if backyard farming activity increases.

***Keywords**:* backyard pig farms, doline ponds, physicochemical properties, pig slurry, water quality

1. Introduction

The pig farming industry has remained a significant contributor to the agricultural sector in the Philippines, accounting for an average of 14.47% of the total agricultural production value between 2000 and 2020 (Fang and Elca, 2021). In 2015, backyard pig farms accounted for 64% of the national swine inventory, while commercial farms contributed 36% (Manalo and Dorado, 2017). Leyte Province led swine production in Eastern Visayas in the 3rd quarter of 2019, boasting a total population of 155,071 heads, representing 51.3% of the region's total (Cayubit, 2020). Notably, as of mid-year 2022, 95.52% of pig farms in the region were backyard operations, with only a tiny fraction classified as commercial farms (Niala, 2023).

A rapid appraisal of the operation of backyard pig farms in Antipolo village in Isabel and Cantuhaon village in Palompon, both within the island of Leyte, revealed that they carry out one to three pig production cycles per year, each lasting three months from farrowing to finishing. Their operation is primarily geared at producing porkers, with an average of six heads raised per cycle per farm. Aside from porkers, which are disposed of either through live pig sales or direct meat sales, some of the pig farms also have breeding sows. Averaging about two sows per farm, these animals produce two litters of piglets per year that the farmers sell or raise in the next production cycle. All assessed farms use commercial feeds placed inside the pigpens in troughs.

Leyte Island’s karst landscapes, primarily found in its northwestern and southwestern regions (Restificar *et al*., 2006), offer a fascinating interplay between natural geology and backyard pig farming. Situated in the island’s northwest, the Tabok Peninsula, home to the villages of Antipolo and Cantuhaon, is characterized by dolines and rolling karst hills (Kusumawati and Widyastuti, 2023). This landscape supports a hydrogeological system in which surface water from doline ponds gradually infiltrates underground aquifers (Parise, 2019; Hofierka *et al*., 2018).This crucial process provides essential water resources for local communities like Antipolo, which rely on pumped underground water for its tap supply (Geraldo, 2021).

Agriculture in karst areas, including backyard pig farming, has often posed challenges for rural communities, and efforts to manage agricultural wastes, such as piggery waste, have frequently impacted karst systems (Gillieson, 2019). Contamination problems from livestock waste disposal are particularly acute where point sources coincide with karst features such as dolines (Coxon, 2011; Parise, 2019). As it is, all of the appraised backyard pig farms in Antipolo and Cantuhaon, are situated directly above doline ponds. While some of these farms directly wash the wastes out of the pens and into the ponds in the form of pig slurry — defined as a mixture of feces, urine, fodder residues, and cleaning water (Venglovsky *et al.*, 2018) — others remove the solid manure before sweeping the concrete floor with water, which is then drained into the doline ponds. The removed manure is either deposited in open pits near the water level of the doline ponds or piled at the base of coconut trees to serve as fertilizer. The situation in the villages of Antipolo and Cantuhaon reflects Maharjan and Fradejas (2005) analysis, showing that independent pig raisers are more affected by waste disposal problems than their organized counterparts, as they have limited access to waste management facilities like biogas and training on waste disposal.

The manner in which piggery wastes are disposed of in Antipolo and Cantuhaon, as outlined above, is indeed concerning as it allows for the transport of significant quantities of solid manure and pig slurry into the nearby doline ponds via surface runoff. According to Koelsch (2019), the transport of such materials in sufficient quantities is generally unlikely unless one or more of four specific conditions are met. In this case, however, the waste disposal practices of the backyard farms in Antipolo and Cantuhaon satisfy two of the four. Specifically: there is a direct discharge from livestock housing into surface water drainage (1); and the current situation does not mitigate the exposure of newly surface-applied solid manure to significant rainfall (2). Once in the doline ponds, according Kulpredarat (2023) and El Bied *et al*. (2021), the flushed untreated pig slurry and manure can result in water fouling, which may or may not be preceded by eutrophication or algal blooms.

The introduction of untreated piggery waste into the doline ponds truly poses a significant threat to water quality. Koelsch (2019) emphasizes that pig manure, whether in slurry or solid form, contains abiotic components such as nitrogen (N), in the form of NH_4^+-N and NO_3^--N; phosphorus (P), in the form of dissolved P; and organic matter, in the form of organic N and organic P — all of which can alter the physicochemical conditions of the doline ponds. Although N and P in piggery waste play essential roles in aquatic ecosystems, they are increasingly scrutinized for their significant contributions to water quality degradation (Chynoweth *et al*., 1999; Kumar *et al*., 2005; Piotrowski *et al*., 2011). The rapid growth of algae and the proliferation of aquatic vegetation under eutrophic conditions driven by N can lead to discolored, hypoxic waters, and the production of toxins that disrupt aquatic life and may even result in fish kills (Koelsch, 2019; Piotrowski *et al*., 2011). Nitrate contamination of drinking water presents severe health risks, particularly for infants and pregnant women, by impairing oxygen (O_2) transport and potentially causing methemoglobinemia or *blue baby* syndrome in infants under six months old (Koelsch, 2019). Similarly, excessive P levels exacerbate eutrophication and promote the unchecked growth of algae and aquatic vegetation, depletion of O_2 levels, and fish mortality. Alongside these concerns, the organic matter component of piggery waste also undergoes microbial mineralization, which leads to the same problems of increased O_2 depletion and negative changes in water quality including increased turbidity, undesirable taste, and foul odor (Chynoweth *et al*., 1999; Koelsch, 2019; Kopp, 2012). Eutrophication, whether driven by N, P, or organic matter in piggery waste, therefore not only destabilizes aquatic ecosystems but also hinders the recreational use of water bodies, reduces the palatability of drinking water, and increases the complexity and cost of water treatment (Koelsch, 2019; Piotrowski *et al*., 2011).

If, in fact, the water quality in the doline ponds is degraded it may compromise their other uses by the communities on Tabok Peninsula, particularly their role in the natural production of tap water for community use. This is hastened in the case of Antipolo and Cantuhaon by critical karst-related factors which contribute to increased water quality vulnerability in karst systems (Leibundgut, 1998). Specifically, these factors include: limited soil cover that restricts the natural filtration of contaminants (1); highly permeable aquifers that promote rapid infiltration (2); and extensive subsurface conduits that transport unfiltered water directly to springs or wells (3). Definitely, numerous studies have demonstrated that abiotic contaminants originating from pig farming operations can infiltrate groundwater systems. In Ho *et al*. (2016) which examined the effects of different piggery systems on the quality of their surrounding surface and underground water, it was determined that due to the insufficient treatment of the systems' wastewaters, the parameters monitored for the surface water, such as COD, PO_4^{3-}, NH_4^+-N, and TSS, did not meet the water quality standards for the examined pig-farming systems, indicating water quality deterioration. The underground water quality also declined as its NH_4^+-N levels under each piggery system exceeded the standard by 13 times. In Tymczyna *et al*. (2000), the effect of a large pig farm on the physicochemical properties of underground water and well water within the close farm vicinity was evaluated. In line with results of Ho *et al*. (2016), the piezometric examinations conducted showed a significant concentration of N compounds, $PO_4^{3-}$and Cl^- in underground water. At the same time, the well water showed the contents of NH_4^+-N and NO_3-N to exceed the boundary values for drinking water 10 times. Lastly, Pedrozo-Acuña and Ramirez (2025) conducted a field campaign to assess the water quality of wells and cenotes located on designated pig farms situated over the karst aquifer of Yucatán, Mexico, in order to evaluate the farms' adherence to environmental regulations. The results of their study indicated signs of contamination from fresh organic waste, primarily originating from diffuse sources of animal effluent such as pig farms, resulting in elevated concentrations of NH_4^+-N. The study concludes that intensive pig farming practices in the Yucatán Peninsula significantly contribute to water pollution through nutrient runoff.

Despite the potential contamination of surface and groundwater through doline ponds in Antipolo and Cantuhaon —as inferred from the relevant works of Leibundgut (1998), Parise (2019) and Koelsch (2019) — no regular monitoring is conducted in these water bodies. After all, backyard and small commercial pig farms are exempt from Environmental Management Bureau (EMB) monitoring and compliance because their wastewater discharge generally falls below 30 m^3 per day (Calub *et al*., 2016). As a result, it is unknown to what extent small-scale backyard pig farms affect the water quality of the doline pond ecosystems. Addressing this knowledge gap is crucial as it can provide empirical basis for the inclusion of the karst hydrogeological system on the Tabok Peninsula in the Local Drinking Water Quality Surveillance (LDWQS) Programs of Isabel and Palompon. Such endeavor is in line with the Philippine Code on Sanitation (PD 856) and its Implementing Rules and Regulations (IRR) which require drinking water to be protected from all types of contamination (Department of Health [DOH] and Department of Interior Local Government [DILG], 2022). Specifically, the present study provides an initial inventory of an identified water supply system within the said municipalities and conducts preliminary fieldwork and water sampling to support its prioritization, as required by PD 856, during the initial phase of establishing LDWQS programs.

In order to generate insights that may serve as critical guidance for policymakers in Isabel and Palompon in the management of the doline ponds on the karst landscape of the Tabok Peninsula, with the ultimate goal of safeguarding the long-term viability of their water resources, this study aims to: assess the physicochemical characteristics of water in the pre-selected doline ponds in Antipolo and Cantuhaon to help characterize baseline water quality conditions (1); investigate nutrient concentrations in the same ponds to complement and complete the baseline water quality profile (2); and compare water quality between slurried and unslurried ponds to identify potential differences that may reflect the impact of pig slurry on doline pond water quality (3).

2. Methodology

2.1 Description of the Study Area

The study was conducted in the villages of Antipolo and Cantuhaon, located on the Tabok Peninsula in Leyte, Philippines (Figure 1). Antipolo, part of the municipality of Isabel, is situated at approximately 10° 56' North and 124° 25' East, while Cantuhaon, within the municipality of Palompon, lies at 10° 57' North and 124° 24' East. These rural communities comprise 1.11% (517) and 3.33% (1,941) of the total populations of their respective municipalities (PhilAtlas, 2022a; PhilAtlas, 2022b).

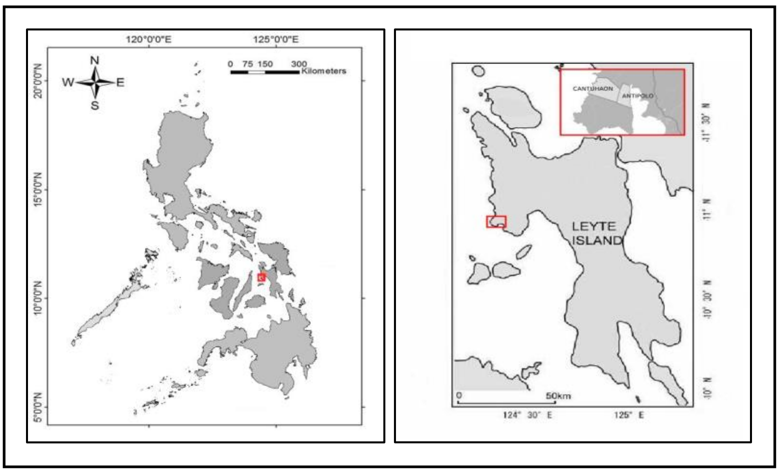

Figure 1. Location of the Tabok Peninsula
[Adapted from Banag *et al*. (2015); Ueno *et al*. (2008)]

As a characteristic of their karst topography, the landscapes of Antipolo and Cantuhaon are dotted with numerous doline ponds, locally known as *basak* (Figure 1). These enclosed circular, oval, or irregularly shaped surface depressions, which can span up to a kilometer in diameter, are intermittently or permanently filled with rainwater (Widyastuti and Haryono, 2017). These ponds are vital in the Tabok Peninsula, where no surface river or stream systems exist.

Ten doline ponds from the villages above were selected for data collection—seven in Antipolo and three in Cantuhaon. The preselected ponds were strategically chosen for their accessibility.

2.2 Collection of Water Samples

To assess the impact of pig slurry on pond water quality, a structured water sampling protocol was implemented in both slurried and unslurried doline ponds. The approach ensured representative, seasonally consistent, and minimally invasive sample collection for subsequent physicochemical analysis. The study achieved this by employing a Two-Group Experimental Design with five replications. The control group (USG) consisted of five unslurried ponds, while the treatment group (SG) comprised of five slurried ponds. The sampling plan for the pre-selected ponds had a dual purpose: capturing their physicochemical heterogeneity and minimizing disturbance to the ecosystems. Sampling points, distributed across various locations within the ponds, were carefully chosen and GPS-marked based on accessibility amid dense pond surface vegetation.

Water samples were collected from the subsurface of each pre-selected pond during the peak wet season (November to January) in 2022 and 2023 to ensure consistent water availability. Three rounds of sampling were conducted to capture the necessary observations during this period.

Two types of water samples were collected in each pond: composite and grab samples. Composite samples were prepared following Ohio Environmental Protection Agency [EPA] (2021) guidelines, requiring triple field rinsing of collection bottles, combining sub-samples from each pond's sampling points, and preserving the composite samples in an iced cooler at ≤ 6 °C for laboratory analysis. Grab samples were also taken directly from each sampling point; however, they were not combined but analyzed individually. Before use, collection bottles were triple-rinsed in the field, and all samples were stored in an iced cooler at ≤ 6 °C for subsequent ex-situ analysis.

2.3 Determining Water Quality

Nine physicochemical properties were measured for each of the pre-selected doline ponds. These variables, which provided insight into the physicochemical effects of pig slurry enrichment on the ponds, included: temperature (°C) (a); electrical conductivity (EC) (µS/cm) (b); pH (c); total dissolved solids (TDS) (ppm) (d); turbidity (NTU) (e); chemical oxygen demand (COD) (mg/L) (f); alkalinity (meq/L) (g); nitrate-nitrogen (NO_3^--N) (mg/L) (h); and total phosphorus (Total P) (mg/L) (i). To avoid measurement errors, the portable testers, except for the Salifert Alkalinity/KH Test Kit, were regularly calibrated using standard calibration compounds specific to the parameter being tested (i.e., excluding temperature). The list of physicochemical properties, methods, and calibration protocols used in the analysis are shown in Table 1.

Table 1. Summary of Physicochemical Properties and Analysis

Water Quality Property	Measurement Source	Method of Analysis	Calibration Protocol per Sampling Round
Temperature	Yieryi BLE-C600 Water Quality Tester	Thermistor-based Measurement	N/A
EC		Conductometric Method	Calibration is done for each pond using 12.88mS/cm & 1413µS/cm EC standard solutions
pH		Electrometric Method	Calibration is done for each pond group using 6.86, 4.00, & 9.18 pH buffer powders
TDS		Conductometric Method; conductivity-to-TDS conversion	Included in the conductivity calibration
Turbidity	Yieryi Portable Digital Turbidity Meter Range	Nephelometric Method	Calibration is done for each pond using 400NTU turbidity standard solution
Alkalinity	Salifert Alkalinity/KH Test Kit	Titration Method	N/A
COD	F.A.S.T Laboratories	522B. Open Reflux Method	Standardization with KHP[a]
Nitrate N		Brucine Method	Calibration Curve Method[b]
Total P		4500-P C Vanadomolybdo-phosphoric Acid-Calorimetric	Calibration Curve Method[c]

a. *As outlined in (Rice et al., 2017), the calibration protocol for the 522B Open Reflux Method involves conducting the test on a standard potassium hydrogen phthalate (KHP) solution. The measured COD of the KHP standard is subsequently compared to its theoretical value to confirm reagent accuracy and procedure reliability. Results that deviated significantly require adjustment of the reagent concentrations or the checking for interferences.*

b. *For the Brucine Method, calibration involves creating a calibration curve by measuring the absorbance of known NO3- standards reacted with Brucine-Sulfanilic acid solution, and then using this curve to determine the NO3- concentration of unknown samples (Bain et al., 2009).*

c. *For the 4500-P C Vanadomolybdo-phosphoric Acid Colorimetric Method, calibration also involves creating a calibration curve by measuring the absorbance of known PO_4^{3-} standards reacted with the Vanadomolybdo-phosphoric acid reagent, and then using this curve to determine the PO_4^{3-} concentration of unknown samples (Rice et al., 2017).*

The composite water samples were used to analyze COD, nitrate-N, and Total P. In contrast, the grab samples were utilized to measure the pre-selected ponds' pH, temperature, EC, TDS, turbidity, and alkalinity.

2.4 Statistical Analyses of Collected Data

The triplicate measurements for each parameter were averaged to obtain a representative value for each pond. The mean values from all ponds within each group were then averaged to calculate the group-level mean for each parameter. Boxplots comparing the two pond groups for each parameter were created using the pond means and generated in Microsoft Excel.

Using the pond means in each group, an independent t-test was conducted to evaluate the significance of differences between the two groups for each parameter, resulting in an observed t-statistic. To obtain a more robust measure of the difference, non-parametric bootstrapping was utilized to generate 10,000 bootstrap samples. Bootstrap t-statistics were calculated from these samples, and the Monte Carlo p-value was determined using Equation 1, with significance assessed at $\alpha = 0.05$. The t-tests and bootstrapping analyses were performed using the R Statistical Software (v4.2.2; R Core Team, 2022).

Computing the Monte Carlo p-value in the present study is advantageous, as it addresses the limitation posed by the small sample size of ponds. The method achieves this by empirically simulating the null distribution of the t-statistic for each parameter through 10,000 random permutations of the observed data. By constructing the null distribution from empirical data, the computed Monte Carlo p-values provide a more accurate estimate of the probability of obtaining t-statistics as large as or larger than the observed value (Park, 2024).

$$p = \frac{\sum(|t.boot.np| > |t.obs|) + 1}{B + 1} \quad (1)$$

Where:

p = Montecarlo p-value

t.boot.np = independent t-statistics of the non-parametric bootstrap samples

t.obs = independent t-statistic of the observed samples

B = number of bootstrap replications.

3. Results and Discussion

3.1. Pond Water Quality Baseline and Its Implications

Figure 2 shows the physicochemical property levels of the two pond types, visually comparing the water quality between the different groups. It is noteworthy that none of the physicochemical datasets exhibit outliers or data points that deviate significantly from their respective distributions (Liu, 2014). The absence of outliers in this case suggests that the datasets are clean and consistent, with no extreme values resulting from measurement errors, sampling anomalies, or natural variation—factors that could otherwise distort the statistical analyses implemented (Frost, 2025).

3.1.1. pH

The mean pH values of all ponds vary between the slightly acidic 6.4 to the slightly basic 7.6 (Figure 2). The fact that fluctuations in water pH affect physicochemical properties—such as decreasing pH associated with elevated dissolved oxygen (DO), turbidity, and COD, and increasing pH with reduced DO and turbidity but elevated EC — underscores the critical role of pH regulation in effective water quality management (Dewangan *et al*., 2023a). As a measure of H^+ concentration, pH influences the solubility of solids, the leaching of essential ions, and the bioavailability of nutrients — all of which carry electrical charges that determine their mobility and reactivity in soil and water systems (El Bied *et al*., 2021; Singer *et al*., 2012).

As a potential source for public water supply, the mean pH values of the pond groups fall within the optimal range of 6.5 to 8.5, in accordance with Department of Environment and Natural Resources (DENR) Administrative Order No. 2016-08 (DENR, 2016). Given that the ponds' mean pH values are not significantly different ($p > 0.05$; Table 2), the water is neither corrosive and prone to toxic metal contamination, nor likely to impair nutrient absorption or cause indigestion and malnutrition when consumed (Arhin *et al*., 2023). The water in the ponds is also considered suitable for irrigation (Ayers & Westcot, 1989) and for supporting the growth of aquatic organisms, as their productivity declines outside the optimal pH range and mortality may occur under extreme pH conditions (Food and Agriculture Organization of the United Nations [FAO], 1981). It is important to emphasize, however, that aside from pH, water temperature and substrate concentration also play significant roles in the enzymatic activities underlying this dynamic (Pandey and Singh, 2012). Lastly, the pH of the ponds may also allow for the optimal availability of nutrients (Dunn and Singh, 2017). This means that micronutrients (i.e., Fe, Mn, B, Zn, Cu) are not at risk of becoming less available—as can occur at high pH—or excessively available, as often happens at low pH (Pennisi and Thomas, 2009). The same holds true for P, which may precipitate with calcium (Ca) at high pH and bind with iron (Fe) and aluminum (Al) at low pH (Cerozi and Fitzsimmons, 2016; Prasad and Chakraborty, 2019), and for N, whose availability decreases at very high pH due to NH_3 volatilization and at very low pH due to conversion into less mobile forms such as ammonium NH_4^+ (Follett *et al.*, 1981).

3.1.2. Temperature

The ponds' mean temperatures ranged between 27.17 and 29.09°C and were within the limit of 26 to 30°C (DENR, 2016). The fact that their temperatures are within the 26 – 30 °C range is ecologically consequential, as it implies that the ponds are providing optimal or near-optimal thermal conditions for the physiological functioning and survival of a wide range of their inhabitant organisms, including aquatic invertebrates, fish, and macrophytes (Kutty, 1987; Ogunji and Awoke, 2017; Souza *et al.*, 2021).

Despite the uneven spread of mean temperatures for the SG ponds (Figure 2), which show a skewness towards the lower end compared to the USG mean temperatures, the closeness of the group means underscores the non-significant difference between the groups' mean temperatures ($p > 0.05$; Table 2). This similarity suggests that the water temperature of the pond groups exert comparable influences on the metabolic rates and biological activities of aquatic organisms living in the doline ponds (Rubalcaba, 2024). This occurs as most chemical reactions as well as physiological performances in organisms are temperature dependent stemming from the activation energy associated with them (Miller and Stillman, 2012; Rubalcaba, 2024; World Health Organization [WHO], 2022). In fact, water temperature along with the amount of decomposer microorganisms have the most important role for the degradation of organic matter in waterbodies (Kopp, 2012). In addition to their potential effects on the physiology of the ponds' living organisms, the ponds' temperatures are also likely exerting comparable influences that keep several of the physical and chemical properties measured in this study near optimal levels. Specifically, pH is affected through the autoionization of water, which intensifies with increasing temperature; EC is influenced by temperature, as higher temperatures increase the kinetic energy of water molecules, thereby enhancing their capacity to carry more charged ions; TDS are influenced due to temperature-dependent changes in the solubility of various compounds; and

COD removal efficiency improves at higher temperatures, as elevated thermal conditions accelerate microbial metabolic activity and proliferation, thereby enhancing the biodegradation of organic pollutants (Dewangan *et al*., 2023b; Health Canada, 2021; Muloiwa *et al*., 2023). Beyond these parameters, pond temperature levels may also be positively influencing the DO concentrations in the ponds, as temperature affects both the O_2 holding capacity of water and the rate of photosynthesis (Mary River Catchment Coordinating Committee [MRCCC], 2025a). The taste and odor of the water might likewise be optimally affected, considering that the water temperature of the ponds are within the favorable range that may help limit the formation of unpleasant-tasting or odor-causing compounds (Health Canada, 2021).

3.1.3. Turbidity

Turbidity exhibited a near-significant difference between the two pond groups ($p = 0.0635$; Table 2). This result implies that, although the evidence is not sufficiently strong to be conclusive, there is nonetheless a possibility of an effect of pig slurry and manure on the ponds' turbidity (Childs *et al*., 2021). Mean turbidity values ranged from 2.83 to 26.59 NTU, with only one sampled pond falling within the allowable limit of 5 NTU (DOH, 2017). These high turbidity levels may be attributed to the karstic location of the ponds, where the weathering of limestone rocks leads to the formation of limestone soils. In the case of Isabel and Palompon, these soils are primarily composed of silt and clay (Oraiz *et al*., 2021). When transported into the ponds by runoff, the silt and clay remain suspended in the water column, causing prolonged turbidity, as they are easily kept from settling, prone to resuspension, and settle at a prolonged rate (Boyd, 2012).

As pointed out by Cole *et al*. (1999), the relatively high turbidity levels of the doline ponds can potentially increase water temperature, by allowing suspended particles to absorb more solar heat, and decrease DO levels, since warm water holds less DO than cold water. The ponds' high turbidity levels may also inhibit photosynthesis in the water by decreasing light penetration of the water column decreasing submerged or suspended plants' survival and further decreasing DO output. Moreover, since turbidity levels of more than 5 NTU can be visible to the average person, the waters in the doline ponds may also look unhealthy and unappetizing (Hassan Omer, 2020). But beyond mere appearances the waters of the doline ponds can potentially be unhealthy, given that suspended particulates can provide hiding places for harmful microorganisms and act as adsorption surfaces for heavy metals and various hazardous organic pollutants (Cole *et al*., 1999; Edzwald, 2010).

3.1.4. Chemical Oxygen Demand, NO_3^--N, and Total P

The mean COD values of the ponds ranged from 43.67 to 178.67 mg/L, while the mean NO_3-N values ranged from 0.031 to 0.163 mg/L. Meanwhile, the mean Total P values of all ponds across all sampling rounds were <1.0 mg/L, which is already below the reporting limit of the contracted external laboratory. The group mean COD and NO_3^--N values for both pond groups were below the allowable limits of 100 mg/L (DENR, 1990) and 7 mg/L (DENR, 2016), respectively, for public water supply sources. No significant differences were detected between the two pond groups for both COD and NO_3^--N ($p > 0.05$; Table 2).

Regarding the low concentrations of NO_3^--N in both pond groups, Oraiz *et al.* (2021) pointed out that limestone terrains generally have low contents of essential nutrients including N. However, the addition of pig slurry and manure is unlikely to have significantly altered the NO_3^--N levels in the doline ponds, at least under the current application volumes. While approximately 10.00% of the inorganic N in pig slurry is NO_3^--N, most N in pig slurry exists in the form of the inorganic NH_4^+-N or organic N, from which NO_3^--N can also be derived (Koelsch, 2019; Kopp, 2012). However, unlike NH_4^+-N, which is readily available for plant uptake, organic N becomes available more slowly through mineralization (Koelsch, 2019; McCutcheon and Quinn, 2020). At the same time, although NH_4^+-N can be converted to NO_3^--N via nitrification, this process could be stunted as it requires sufficient O_2, which is often depleted by the decomposition of organic matter. Additionally, NH_4^+-N is prone to volatilization, resulting in N loss to the atmosphere (Koelsch, 2019; U.S. Environmental Protection Agency [EPA], 2012).

In freshwater systems such as the doline ponds, N plays a critical role and warrants careful consideration. Nitrogen, next to P, is considered the most important element limiting phytoplankton growth in freshwater bodies and its enrichment can lead to harmful algal blooms, which in turn cause nuisance conditions such as unfavorable odors, discoloration, or the production of toxins harmful to aquatic organisms (De Vries, 2021; Environment Agency, 2019). Petr (2000) pointed out that algal blooms can result in the dominance of phytoplankton over macrophytes, as former can outcompete the latter for resources such as light and nutrients, and inhibit their growth through toxic factors of algal and bacterial origin. Furthermore, phytoplankton proliferation can lead to the formation of hypoxic (i.e., oxygen-depleted) waters due to the decomposition of excess algal and other biomass, ultimately reducing the ecosystem's productivity, increasing the incidence of fish kills, and contributing to ecosystem collapse (De Vries, 2021; Koelsch, 2019; Piotrowski *et al*., 2011). From a consumption standpoint, Ward et al. (2018) concluded that substantial evidence links NO_3^- in drinking water to adverse health outcomes, including methemoglobinemia, colorectal cancer, thyroid disorders, and neural tube defects.

Considering the absence of a significant difference between pond groups, and the fact that none of the pond means exceeded the DENR NO_3^- limit for water supply (7 mg/L) or the 0.3 mg/L limit associated with supporting algal blooms, the NO_3^--N content of the doline ponds poses no risk of causing eutrophication, algal blooms, or related health problems (Center for Agriculture, Food and the Environment [CAFE], 2016; DENR, 2016).

Similar to N, Oraiz *et al*. (2021) emphasized that limestone terrains generally have low contents of P. Additionally, the limited availability of P under these conditions may be due to its reaction with Ca^{2+}, leading to the formation of insoluble Ca-P compounds (Cable *et al*., 2002) or its absorption and precipitation by $CaCO_3$ (Yanamadala, 2005). Regardless of the cause, the finding of undetectable total P levels in the sample ponds supports the suggestion — based on NO_3-N level findings — that piggery waste input into the doline ponds is not currently exerting a noticeable influence on nutrient concentrations. At the same time, it is also in line with the fact that P is usually present in very small amounts and is considered the ‘limiting factor' for algae and plant growth in freshwater bodies (CAFE, 2016; Environment Agency, 2019). Hence, it is unsurprising that in Pennsylvania, USA, very low P levels (i.e., < 1 mg/L) in groundwater and surface waters are considered indicators that they are unpolluted (Swistock, 2022). As such, higher levels often signal contamination from fertilizer or manure runoff and levels above 5 mg/L may cause antagonism and deficiencies in other nutrients. The relatively low P levels observed in both pond groups suggest they are less likely to experience the ecological impacts typically associated with P over-enrichment. Like N, excessive P levels can drive eutrophication, triggering rapid plant and algal growth that lowers DO through respiration and decomposition, releases harmful toxins, blocks sunlight, and degrades habitats for benthic macroinvertebrates and other aquatic life (Chynoweth *et al*., 1999; US EPA, 2025; Koelsch, 2019; Kopp, 2012).

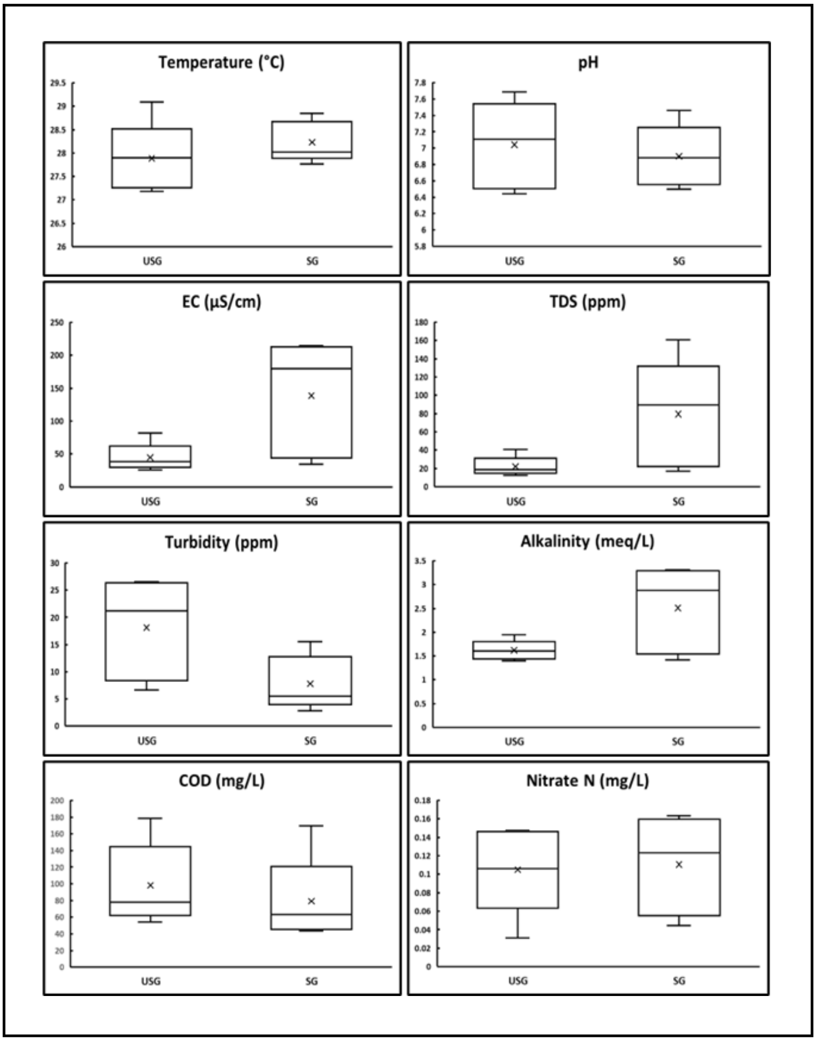

Figure 2. The Physicochemical and Nutrient Properties of the Doline Ponds: Boxplot graphs showing the distribution for the two pond groups' datasets on pH, Temperature, Electrical Conductivity (EC), total phosphorus (TP), Total Dissolved Solids (TDS), Turbidity, Alkalinity, Chemical Oxygen Demand (COD), and Nitrate Nitrogen (Nitrate N), where: x = mean; rectangle = standard mean error; vertical bars = standard deviation; USG = Unslurried Group; SG = Slurried Group

3.1.5. Electrical Conductivity, Total Dissolved Solids, and Alkalinity

In contrast to the water parameters above, the two pond groups exhibited significant differences in their EC, TDS, and alkalinity ($p>0.05$; Table 2). This finding is expected, given that water in karst terrains is rich in $Ca(HCO_3)_2$, derived from the abundant limestone parent material (Oraiz *et al.*, 2021). In Figure 2, the EC, TDS, and alkalinity graphs show that the values measured for the SG are much higher than those in the USG. The range of mean values for EC is from 25.56 to 214. 33 μS/cm; for TDS, it is from 12.44 to 161 ppm; and for alkalinity, it is from 1.39 to 3.31 meq/L. As it is, all ponds were within the permissible limits for these properties: 300 μS/cm for EC, 500 ppm for TDS (Sandoval, 2024), and 5.99 meq/L for alkalinity (Tonog and Poblete, 2015).

The fact that the EC and TDS levels are within permissible limits provides evidence against the notion that the pond waters have deteriorated, particularly in the case of the SG ponds (Kadhem, 2013). Overall, the SG and USG ponds averaged 44.74 μS/cm and 138.76 μS/cm for their ECs and 22.09 ppm and 79.5 ppm for their TDSs, respectively. These levels are considered safe for potential municipal water sources. According to the World Health Organization (WHO, 2003), TDS levels < 300 ppm are associated with excellent palatability in drinking water. Given that the measured TDS levels in the doline ponds fall within this range, their water may be considered highly palatable if used for potable purposes. This is supported by the fact that the average EC levels of the doline ponds fall in the range from 0 to 800 μS/cm which would classify their waters as good for human consumption (MRCCC, 2025b). These EC and TDS levels, in terms of irrigation use, are not problematic as well as they fall within the low salinity class, implying a low salinity hazard or osmotic stress to vegetation (Kadhem, 2013). Given that EC and TDS are reliable indicators of salt content and other dissolved compounds such as organic matter, their significant differences between the groups suggest that SG ponds might have higher nutrient availability and can potentially support greater vegetation growth compared to USG ponds (Dunn and Singh, 2017).

Based on the work of Kopp (2012), the higher alkalinity levels of the SG ponds are likely to make them more resistant to sudden changes in pH compared to the USG ponds. However, the fact that the average alkalinity of both groups is above 1.00 meq/L, is indicative that their waters are not experiencing poor buffering capacity either, which could otherwise result in wide pH fluctuations. In fact, the mean pH values also suggest this as they fall within the range of 6.5 to 9 (Sallenave, 2019). Furthermore, considering that the alkalinity levels of the ponds are not too low, their water is unlikely to promote chemical corrosion of piping and fixtures, which could otherwise elevate metal concentrations in tap water sourced from them (KnowYourH2O Water Research Center, 2025). At the same time, their alkalinity levels are also not too high as to impart a bitter or chalky taste to the water if used for drinking, or to cause harmful reactions with certain cations in the water, which may lead to sediment formation and clogging of pipes and other water supply infrastructure (Bozorg-Haddad *et al.*, 2021).

Table 2. Monte Carlo P-values from independent T-tests of Physicochemical Properties between Slurried and Unslurried Pond Groups

Property	P-Values	Significance
pH	0.6322	—
Temperature	0.4067	—
EC	0.0444	*
TDS	0.0528	*
Turbidity	0.0635	—
Alkalinity	0.0519	*
COD	0.5851	—
Nitrate N	0.8590	—
Total P	N/A	N/A

* *Statistically significant difference observed at α = 0.05*
-- *No statistically significant difference detected at α = 0.05*
N/A Not Applicable

3.2 Potential Drivers of Pond Water Quality

3.2.1 pH and Alkalinity

Given the significantly different alkalinities between the two pond groups, the similarity in their pH levels suggests that the SG ponds may have been more acidic initially before being buffered by their higher alkalinity. The observed parity in pH, despite this significant difference in alkalinity, could be due to the neutralizing effect of NH_3 in the manure countering the acidity of its volatile fatty acids (VFAs), which are the primary contributors to the acidifying effect of pig slurries (Jayasundara, 2015).

The presence of cations, particularly Ca^{2+} and Mg^{2+} (Bokossa *et al.*, 2014a), at the end of the decomposition process of pig slurry and manure, is also a good source for the higher alkalinity (Baboo, 2015) in the SG ponds that can neutralize the effect of VFAs. These cations react with CO_2 present in water or air, or with water itself, to form alkaline compounds such as $CaCO_3$, $MgCO_3$, $Ca(HCO_3)_2$, and $Mg(HCO_3)_2$ (Bokossa *et al*., 2014a). Consequently, pig manures are low-cost sources for increasing alkalinity (Gao *et al*., 2022).

Pig manure has been used, for instance, in biological treatment systems to eliminate COD and remove the nutrient contents of treated waste materials. In a study examining such an application, Piasai *et al*. (2020) reported that the addition of alkalinity from pig manure to wastewater resulted in a mean P release that is 1.32 times higher than normal, over 99% of COD removed, and more than 95% of total Kjedahl nitrogen (TKN) removed.

Pig manures are also added to agricultural soils to improve their alkalinity and productivity. A study conducted by Luo *et al*. (2023) analyzed the effect of eight years of pig manure application on soil quality and concluded that it may reduce soil acidity, increase soil fertility, and raise crop yields. Based on these findings, they even recommended that a manure application rate of 15 Mg/ha should be observed in their studied soil.

The apparent contribution of piggery waste to elevated alkalinity levels in the SG ponds is regarded as advantageous for attaining favorable water quality conditions in the ponds. This is because increased alkalinity — as long as it is within the optimal range — contributes to pH stability (Suter *et al*., 2025) which the present study demonstrates. This is beneficial for organisms in the doline ponds considering that fluctuating pH levels or prolonged exposure to pH outside the optimal range can physiologically stress many species, leading to reduced reproduction, inhibited growth, disease, or even death (Dewangan *et al*., 2007; FAO, 1981; Suter *et al*., 2025). Additionally, sudden shifts in pH can alter the chemical states of pollutants, such as NH_3, affecting their solubility, transport, and bioavailability—thereby increasing the exposure and toxicity of metals and nutrients to aquatic plants and animals, as well as to humans who rely on aquifers fed by these ponds (Cerozi and Fitzsimmons, 2016; Dewangan *et al*., 2007; Follett *et al*., 1981; Pennisi and Thomas, 2009; Prasad and Chakraborty, 2019).

A stable pH regime, potentially maintained by the elevated alkalinity associated with pig slurry inputs into the doline ponds, is essential for sustaining aquatic biodiversity and facilitating efficient nutrient cycling within these freshwater ecosystems. However, these potential outcomes are themselves important factors in ensuring the sound quality of water in the doline ponds. In a seminal study by Cardinale (2011), N uptake rates of algae — measured using NO_3^- (i.e.,^{15}N-labelled), a primary nutrient pollutant contributing to water quality deterioration — increased linearly with species richness and were driven by niche differences among species. Conversely, when these niche opportunities were experimentally removed, species diversity no longer influenced N uptake. As it stands, Cardinale's (2011) results provide direct evidence that communities with greater species richness capture a larger proportion of biologically available resources, such as nutrient pollutants, thereby buffering natural ecosystems against the ecological impacts of nutrient pollution. Likewise, balanced nutrient cycling, as can be facilitated by the increased alkalinity along with other factors, is important as aquatic nutrient cycles are particularly vulnerable to change (Meunier and Boersma, 2017; Wetzel, 1996). If unabated, alterations in nutrient availability — such as those driven by pH fluctuations — can degrade habitat quality and indirectly affect ecosystem productivity and biodiversity (Meunier and Boersma, 2017).

3.2.2 Electrical Conductivity and Total Dissolved Solids

In line with the proposed scenario of pig slurry and manure decomposition, the EC levels of SG ponds show a significantly higher presence of inorganic solids than those in the USG ponds. These inorganic solids are likely the salts left after the volatile dissolved solids in the pig manure have been converted to CO_2 and CH_4 during decomposition (Hamilton and Zhang, 2011).

Apart from the previously mentioned alkaline compounds, these salts can also include NH_4NO_3, $(NH_4)_2SO_4$, NH_4Cl, and KNO_3, depending on the N and sulfur content in the manure (Bokossa *et al*., 2014b). As indicated by Hjorth *et al*. (2010), the elevated EC in pig slurry is primarily a result of the salt-based and high-protein diets required to meet the nutritional needs of pigs.

Accordingly, the higher TDS of the SG ponds can now be explained by the accumulation of these dissolved residual salts in their water column (Hamilton and Zhang, 2011) compared to that in the USG ponds. The study by Fridrich *et al*. (2014) highlighted the potential of pig slurry as a significant source of inorganic solids and residual salts. By using EC levels in groundwater as an indicator of pig slurry lagoon leakage into shallow aquifers, the researchers found that piezometers positioned closest to the lagoons had significantly higher EC values compared to those located farther away, suggesting the extent of salt contamination decreases with distance from the source.

Further supporting this, Díez *et al*. (2004) investigated the impact of pig slurry applications on irrigated Mediterranean soils and found that both optimal and excessive slurry applications led to substantial increases in soil EC values across all sampling periods, compared to urea-treated soils and the control group. Additionally, EC levels in the soil solution increased with depth, likely due to salt mobilization under irrigation. This finding was accompanied by a significant increase in TDS leaching in slurry-treated soils, further demonstrating the link between the two parameters.

The suggested correspondence of EC and TDS in the doline ponds is in line with the results of many studies such as that of Dewangan and Shrivastava (2024) which found a strong correlation between these two parameters. Since EC and TDS can be used to indicate nutrient levels in aquatic habitats (Dunn and Singh, 2017; Wu *et al*., 2020), the significantly higher values observed in the SG suggest that backyard pig farms can potentially cause severe deterioration in pond water quality if their activity becomes excessive (Dorado *et al*., 2019; Dunn and Singh, 2017). Numerous studies have highlighted the relationship between these parameters and the extent of water pollution. In one such study, Wu *et al*. (2020) found the EC of the waters in Lake Taihu in China to have increased rapidly from 1992 to 2007 due to eutrophication processes brought about by the disposal of sewage in the lake. After 2007, with the implementation of various pollution control measures, the EC subsequently decreased along with gradual improvement in the pollution situation. If such eutrophication happens in the doline ponds the growth of aquatic plant life within them may become overstimulated, potentially leading to DO depletion (Marshall and Wilcox, 2015). As it is, elevated EC and TDS levels can contribute to DO depletion by increasing the availability of organic and inorganic substrates for microbial decomposition, thereby accelerating O_2 consumption. Demonstrating this dynamic, Njue *et al.* (2022), in their study on agricultural nutrient pollution in the Thiba River in Kenya, an area vulnerable to eutrophication driven by inorganic fertilizer inputs, reported that during the period of peak microalgae abundance, the spatial patterns of EC and TDS were positively correlated, whereas DO exhibited a negative correlation with these parameters.

Another key finding reported by Njue *et al*. (2022) was that salinity exhibited a positive correlation with both EC and TDS, and a negative correlation with DO. This report underscores an additional adverse consequence of intense backyard pig farming activity, which is the increased risk of salinization in the soil and water systems adjacent to the effluent source (Díez *et al*., 2004). This issue is particularly critical given that the pig farms and doline ponds analyzed in the present study are situated within a karst landscape. Salinization of the doline aquifers resulting from waste disposal by backyard pig farms in the study area may become acute, particularly because specific hydrogeological characteristics of karst landscapes amplify the susceptibility of groundwater quality to degradation (Coxon, 2011; Parise, 2019). As outlined by Leibundgut (1998), these relevant karst characteristics are: the presence of thin or absent soil cover in some karst areas, which significantly weakens the natural breakdown of contaminants by microorganisms and by physical and chemical processes(1); the high permeability of karst aquifers, resulting from solutionally enlarged fissures and channels that diminish attenuation mechanisms and enable rapid water passage through the unsaturated zone (2); and the presence of large conduits and channels in the saturated zone that directly transport unfiltered recharge water to springs or wells (3). These factors were particularly evident in an assessment of water quality in wells and cenotes situated on designated pig farms overlying the karst aquifer of Yucatán, Mexico. In this study, Pedrozo-Acuña and Ramírez (2025) observed an increasing trend in EC and TDS levels — indicating a significant presence of dissolved salts — in wells aligned with the principal flow direction of the peninsula's subterranean aquifer, confirming the occurrence of a diffuse contamination process. In the event of slurry seepage in the doline ponds, although NO_3^- leachate is the nutrient most likely to infiltrate the subsurface and contaminate the underlying aquifer (Díez *et al*., 2004), Na^+ and K^+ ions may also leach into the groundwater, potentially contributing to the degradation of its quality (Rosa *et al*., 2017). If these ions and others contribute to groundwater salinization, subsequent extraction and use for domestic or agricultural purposes may significantly increase soil salinity at the application sites. This scenario is illustrated by Bernal *et al*. (1992), who reported that during two years of pig slurry application in calcareous soils, significant increases in EC and soluble salt concentrations — primarily involving Na^+ and K^+ — were observed in treated soils compared to control soils, indicating a potential salinity risk.

Clearly, high levels of TDS and EC can cause significant damage to aquatic ecosystems, agricultural crops, and human health. If left unabated, the salinization of freshwater ecosystems they cause can ultimately impair fundamental physiological processes in aquatic biota — including osmoregulation, ion transport, and reproduction — while also driving shifts in the structural composition and functional dynamics of aquatic communities (Castillo *et al*., 2018). Overall, species richness in inland aquatic ecosystems tends to exhibit a negative correlation with increasing salinity levels, reflecting a progressive decline in biodiversity along the salinity gradient (Kefford *et al*., 2011; Pinder *et al*., 2005). For agricultural crops, high salt concentrations in the soil solution can induce an osmotic or water-deficit effect, thereby reducing the plants' ability to uptake water (Machado and Serralheiro, 2017). In addition, crop growth may also be inhibited by the accumulation of salts in the shoots at toxic levels under such conditions. According to Ahmed *et al.* (2024), citing Maas (1990), among the vital crops in the Philippines, *Zea mays* L. has been shown to reduce its yield by 19.00%, *Solanum tuberosum* L. by 12.00%, *Lycopersicon esculentum* Mill. by 9.90%, and *Oryza sativa* L. by 12.00% in response to high salinity in their substrate. In humans, drinking water with elevated salinity increases the risk of adverse health effects. For instance, Chakraborty *et al.* (2019) found that elevated drinking water salinity and TDS in the rural sub-districts of southern Bangladesh were significantly associated with increased hospital visits for cardiovascular diseases, diarrhea, and abdominal pain. High levels of salts may also affect the taste of drinking water which reduces their suitability not only for human consumption but also as water supply for grazing animals (Queensland Government, 2013).

According to the Safe Drinking Water Foundation (2025), water with high TDS and EC requires a specialized treatment process to correct its impaired quality. This typically involves reverse osmosis (RO) to remove dissolved solids, including salts. However, this process also eliminates beneficial minerals such as Ca and Mg; therefore, the treated water should ideally be re-mineralized by passing it through a Ca- and Mg mineral bed. As it is, drinking water treatment plants utilize energy-intensive unit processes to treat raw water to desired water quality standards for consumer protection (Bukhary, 2024). Empirically, the higher the amount of TDS, EC and salinity concentrations in the water, the greater amount of pressure is required for the pumps to push the water through the membranes in the RO systems which consequently increases the cost of the whole RO operation (Adjovu *et al.*, 2023).

Considering the substantive implication of water TDS and EC levels, especially when they are outside recommended ranges, their monitoring and assessment might be crucial to fully comprehend how human activity, such as backyard pig farming, affect water bodies. These water quality parameters can be good indicators for monitoring piggery waste pollution because they reflect the concentration of dissolved ions and solids in the wastewater, which are likely to be elevated in piggery wastes due to the presence of salts, organic matter, and other contaminants (Bokossa *et al.*, 2014a; Dunn and Singh, 2017; Hamilton and Zhang, 2011; Hjorth *et al.*, 2010). Furthermore, the salts in the pig manure slurry, which primarily include NH_4SO_3, $(NH_4)_2SO4$, NH_4NO_3, P_2O_5, K_2O, $MgHCO_3$, $MgSO_4$, $CaHCO_3$, $CaSO_4$ and NaCl are water soluble and can be measured easily and directly by EC (Manitoba Agriculture, Food and Rural Development, 2015). Hence, consistent with the results of the present study, Ravbar *et al*. (2023) specifically promoted EC and major ions such as Ca^{2+}, Mg^{2+}, and Cl^{-} as key parameters to indicate the dynamics of water inflow from different subsystems of a karst hydrogeologic system. They further emphasized that in karst landscapes, where the risk of groundwater contamination is high, continuous monitoring of these easily measurable indicators and surrogate parameters is advantageous and should be done, as it facilitates the identification of contamination sources in early warning systems.

3.2.3 Chemical Oxygen Demand, Nitrate Nitrogen and Total Phosphorus

Another implication of the posited decomposition of piggery wastewater would be that the SG ponds should have had elevated COD levels and increased N and P release. The fact that COD and NO_3-N levels in both pond groups are not significantly different and that their TP levels are too low to be problematic points to a potential mechanism in the SG ponds that removes excess nutrients produced from the decomposition of organic materials in the slurry.

In a macrophyte inventory of the studied ponds, Monserate (2024a) determined that the SG has a significantly higher ($p < 0.05$) macrophyte density compared to the USG. Consequently, this observation identifies the excess macrophyte density as the primary driver in removing additional nutrients and organic matter through biomass assimilation in the SG ponds (Elliott *et al*., 2020). This is consistent with the proposed implication that elevated EC and TDS levels in SG ponds may reflect increased nutrient availability and a greater potential to support enhanced vegetation growth compared to USG ponds (Dunn and Singh, 2017). As it is, macrophytes can assimilate N and P from both the water column through their leaves and the water body sediments through their roots (Preiner *et al*., 2020). Rooted macrophytes — the sole type in the doline ponds (Monserate, 2024) — typically do not compete with phytoplankton and algae for nutrients, as they absorb most from nutrient-rich sediments, with uptake from the overlying water serving only as a secondary source (Burkholder and Glibert, 2013). According to Dhir *et al*. (2009), the removal of inorganic nutrients by aquatic plants, particularly macrophytes, primarily occurs through phytoassimilation wherein contaminants are transported and metabolized in the plant body (Ansari *et al*., 2020).

Phosphorus and N in the forms of PO_4^{3-} and NO_3^-, respectively, are the most essential nutrients in aquatic systems and are critical for the growth of aquatic vegetation (Sallenave, 2019). Based on this relationship, many studies have shown the capability of aquatic macrophytes to lower either or both PO_4^{3-}- and NO_3^- containing nutrients and organic matter in waters.

As highlighted by Aljawahiry *et al*. (2022) in their investigation of the feasibility of NO_3^- removal from agricultural wastewater using the macrophytes *Myriophyllum spicatum* L. and *Lemna gibba* L., a significant difference ($p < 0.05$) in NO_3^- absorption was observed between samples containing the two macrophyte species and the control sample without them. Additionally, *L. gibba*'s ability to utilize NO_3^- as a nutrient to create biomass was demonstrated by its significantly increased ($P < 0.05$) dry weight at the end of the experiment.

Kalengo *et al*. (2021) examined the efficiency of four aquatic macrophytes (i.e., *Lemna spp, Pistia stratiotes* L., *Ipomoea aquatica* Forssk., and *Eichhornia crassipes* (Mart.) Solms) for N and P utilization from aquacultural effluents. They found that regardless of the species, the TN, NH_3-N, NO_3-N, TP, and ortho-P concentrations still decreased with no significant difference ($p > 0.05$) between treatments.

In Mohan *et al*. (2010), floating, emergent, and submergent aquatic macrophytes were incorporated in an ecologically engineered system (EES) designed to mimic the natural cleansing functions of wetlands to bring about wastewater treatment. Based on the operation of the ESS, the researchers reported that among the three tanks of the system, the one with the macrophytes species *E. crassipes* was able to achieve an average COD removal efficiency of 72.92% to 76.19%, depending on the substrate used. It also attained an average NO_3^- removal efficiency of 23.15%. As for the other tank, which had macrophytes (i.e., *Bryophyllum pinnatum* (Lam.) Oken., *Lycopodium esculentum* L., *Coriandrum sativum* L., *Capsicum annum* L., *Oryza sativa* L., *Hydrilla verticillate* (L. f.) Royle, and *Myriophyllum*) its average NO_3^- removal efficiency is 15.99%. Both macrophyte tanks had higher average COD and NO_3^- removal efficiency compared to the last tank containing two snail and one carp species.

In light of the above, the relatively low COD levels observed in the pond groups indicate a lower presence of organic matters requiring chemical oxidation (Li and Liu, 2019). Consequently, this will likely result in higher DO levels, as less oxygen will be consumed in the subsequent oxidation process (Rekrak *et al*., 2020). Since NO_3-N and Total P levels are low in the doline ponds, eutrophication is less likely to occur (Akinnawo, 2023). Collectively, the inferred high DO concentrations and absence of eutrophic conditions in the doline ponds suggest a healthy and diverse aquatic ecosystem. If the opposite conditions were present, i.e., elevated nutrient levels and reduced O_2 concentrations, the ponds would likely exhibit diminished biodiversity. In support of this, Wang *et al*. (2021), in their study of zooplankton and zoobenthos diversity across 261 lakes in the eutrophication-affected Lake Taihu watershed in China, confirmed that excessive nutrient levels led to a significant loss of diversity and community simplification.

As the results of this study suggest, the macrophytes present in the SG ponds have likely played a role in remediating the pond water by absorbing excess nutrients and decreasing the risk of algal blooms. In effect, they have functioned as natural filters, removing pollutants and enhancing the overall health of the said aquatic ecosystem. Carefully conducted studies, such as that of Pastor *et al*. (2023), have demonstrated this capability of macrophytes. In that study, macrophyte removal in stream ecosystems led to a marked decline in nutrient retention capacity, with NH_4^+ uptake velocity decreasing by 34–77% and PO_4^{3-} uptake by 50–77%. Many macrophytes can also reduce the toxicity of a contaminated habitat by developing large central vacuoles that store harmful substances, such as heavy metals absorbed from the water (Maranho and Gomes, 2024). In Munyai and Dalu (2023), for example, their assessment of macrophytes' potential for phytoremediation of metals in an Austral subtropical river across three seasons found that the studied macrophytes, namely *Phragmites australis* (Cav.) Trin. ex Steud., *Schoenoplectus corymbosus* (Roth ex Roem. & Schult.) J.Raynal, and *Typha capensis* (Rohrb.) N.E.Br., were effective phytoremediators, with the ability to accumulate metals such as B, Na, Mg, Ca, and N. The improvement in water quality of the doline ponds, achieved through the reduction of excess nutrients and heavy metals as outlined here, can yield dividends by providing safer and more palatable potable water for the immediate community relying on the karst aquifer, as well as supporting healthier aquatic life in the ponds. In support of this, the study by Nahar and Hoque (2021) offers compelling evidence. In their study, the authors evaluated the capacity of *Pistia stratiotes* L. to enhance the quality of eutrophic water. The results showed a 100% survival rate of the species in the aquatic plant treatment setup, with no visible signs of toxicity in the biomass. Notably, the plant's extensive root system and overall biomass contributed to water quality improvement after just one week of treatment. This was evidenced by a significant reduction in turbidity, TDS, EC, and NaCl, alongside an increase in pH and DO levels. In fact, DO levels increased several-fold over the 168-hour (7-day) treatment period.

In addition to the benefits mentioned above, the high density of macrophytes in SG ponds can also play a more significant role in carbon sequestration by storing C in their biomass and accumulating organic C in the soil and water, even after they die and decompose. In a related study, Lolu *et al.* (2019) found that the twelve dominant macrophytes of Hokersar Wetland in India, act as a C pool of 0.85 kg C m^{-2} yr^{-1}, indicating their massive potential for C storage and thus helping to neutralize the effects of global warming. When it comes to C sequestration, macrophytes, alongside microalgae, are uniquely special because they can be cultivated in water, thus eliminating competition with food crops for fertile land, and have much higher growth rates as well as CO_2 fixation efficiencies that are almost 10–15 times greater than those of terrestrial plants (Khalid *et al.*, 2022).

However, while macrophytes exhibit a well-documented capacity to enhance water quality in aquatic ecosystems through nutrient assimilation, their more massive development in SG ponds could, however, be perceived as a nuisance that is hard to eradicate due to rapid macrophyte regrowth (Schneider *et al.*, 2024). Furthermore, their senescence and subsequent decomposition can result in the re-release of assimilated nutrients that can lead to eutrophication if unabated (Dhote, 2007). In relation to this, Rudic *et al.* (2018) highlighted two additional critical constraints associated with the use of macrophytes for nutrient remediation. First, effective macrophyte management necessitates the timely harvesting of biomass to prevent the reintroduction of sequestered nutrients into the water column during decomposition. This harvesting must occur prior to senescence; but, in the absence of mechanized equipment, the process becomes highly labor-intensive. Second, while the complete removal of macrophytes at the end of the growing season prevents nutrient recycling into the water, it also results in the permanent loss of those nutrients from the ecosystem, which may have implications for long-term ecological balance.

The above finding regarding the potential role of macrophytes in doline pond ecosystems — particularly in the SG ponds — is relevant to advancing the understanding of the impact of backyard pig farming on water quality. While such farming practices can adversely affect water quality, the presence of a manageable density of macrophytes may help mitigate these effects. This insight is especially relevant for the management of karstic aquatic systems, as karst landscapes possess geological properties that promote greater interaction between surface water and groundwater. Given these features, phytoremediation strategies using macrophytes can be considered as a mitigation measure against eutrophication for small-scale backyard pig farms that discharge slurry and manure into adjacent doline ponds. These strategies could provide preliminary natural treatment of the water before it infiltrates the aquifer, which supplies potable water to residents of Antipolo and the nearby village of Bantigue.

3.2.4 Turbidity

The marginally significant ($p = 0.06$) difference in the turbidity of the two pond groups, in which the USG ponds have higher mean turbidity values than the SG ponds, can also be attributed to the higher density of macrophytes in the latter.

Scheffer (1999) notes that aquatic macrophytes contribute to improved water transparency and decreased phytoplankton biomass through shading, reduction of nutrient availability, excretion of allelopathic substances, and reduction of resuspension. Elliott *et al*. (2020) also revealed that macrophytes can reduce resuspension by stabilizing the bed sediments, resulting in higher water clarity and improved water quality. James *et al*.'s (2000) examination of the effects of macrophyte shredding further demonstrates this connection between macrophytes and water turbidity. Turbidity levels increased dramatically over 14 days after removing macrophytes, suggesting some sediment resuspension due to increased wave activity.

As it is, macrophytes can be an effective means for the purpose of water transparency improvement as they promote sedimentation, which is one of the main turbidity reduction mechanisms according to Gomes *et al*., 2024. In Li *et al*. (2022), it was indicated that the presence of macrophytes and the distribution of their fixed or free root structures in the water column slows water flow velocity, which facilitates the settling of suspended solid particles in the water due to gravity. As for filtration, which is the other primary mechanism according to Li *et al*. (2022), the stems of aquatic plants, particularly in the case of emergent macrophytes, and their roots, as in the case free-floating macrophytes, increase the contact surface for trapping suspended particles and contribute significantly to reducing turbidity (Vymazal *et al*., 2007). The extensive root systems of some macrophytes also anchor the soil, minimizing sediment movement, which is crucial for maintaining water clarity and preventing the resuspension of particles and the spread of contaminants (Maranho and Gomes, 2024). The fact that macrophytes are highly effective in removing nutrients also contribute to their capability of reducing turbidity.

If not correctly managed, these nutrients—primarily N and P—which are commonly found in piggery wastewater can lead to eutrophication (Maranho and Gomes, 2024) characterized by a bloom of algae on the water's surface that creates a cloudy underwater environment (Denchak, 2019).

The reduced turbidity in SG ponds, if present, is likely beneficial to their ecological functioning. As pointed by Cole *et al*. (1999) high turbidity prevents much of the sun's light from reaching bottom-dwelling organisms, including submergent macrophytes. This is crucial as underwater autotrophs are often a critical source of food and shelter for other organisms, and without them entire aquatic food webs and ecosystems can suffer (Denchak, 2019). This was clearly demonstrated in a controlled experimental study that simulated varying levels of turbidity disturbance within the Yellow River wetland in China. In the said experiment, Shen *et al*. (2019) revealed that increases in turbidity can significantly reduce gross primary production (GPP) and ecosystem respiration (ER) rates, even within a single day. This result was explained by the fact that increases in turbidity limited photosynthetic O_2 production which in turn limited the GPP rate. And since the GPP declined more than the ER, the result was a lower net ecosystem production and a more heterotrophic water column.

Macrophytes are frequently incorporated into integrated farming systems, where they enhance overall farm productivity by fulfilling a range of essential ecological functions such as nutrient supply, heavy metals sorption, and improvement of soil structure (Poveda, 2022). These services may be attributed to the macrophytes ability to provide valuable feed ingredients for various aquatic and terrestrial animals, as well as their influence on hydrological processes, sediment dynamics, and biogeochemical cycles (Majeed *et al*., 2025). The results of the present study provide empirical support for the inclusion of macrophytes in policy frameworks aimed at mitigating elevated turbidity in aquatic ecosystems, particularly in karst landscapes. Moreover, the findings reinforce the argument that the carefully regulated introduction of piggery waste into doline ponds may be justified, as it can promote a balanced and ecologically appropriate level of macrophyte growth. According to Gomes *et al*. (2024), the most successful macrophyte morphotype in terms of turbidity reduction are those that have denser structures since they provide a larger contact surface, resulting in more efficient retention of suspended particles in the water. Macrophytes of this type may be incorporated into farming systems that integrate aquaculture and pig husbandry, such as the pig–fish integrated system, in which pig pens are typically situated adjacent to or on the dikes of fish ponds to facilitate the direct discharge of pig manure and waste into the aquatic environment (Tokrishna, 1992). Integrated pig-fish culture is not a new concept as it has been practiced for many years in many parts of Asia, including the Philippines (Fermin, 2001). In this integrated system, the addition of pig manure into fish ponds increases fish production through both the direct consumption of manure by fish and the enhancement of natural fish food via nutrient release from manure decomposition (Nnaji, 2008). The integration of freshwater macrophytes into this system aims to improve water quality by reducing pond turbidity through mechanisms outlined by Li *et al*. (2022) and Maranho and Gomes (2024). In addition, macrophytes can absorb excess nutrients and help prevent eutrophication of the fish ponds, thereby supporting the overall health of the agro-ecosystem (Mebane *et al*., 2014).

3.2.5 Temperature

Temperature is considered a key indicator of composting, as it is closely linked to the decomposition of organic matter and the growth of microorganisms and microbial communities (Wei *et al*., 2022). However, several studies have shown no significant change in the temperature of water bodies despite the addition of pig manure.

For instance, Dhawan and Kaur (2002) observed no significant adverse effect on the water temperature even after adding 18 and 36 t/ha/year of pond manure into their experimental carp polyculture tanks. Similarly, Hussein (2012), studying the effect of nutrient inputs (i.e., feed, manure, and their combination) on the common carp (*Cyprinus carpio*), found that the values of water temperature in the diurnal samples showed no effect of treatments. Instead, they concluded that its fluctuations are correlated with the presence and absence of sunlight.

Therefore, the absence of any significant difference in the water temperatures of the SG and USG despite the potential decomposition of organic matter in the former is perhaps driven by natural processes such as thermal radiation. According to Knud-Hansen (1998), thermal-radiation temperature losses occur when the ponds' surface water temperature is warmer than the air above, similar to the heat radiating from a pie fresh out of the oven cooling it in return.

Due to the exposure of pond waters to ambient air and wind, any heat generated by pig slurry decomposition would likely dissipate from the surface, balancing the temperature between the ponds and their immediate environment. In line with this, Bokossa *et al*. (2014a), investigating the effects of pig dejection decomposition in wetland conditions using pots experiment, reported that water temperature values after pig manure addition were similar in all treatments and just reflected the climatic condition during the experimentation period.

Apart from thermal radiation as the potential primary influencing factor, the non-significant difference in temperature between SG and USG ponds may also reflect observations in pond fertilization practices, that the application of pig slurry on ponds, as long as it is appropriately done, does not necessarily exert adverse impacts on the affected water bodies (Bwala and Omoregie, 2009). Consistent with this study's explanation for the non-significant differences in COD and NO_3-N, Kopp *et al*. (2008) reported that, because properly applied slurry is rapidly assimilated by biological communities for biomass growth, the resulting water quality impacts, including any temperature change, occur only in the period immediately following application. This was evident in their monitoring of the hydrochemical properties of Jarohněvický Pond in Moravia after pig slurries were applied. In this context, even at the highest sustainable application rates—16.1 kg/m^2 in 2001 and 15.6 kg/m^2 in 2002—used in their study, the resulting impacts on the pond ecosystem were transient rather than long-lasting. When applied to the present study, this reasoning supports the suggestion that backyard pig farming in Antipolo and Cantuhaon may not yet be excessive. As a result, the addition of piggery waste into the SG ponds may have remained within appropriate limits, thereby preventing sustained biodegradation activity that could have led to significant alterations in the water temperature of the affected ponds. This dynamic is reflected in the fact that the average pig-to-water surface ratio of the backyard pig farms associated with the SG ponds is very low, at 0.23 pigs/100 m^2 (Monserate, 2024). This ratio is likely insufficient to generate more than 10 liters/100 m^2 per day of pig slurry, which is considered the maximum safe loading rate for ponds in warm and tropical climates (Coche, 1996). To put it into perspective, Manh *et al*. (2012), in their investigation of the treatment of wastewater from pig farms in the Mekong delta, Vietnam, found that the pig-to-water surface ratio recorded in their study—from 2.36 to 9.12 pigs/100m^2—did not affect the temperature of the slurried ponds.

Although water temperature may not constitute a primary determinant of water quality in the present study, it remains a critical parameter due to its strong associations with and influence on other physicochemical properties. As previously noted, temperature is crucial for water quality, as it governs various physicochemical and biological processes within aquatic systems. It influences the solubility of gases, particularly DO (MRCCC, 2025a); regulates the rates of chemical reactions and biological activity in the water, including the metabolism of aquatic organisms (Kopp, 2012); affects their exposure to pollutants through corresponding changes in pH, EC, TDS, and COD removal efficiency (Dewangan *et al*., 2023b; Health Canada, 2021; Muloiwa *et al*., 2023); and impacts the palatability of water to consumers (Health Canada, 2021). Due to these implications, it is prudent that there should be a long-term monitoring of water temperature differences between the two pond groups as it can provide the opportunity to detect temporal points of excessive discharge of piggery wastes. Despite the fertilization observations cited above, the addition of pig slurry can induce changes in water temperature, particularly when not properly managed. In an investigation of the biochemical mechanisms affecting the availability of nutrients released from litter bags in water pots containing various types of pig dejections, Bokossa *et al*. (2014b) observed an increase in pot temperature after the 3rd and 6th week of fertilization in all treatments. These observed temperature rise, according to the authors, shows activation of metabolic reactions of nutrients released by microorganisms. Consequently, a decrease in DO was also observed during these time points as the increases in temperature triggered consumption of O_2 in the water which supports the faster degradation of organic matter. They also led to further increases in pH underscoring a propensity to alkalinity in water containing pig manure mainly due to a release of NH_3 from NH_4^+.

4. Conclusion and Recommendation

In terms of the water quality baseline, the present study found that all tested physicochemical properties, except for turbidity, were within optimal levels. The high turbidity of the doline ponds makes the water appear unhealthy. However, the other parameters indicate that the doline pond ecosystem is not deteriorating and that its water resource, when pumped from the aquifer and treated for turbidity, can be utilized for household tap water supply and agricultural irrigation.

Measurements for pH, Turbidity, COD, NO_3^--N, and Total P could be a reflection of the karstic nature of the ponds' locations. But aside from the geologic factor, the addition of pig slurry and manure at tolerable levels may also have influenced the physicochemical configuration of the ponds. This addition could have contributed to the parity in pH between the pond groups by significantly increasing the alkalinity of the SG ponds, thereby counteracting the potential acidity resulting from the decomposition of pig slurry and manure. This proposed scenario of intensified decomposition in the SG ponds is supported not only by their elevated alkalinity but also by their significantly higher EC and TDS. As these two indicators imply a higher nutrient load, the SG ponds were able to support a greater density of macrophytes. This, in turn—due to their phytoassimilative activity—may help explain the low levels and the absence of a significant difference between the two pond groups in terms of COD, NO_3^-–N, and Total P concentrations. Moreover, the presence of greater macrophyte biomass in the SG ponds may have contributed to the near-significant difference in turbidity between the groups, with turbidity being relatively lower in the SG ponds. The fact that water temperature remained within optimal levels and did not differ significantly between pond groups further supports both the influence of thermal radiation and the notion that piggery waste discharge into the SG ponds remained within acceptable limits.

Analysis of the results also shows that the current level of pig slurry and manure input into the doline ponds does not adversely affect water quality. However, evidence from the elevated EC and TDS values indicates that if this waste disposal practice increases without regulation, it could lead to negative consequences such as eutrophication. Given that groundwater is utilized in the Tabok Peninsula, it is therefore prudent that doline pond water resources be prioritized in the LDWQS monitoring programs of Isabel and Palompon, particularly if an uptick in backyard pig farming activity is observed.

The assessment was limited to doline ponds accessible within the Tabok Peninsula, with data collection conducted exclusively during the wet season. A more comprehensive understanding of the doline pond water quality—both in the presence and absence of slurry and manure discharge—would benefit from a broader spatial coverage and a longer temporal scale, ideally spanning at least one year to account for seasonal variations.

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6. References

Adjovu, G.E., Stephen, H., James, D., & Ahmad, S. (2023). Measurement of total dissolved solids and total suspended solids in water systems: A review of the issues, conventional, and remote sensing techniques. Remote Sensing, 15(14), 3534. https://doi.org/10.3390/rs15143534

Ahmed, M., Tóth, Z., & Decsi, K. (2024). The impact of salinity on crop yields and the confrontational behavior of transcriptional regulators, nanoparticles, and antioxidant defensive mechanisms under stressful conditions: A review. International Journal of Molecular Sciences, 25(5), 2654. https://doi.org/10.3390/ijms25052654

Akinnawo, S.O. (2023). Eutrophication: Causes, consequences, physical, chemical and biological techniques for mitigation strategies. Environmental Challenges, 12, 100733. https://doi.org/10.1016/j.envc.2023.100733

Aljawahiry, T., Hasoon, A., Imran, A.F., Abdulla, A.K., Al-Mualm, M., & Abbas, S.N. (2022). Effectiveness of aquatic plants in reducing water nitrates. Caspian Journal of Environmental Sciences, 20(5), 1031–1037. https://doi.org/10.22124/cjes.2022.6066

Ansari, A.A., Naeem, M., Gill, S.S., & Alzuaibr, F.M. (2020). Phytoremediation of contaminated waters: An eco-friendly technology based on aquatic macrophytes application. The Egyptian Journal of Aquatic Research, 46(4), 371–376. https://doi.org/10.1016/j.ejar.2020.03.002

Arhin, E., Osei, J.D., Anima, P.A., Damoah-Afari, P., & Yevugah, L.L. (2023). The pH of drinking water and its human health implications: A case of surrounding communities in the Dormaa Central Municipality of Ghana. Healthcare Treatment Development, 4(1), 15–26. https://doi.org/10.55529/jhtd.41.15.26

Ayers, R.S., & Westcot, D.W. (1989). Water quality for agriculture (FAO Irrigation and Drainage Paper No. 29 Rev. 1). Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/4/t0234e/T0234E06.htm

Baboo, P. (2015). Re: Could anyone tell which are the factors that affect pH in cow manure and pig manure? ResearchGate. Retrieved from https://www.researchgate.net/post/Could-anyone-tell-which-are-the-factors-that-affect-pH-in-Cow-manure-and-Pig-manure/5648b47160614b4cde8b4569/citation/download

Bain, G., Allen, M.W., & Kreuziger Keppy, N. (2009). Analysis of nitrate nitrogen (NO_3^-) in water by the EPA approved Brucine method [Application Note]. Thermo Fisher Scientific. Retrieved from https://assets.thermofisher.com/TFS-Assets/CMD/Application-Notes/AN-51862-Analysis-of-Nitrate-Nitrogen-in-Water-by-the-EPA-Approved-Brucine-Method.pdf

Banag, C., Thrippleton, T., Alejandro, G.J., Reineking, B., & Liede-Schumann, S. (2015). Bioclimatic niches of selected endemic Ixora species on the Philippines: Predicting habitat suitability due to climate change. Plant Ecology. https://doi.org/10.1007/s11258-015-0512-6

Bernal, M.P., Roig, A., Lax, A., & Navarro, A.F. (1992). Effects of the application of pig slurry on some physico-chemical and physical properties of calcareous soils. Bioresource Technology, 42(3), 233–239. https://doi.org/10.1016/0960-8524(92)90026-T

Bokossa, H.K.J., Saïdou, A., Sossoukpe, E., Fiogbé, D.E., & Kossou, D. (2014b). Decomposition and mineralization effect of various sources of pig manure on water quality and nutrients availability for agro-fish system in Benin. Agricultural Sciences, 5(12), 1111–1120. https://doi.org/10.4236/as.2014.512121

Bokossa, J., Saidou, A., Fiogbe, E., & Kossou, D. (2014a). Decomposition rate of pigs' manures and nutrient release pattern in wetland condition. Journal of Agriculture, Forestry and Fisheries, 3(4), 271–278. https://doi.org/10.11648/j.aff.20140304.19

Boyd, C.E. (2012, September 2). Turbidity removal from pond waters. Global Seafood Alliance. Retrieved from https://www.globalseafood.org/advocate/turbidity-removal-from-pond-waters/

Bozorg-Haddad, O., Delpasand, M., & Loáiciga, H.A. (2021). Water quality, hygiene, and health. In O. Bozorg-Haddad (Ed.), Economical, political, and social issues in water resources (pp. 217–257). Elsevier. https://doi.org/10.1016/B978-0-323-90567-1.00008-5

Bukhary, S.S. (2024). The renewable energy–water nexus. In S. Jafarinejad & B.S. Beckingham (Eds.), The renewable energy–water–environment nexus (pp. 143–176). Elsevier. https://doi.org/10.1016/B978-0-443-13439-5.00006-5

Burkholder, J.M., & Glibert, P.M. (2013). Eutrophication and oligotrophication. In S.A. Levin (Ed.), Encyclopedia of biodiversity (2nd ed). pp. 347–371. Academic Press. https://doi.org/10.1016/B978-0-12-384719-5.00047-2

Bwala, R., & Omoregie, E. (2009). Organic enrichment of fish ponds: Application of pig dung vs. tilapia yield. Pakistan Journal of Nutrition, 8(9), 1373–1379. https://doi.org/10.3923/pjn.2009.1373.1379

Cable, J.E., Corbett, D.R., & Walsh, M.M. (2002). Phosphate uptake in coastal limestone aquifers: A fresh look at wastewater management. Limnology and Oceanography Bulletin, 11(2), 1–4. https://doi.org/10.1002/lob.200211229

Calub, A.D., Saludes, R.B., & Tabing, E.V.P. (2016). An overview of agricultural pollution in the Philippines: The livestock sector. The World Bank. Retrieved from https://documents1.worldbank.org/curated/en/640711516770288512/pdf/122930-WP-P153343-PUBLIC-Philippines-Livestock.pdf

Cardinale, B.J. (2011). Biodiversity improves water quality through niche partitioning. Nature, 472(7341), 86–89. https://doi.org/10.1038/nature09904

Castillo, A.M., Sharpe, D.M.T., Ghalambor, C.K., & De León, L.F. (2018). Exploring the effects of salinization on trophic diversity in freshwater ecosystems: A quantitative review. Hydrobiologia, 807(1), 1–17. https://doi.org/10.1007/s10750-017-3403-0

Cayubit, R. (2020). Leyte records highest swine production in Eastern Visayas in 3rd quarter of 2019. Manila Bulletin. Retrieved from https://mb.com.ph/2020/01/10/leyte-records-highest-swine-production-in-eastern-visayas-in-3rd-quarter-of-2019/

Center for Agriculture, Food and the Environment. (2016). Nitrogen fact sheet. University of Massachusetts Amherst. Retrieved from https://www.umass.edu/mwwp/resources/factsheets.html

Cerozi, B.D.S., & Fitzsimmons, K. (2016). The effect of pH on phosphorus availability and speciation in an aquaponics nutrient solution. Bioresource Technology, 219, 778–781. https://doi.org/10.1016/j.biortech.2016.08.079

Chakraborty, R., Khan, K.M., Dibaba, D.T., Khan, M.A., Ahmed, A., & Islam, M.Z. (2019). Health implications of drinking water salinity in coastal areas of Bangladesh. International Journal of Environmental Research and Public Health, 16(19), 3746. https://doi.org/10.3390/ijerph16193746

Childs, D.Z., Hindle, B.J., & Warren, P.H. (2021). Data analysis and statistics with R. Retrieved from https://dzchilds.github.io/stats-for-bio/index.html

Chynoweth, D.P., Wilkie, A.C., & Owens, J.M. (1999). Anaerobic treatment of piggery slurry - Review. Animal Bioscience. Retrieved from https://www.animbiosci.org/upload/pdf/12-85.pdf

Coche, A.G. (1996). Management for freshwater fish culture: Ponds and water practices (Vol. 1). Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/fishery/static/FAO_Training/FAO_Training/General/x6709e/x6709e06.htm

Cole, S., Codling, I.D., Parr, W., & Zabel, T. (1999). Guidelines for managing water quality impacts within UK European marine sites. UK Marine SACs Project. Retrieved from http://ukmpa.marinebiodiversity.org/uk_sacs/pdfs/water_quality.pdf

Coxon, C. (2011). Agriculture and karst. In P.E. van Beynen (Ed.), Karst management (pp. 103–138). Springer. https://doi.org/10.1007/978-94-007-1207-2_5

De Vries, W. (2021). Impacts of nitrogen emissions on ecosystems and human health: A mini review. Current Opinion in Environmental Science & Health, 21, 100249. https://doi.org/10.1016/j.coesh.2021.100249

Denchak, M. (2019). Freshwater harmful algal blooms 101. Natural Resources Defense Council. Retrieved from https://www.nrdc.org/stories/freshwater-harmful-algal-blooms-101

Department of Environment and Natural Resources. (1990). DENR Administrative Order No. 35: Revised effluent regulations of 1990, revising and amending the effluent regulations of 1982. Retrieved from https://water.emb.gov.ph/wp-content/uploads/2016/07/DAO-1990-35.pdf

Department of Environment and Natural Resources. (2016). DENR Administrative Order No. 2016-08: Water quality guidelines and general effluent standards of 2016. Retrieved from https://emb.gov.ph/wp-content/uploads/2019/04/DAO-2016-08_WATER-QUALITY-GUIDELINES-AND-GENERAL-EFFLUENT-STANDARDS.pdf

Department of Health [DOH], & Department of the Interior and Local Government [DILG]. (2022). Guidelines on establishing local drinking water quality surveillance (LDWQS) program through the creation of local drinking water quality monitoring committee (LDWQMC) as mandated by the Code on Sanitation (PD 856). Retrieved from https://faolex.fao.org/docs/pdf/phi210925.pdf

Department of Health [DOH]. (2017). DOH Administrative Order No. 2017-0010: Philippine national standards for drinking water of 2017. Retrieved from https://www.fda.gov.ph/wp-content/uploads/2021/08/Administrative-Order-No.-2017-0010.pdf

Dewangan, S.K., & Srivastava, S.K. (2024). A correlation between EC and TDS in water: A review. International Journal of Worldwide Engineering Research, 5, 180–186. Retrieved from https://www.researchgate.net/publication/386075952_A_CORRELATION_BETWEEN_EC_AND_TDS_IN_WATER_A_REVIEW

Dewangan, S.K., Shrivastava, S., Tigga, V., Lakra, M., Namrata, & Preeti. (2007). Review paper on the role of pH in water quality: Implications for aquatic life, human health, and environmental sustainability, 10, 215–218. https://doi.org/10.17148/IARJSET.2023.10633

Dewangan, S.K., Toppo, D.N., & Kujur, A. (2023a). Investigating the impact of pH levels on water quality: An experimental approach. International Journal for Research in Applied Science & Engineering Technology, 11(9), 756–761. Retrieved from https://www.researchgate.net/publication/374329780_Investigating_the_Impact_of_pH_Levels_on_Water_Quality_An_Experimental_Approach

Dewangan, S.K., Shrivastava, S.K., Kadri, M.A., Saruta, S., Yadav, S., & Minj, N. (2023b). Temperature effect on electrical conductivity (EC) & total dissolved solids (TDS) of water: A review. Retrieved from https://www.researchgate.net/publication/371539432_TEMPERATURE_EFFECT_ON_ELECTRICAL_CONDUCTIVITYEC_TOTAL_DISSOLVED_SOLIDS_TDS_OF_WATER_A_REVIEW

Dhawan, A., & Kaur, S. (2002). Pig dung as pond manure: Effect on water quality, pond productivity, and growth of carps in polyculture system. Naga, The ICLARM

Quarterly, 25(1), January–March. Retrieved from https://aquadocs.org/bitstream/handle/1834/25772/NAGA%2025no1_aquabyte.pdf?sequence=1&isAllowed=y

Dhir, B., Sharmila, P., & Saradhi, P.P. (2009). Potential of aquatic macrophytes for removing contaminants from the environment. Critical Reviews in Environmental Science and Technology, 39(9), 754–781. https://doi.org/10.1080/10643380801977776

Dhote, S. (2007). Role of macrophytes in improving water quality of an aquatic ecosystem. Journal of Applied Sciences and Environmental Management, 11(4), 141–146. Retrieved from https://www.researchgate.net/publication/27796849_Role_Of_Macrophytes_In_Improving_Water_Quality_Of_An_Aquatic_Eco-system

Díez, J.A., Hernaiz, P., Muñoz, M.J., de la Torre, A., & Vallejo, A. (2004). Impact of pig slurry on soil properties, water salinization, nitrate leaching and crop yield in a four-year experiment in Central Spain. Soil Use and Management, 20(4), 444–450. https://doi.org/10.1079/SUM2004283

Dorado, M., Agbisit, E., & Catelo, M.A. (2019). Backyard and commercial piggeries in the Philippines: Environmental consequences and pollution control options. https://doi.org/10.13140/RG.2.2.26210.89288

Dunn, B., & Singh, H. (2017). Electrical conductivity and pH guide for hydroponics. Oklahoma State University Extension. Retrieved from https://extension.okstate.edu/fact-sheets/electrical-conductivity-and-ph-guide-for-hydroponics.html

Edzwald, J.K. (2010). Water quality and treatment: A handbook on drinking water. McGraw-Hill. Retrieved from https://www.accessengineeringlibrary.com/binary/mheaeworks/f6f94736da5dad98/ed297a41abdf8460efdf71bfbd99e28106b3b23e62982398702852f4e05d8a43/book-summary.pdf

El Bied, O., Kessler, M., Terrero, M., Fechtali, T., Cano, A., & Acosta, J. (2021). Turbidity and chemical oxygen demand reduction from pig slurry through a coagulation flocculation process. Agronomy, 11(11), 2158. https://doi.org/10.3390/agronomy11112158

Elliott, S., Graham, E., Woodward, B., Dudley, B., Stevens, L., Verburg, P., Zeldis, J., Hofstra, D., & Matheson, F. (2020). Consequences of inaction: Potential ramifications of delaying proposed nutrient source reductions for New Zealand rivers, lakes, and estuaries. Ministry for the Environment. Retrieved from https://environment.govt.nz/assets/Publications/Files/consequences-of-inaction-potential-ramifications-of-delaying-proposed-nutrient-source-reductions.pdf

Environment Agency. (2019). Phosphorus and freshwater eutrophication pressure narrative. Department for Environment, Food & Rural Affairs. Retrieved from https://consult.environment-agency.gov.uk/++preview++/environment-and-business/challenges-and-choices/user_uploads/phosphorus-pressure-rbmp-2021.pdf

Fang, C.P.L., & Elca, C.D. (2021). An assessment of swine industry in the Philippines. Journal of Economics, Management and Agricultural Development, 7(1). Retrieved from https://jemad.cem.uplb.edu.ph/wp-content/uploads/2021/11/JEMAD-Vol-7-No-1-Fang.pdf

Fermin, F.V. (2001). Backyard integrated pig-fish culture in the Philippines. In Integrated agriculture-aquaculture: A primer. Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/4/y1187e/y1187e17.htm

Follett, R.H., Murphy, L.S., & Donahue, R.L. (1981). Fertilizers and soil amendments. Prentice-Hall.

Food and Agriculture Organization of the United Nations. (1981). Chapter 2: Improving pond water quality. In Simple methods for aquaculture: Water for freshwater fish culture (FAO Training Series). Retrieved from https://www.fao.org/fishery/static/FAO_Training/FAO_Training/General/x6709e/x6709e02.htm#top

Fridrich, B., Krčmar, D., Dalmacija, B., Molnar, J., Pešić, V., Kragulj, M., & Varga, N. (2014). Impact of wastewater from pig farm lagoons on the quality of local groundwater. Agricultural Water Management, 135, 40–53. https://doi.org/10.1016/j.agwat.2013.12.014

Frost, J. (2025). Guidelines for removing and handling outliers in data. Statistics by Jim. Retrieved from https://statisticsbyjim.com/basics/remove-outliers

Gao, Y., Zhang, C., Tan, L., Wei, X., Li, Q., Zheng, X., Liu, F., Wang, J., & Xu, Y. (2022). Full-scale of a compost process using swine manure, human feces, and rice straw as feedstock. Frontiers in Bioengineering and Biotechnology, 10, 928032. https://doi.org/10.3389/fbioe.2022.928032

Geraldo, R. (2021). Company history. Retrieved from https://isabelwd.com/index.php/company-profile/

Gillieson, D. (2019). A second edition of the IUCN guidelines for cave and karst protection. Retrieved from https://www.researchgate.net/publication/340684086_A_Second_Edition_of_the_IUCN_Guidelines_for_Cave_and_Karst_Protection

Gomes, P.C.S., Rochinha, I.d.S.P., Paiva, M.H.R.d., & Santiago, A.d.F. (2024). Performance of different macrophytes and support media in constructed wetlands for high turbidity reduction from mine spoil rainwater. Resources, 13(12), 168. https://doi.org/10.3390/resources13120168

Hamilton, D., & Zhang, H. (2011). Solids content of wastewater and manure. Oklahoma Cooperative Extension Service. Retrieved from https://core.ac.uk/download/pdf/215270701.pdf

Hassan Omer, N. (2020). Water quality parameters. IntechOpen. Retrieved from https://www.intechopen.com/chapters/69568

Health Canada. (2021). Guidance on the temperature aspects of drinking water (Catalogue No. H144-92/2021E-PDF). Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch, Health Canada. Retrieved from https://www.canada.ca/content/dam/hc-sc/documents/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-temperature/27-21-2998-Guidance-Temp-Aspects-Drinking-Water-EN.pdf

Hjorth, M., Christensen, K.V., Christensen, M.L., & Sommer, S.G. (2010). Solid-liquid separation of animal slurry in theory and practice: A review. Agronomy for Sustainable Development, 30(1), 153–180. https://doi.org/10.1051/agro/2009010

Hofierka, J., Gallay, M., Bandura, P., & Šašak, J. (2018). Identification of karst sinkholes in a forested karst landscape using airborne laser scanning data and water flow analysis. Geomorphology, 308, 265–277. https://doi.org/10.1016/j.geomorph.2018.02.004

Hussein, M.S. (2012). Effect of feed, manure, and their combination on the growth of Cyprinus carpio (L.) fry and fingerlings. Egyptian Journal of Aquatic Biology and Fisheries, 16(2), 153–168. Retrieved from https://ejabf.journals.ekb.eg/article_2133_68a08fe7dfa08132eac5e7553ceb5083.pdf

James, W.F., Barko, J.W., & Eakin, H.L. (2000). Macrophyte management via mechanical shredding: Effects on water quality in Lake Champlain (Vermont–New York). APCRP Technical Notes Collection (ERDC TN-APCRP-MI-05). U.S. Army Engineer Research and Development Center. Retrieved from https://www.noaa.gov/sites/default/files/legacy/document/2020/Oct/07354626175.pdf

Jayasundara, S. (2015). Re: Could anyone tell which are the factors that affect pH in cow manure and pig manure? ResearchGate. Retrieved from https://www.researchgate.net/post/Could-anyone-tell-which-are-the-factors-that-affect-pH-in-Cow-manure-and-Pig-manure/564948c46307d916848b4567/citation/download

Kadhem, A.J. (2013). Assessment of water quality in Tigris River-Iraq by using GIS mapping. Natural Resources, 4(6), 441–448. https://doi.org/10.4236/nr.2013.46054

Kalengo, L., Ge, H., Liu, N., & Wang, Z. (2021). The efficiency of aquatic macrophytes on the nitrogen and phosphorous uptake from pond effluents in different seasons. Journal of Ecological Engineering, 22(5), 75–85. Retrieved from https://www.jeeng.net/pdf-140308-67670

Kefford, B.J., Marchant, R., Schäfer, R.B., Metzeling, L., Dunlop, J.E., Choy, S.C., & Goonan, P. (2011). The definition of species richness used by species sensitivity distributions approximates observed effects of salinity on stream macroinvertebrates. Environmental Pollution, 159(1), 302–310. https://doi.org/10.1016/j.envpol.2010.08.025

Khalid, Z., Alam, S.N., Singh, B., & Guldhe, A. (2022). Prospects of carbon capture and carbon sequestration using microalgae and macrophytes. In V.C. Pandey (Ed.), Algae and aquatic macrophytes in cities (pp. 119–134). Elsevier. https://doi.org/10.1016/B978-0-12-824270-4.00013-4

KnowYourH2O Water Research Center. (2025). Alkalinity. Water Quality Association, Eastern Water Quality Association. Retrieved from https://www.knowyourh2o.com/indoor-6/alkalinity

Knud-Hansen, C.F. (1998). Pond fertilization: Ecological approach and practical application. Pond Dynamics/Aquaculture CRSP. Retrieved from https://pdf.usaid.gov/pdf_docs/Pnach582.pdf

Koelsch, R. (2019). Principles of environmental stewardship. Livestock and Poultry Environmental Learning Community. Retrieved from https://lpelc.org/wp-content/uploads/2019/03/LES_01.pdf

Kopp, R. (2012). Water quality after application of pig slurry. InTechOpen. https://doi.org/10.5772/29100

Kopp, R., Mareš, J., Zikova, A., & Vítek, T. (2008). Variations of physical and chemical parameters in a hypertrophic pond with pig slurry application. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 56(2), 95–99. https://doi.org/10.11118/actaun200856020095

Kulpredarat, N. (2023). The impact of pig wastewater to water environment in Thailand [PowerPoint slides]. WEPA. Retrieved from https://wepa-db.net/wp-content/uploads/2023/02/5_2-The-impact-of-pig-wastewater-to-water-environment-in-Thailand.pdf

Kumar, D., Martin, S., Thai, B., Luu, L., & Clarke, S. (2005). Evaluation of fish production using organic and inorganic fertilizer: Application to grass carp polyculture. Journal of Applied Aquaculture, 17(3), 19–34. Retrieved from https://www.researchgate.net/publication/233037102_Evaluation_of_Fish_Production_Using_Organic_and_Inorganic_Fertilizer_Application_to_Grass_Carp_Polyculture

Kusumawati, S., & Widyastuti, M. (2023). Water quality status of Omang Pond in Gunungsewu Karst area, Gunungkidul, Indonesia. E3S Web of Conferences, 468, 08009. https://doi.org/10.1051/e3sconf/202346808009

Kutty, M.N. (1987). Site selection for aquaculture: Chemical features of water. United Nations Development Programme, African Regional Aquaculture Center. Retrieved from https://www.fao.org/3/ac175e/ac175e00.htm

Leibundgut, C. (1998). Vulnerability of karst aquifers. In Karst Hydrology (Proceedings of Workshop W2 held at Rabat, Morocco, April–May 1997; IAHS Publ. No. 247). Retrieved from https://www.researchgate.net/profile/Chris-Leibundgut/publication/294570938_Vulnerability_of_karst_aquifers/links/5b066d440f7e9b1ed7e8365f/Vulnerability-of-karst-aquifers.pdf

Li, D., & Liu, S. (2019). Chapter 8 – Water quality detection for lakes. In D. Li & S. Liu (Eds.), Water quality monitoring and management (pp. 221–231). Academic Press. https://doi.org/10.1016/B978-0-12-811330-1.00008-9

Li, D., Yang, Z., & Guo, M. (2022). Study of suspended sediment diffusion coefficients in submerged vegetation flow. Water Resources Research, 58(3), e2021WR031155. https://doi.org/10.1029/2021WR031155

Liu, Y. (2014). Outliers. In A.C. Michalos (Ed.), Encyclopedia of quality of life and well-being research. Springer. https://doi.org/10.1007/978-94-007-0753-5_2039

Lolu, A.J., Ahluwalia, A.S., Sidhu, M.C., & Reshi, Z.A. (2019). Carbon sequestration potential of macrophytes and seasonal carbon input assessment into the Hokersar Wetland, Kashmir. Wetlands, 39(3), 453–472. https://doi.org/10.1007/s13157-018-1092-8

Luo, P., Long, Z., Sun, M., Feng, Q., Zeng, X., Wang, H., Luo, Z., & Sun, G. (2023). Long-term application of pig manure to ameliorate soil acidity in red upland. Agriculture, 13(9), 1837. https://doi.org/10.3390/agriculture13091837

Machado, R.M.A., & Serralheiro, R.P. (2017). Soil salinity: Effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. Horticulturae, 3(2), 30. https://doi.org/10.3390/horticulturae3020030

Maharjan, K., & Fradejas, C. (2005). A study of the problems confronting the backyard pig raisers in Batangas Province of Southern Luzon. Journal of Rural Problems, 41(3), 236–241. Retrieved from https://www.jstage.jst.go.jp/article/arfe1965/41/1/41_1_236/_pdf/-char/en

Majeed, L.R., Sharma, D., Rautela, K.S., & Kumar, M. (2025). Sustainable agriculture, aquaculture and phytoremediation through freshwater macrophytes: A comprehensive review of mineral uptake, soil health, and water quality dynamics. Discover Water, 5(1). https://doi.org/10.1007/s43832-024-00188-5

Manalo, N.Q., & Dorado, R.A. (2017). ASEAN Economic Community: Opportunities and challenges for the livestock and forestry sector (Project Report). Los Baños, Laguna, Philippines: Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development. Retrieved from https://ispweb.pcaarrd.dost.gov.ph/isp-commodities/swine/

Manh, L.H., Dung, N.N.X., Minh, B.T.L., & Duong, M.T. (2012). Treating pig wastewater by applying a model of fish pond or biodigester tank followed by a fish pond in Phuoc Tho state farm. Livestock Research for Rural Development, 24(2). Retrieved from http://www.lrrd.org/lrrd24/2/manh24029.htm

Manitoba Agriculture, Food and Rural Development. (2015). Properties of manure. Retrieved from https://www.gov.mb.ca/agriculture/environment/nutrient-management/pubs/properties-of-manure.pdf

Maranho, L.T., & Gomes, M.P. (2024). Morphophysiological adaptations of aquatic macrophytes in wetland-based sewage treatment systems: Strategies for resilience and efficiency under environmental stress. Plants, 13(20), 2870. https://doi.org/10.3390/plants13202870

Marshall, J.P., & Wilcox, H. (2015). How green and does it clean: Methodologies for assessing cleaning products for safety and performance. In R. Kohli & K.L. Mittal (Eds.), Developments in surface contamination and cleaning (Vol. 1, pp. 1–69). William Andrew Publishing. https://doi.org/10.1016/B978-0-323-29961-9.00001-6

Mary River Catchment Coordinating Committee [MRCCC]. (2025a). What is water quality? Retrieved from https://mrccc.org.au/wp-content/uploads/2013/10/Fact-sheet-Water-Quality.pdf

Mary River Catchment Coordinating Committee [MRCCC]. (2025b). Water quality salinity standard factsheet. Retrieved from https://mrccc.org.au/wp-content/uploads/2013/10/Water-Quality-Salinity-Standards.pdf

McCutcheon, G., & Quinn, A. (2020). Pig manure: A valuable fertiliser (2nd ed.). TEAGASC. Retrieved from https://www.teagasc.ie/media/website/publications/2020/pig-manure-a-valuable-fertiliser.pdf

Mebane, C.A., Simon, N.S., & Maret, T.R. (2014). Linking nutrient enrichment and streamflow to macrophytes in agricultural streams. Hydrobiologia, 722(1), 143–158. https://doi.org/10.1007/s10750-013-1693-4

Meunier, C.L., & Boersma, M. (2017). Aquatic nutrient cycling. Oxford Bibliographies. https://doi.org/10.1093/obo/9780199830060-0177

Miller, N.A., & Stillman, J.H. (2012). Physiological optima and critical limits. Nature Education Knowledge, 3(10), 1. Retrieved from https://www.nature.com/scitable/knowledge/library/physiological-optima-and-critical-limits-45749376/

Mohan, S.V., Mohanakrishna, G., Chiranjeevi, P., Peri, D., & Sarma, P.N. (2010). Ecologically engineered system (EES) designed to integrate floating, emergent, and submerged macrophytes for the treatment of domestic sewage and acid-rich fermented-distillery wastewater: Evaluation of long-term performance. Bioresource Technology, 101(10), 3363–3370. https://doi.org/10.1016/j.biortech.2009.12.027

Monserate, N.F. (2024). Assessment of the effect of pig slurry drainage on macrophyte biodiversity in doline ponds of Tabok Peninsula, Isabel, Leyte, Philippines (Dissertation). School of Arts and Sciences, University of San Carlos - Talamban Campus, Cebu City, Cebu, Philippines.

Muloiwa, M., Dinka, M.O., & Nyende-Byakika, S. (2023). Impact of temperature and airflow rate on the removal of organic pollutants and inorganic pollutants in the biological treatment process. South African Journal of Chemical Engineering, 43, 245–256. https://doi.org/10.1016/j.sajce.2022.11.007

Munyai, L.F., & Dalu, T. (2023). Aquatic macrophytes metal and nutrient concentration variations, with implication for phytoremediation potential in a subtropical river system. Sustainability, 15(20), 14933. https://doi.org/10.3390/su152014933

Nahar, K., & Hoque, S. (2021). Phytoremediation to improve eutrophic ecosystem by the floating aquatic macrophyte, water lettuce (*Pistia stratiotes* L.) at lab scale. The Egyptian Journal of Aquatic Research, 47(3), 317–322. https://doi.org/10.1016/j.ejar.2021.05.003

Niala, C.D. (2023). Swine situation report in Central Visayas: July to September 2022 preliminary results. Retrieved from https://rsso07.psa.gov.ph/system/files/attachment-dir/2023-SR07-009.pdf

Njue, J.M., Magana, A.M., & Githae, E.W. (2022). Effects of agricultural nutrients influx on water quality in Thiba River Basin, a sub-catchment of Tana River Basin in Kirinyaga County, Kenya. East African Journal of Agriculture and Biotechnology, 5(1). https://doi.org/10.37284/2707-4307

Nnaji, J. (2008). Integrated pig-fish farming. https://doi.org/10.13140/RG.2.2.14999.68000

Ogunji, J.O., & Awoke, J. (2017). Effect of environmentally regulated water temperature variations on survival, growth performance, and haematology of African catfish (*Clarias gariepinus*). Our Nature, 15(1–2), 26–33. https://doi.org/10.3126/on.v15i1-2.18791

Ohio Environmental Protection Agency [EPA]. (2021). Surface water field sampling manual – Appendix III. Retrieved from https://gphohio.org/wp-content/uploads/sites/17/2023/02/Field_Manual_4_13_12_revision.pdf

Oraiz, K., Saz, V., Cascante, M., Garrido, A.N., Galvez, S., & Asio, V. (2021). Characteristics and nutrient status of limestone soils in Leyte and Samar, Philippines. ResearchGate. Retrieved from https://www.researchgate.net/publication/352492545_Characteristics_and_Nutrient_Status_of_Limestone_Soils_in_Leyte_and_Samar_Philippines

Pandey, S., & Singh, S.P. (2012). Organic solvent tolerance of an α-amylase from haloalkaliphilic bacteria as a function of pH, temperature, and salt concentrations. Applied Biochemistry and Biotechnology, 166(7), 1747–1757. https://doi.org/10.1007/s12010-012-9580-4

Parise, M. (2019). Sinkholes. In W.B. White, D.C. Culver, & T. Pipan (3rd dd.), Encyclopedia of caves (pp. 934–942). Academic Press. https://doi.org/10.1016/B978-0-12-814124-3.00110-2

Park, S.N. (2024, March 15). Monte Carlo hypothesis tests versus traditional parametric tests. Medium. Retrieved from https://medium.com/@snp.kriss/monte-carlo-hypothesis-tests-versus-traditional-parametric-tests-669a701a0b9c

Pastor, A., Holmboe, C.M.H., Pereda, O., Giménez-Grau, P., Baattrup-Pedersen, A., & Riis, T. (2023). Macrophyte removal affects nutrient uptake and metabolism in lowland streams. Aquatic Botany, 189, 103694. https://doi.org/10.1016/j.aquabot.2023.103694

Pedrozo-Acuña, A., & Ramirez, N. (2025). Water sustainability criteria to regulate the proliferation of pig farms on a karst aquifer. Sustainability, 17(7), Article 3069. https://doi.org/10.3390/su17073069

Pennisi, S.V., & Thomas, P.A. (2009). Essential pH management in greenhouse crops – Part 1: pH and plant nutrition. University of Georgia. Retrieved from https://openscholar.uga.edu/record/23377?v=pdf

Petr, T. (2000). Interactions between fish and aquatic macrophytes in inland waters: A review (FAO Fisheries Technical Paper No. 396). Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/4/x7580e/X7580E04.htm

PhilAtlas. (2022a). Isabel profile. PhilAtlas. Retrieved from https://www.philatlas.com/visayas/r08/leyte/isabel.html

PhilAtlas. (2022b). Palompon profile. PhilAtlas. Retrieved from https://www.philatlas.com/visayas/r08/leyte/palompon.html

Piasai, C., Phorndon, T., Boontian, N., & Padri, M. (2020). Swine manure as alternative source of alkalinity to remove nitrogen and phosphorus in biological treatment systems. KKU Research Journal (Graduate Studies), 20(4), 1–10. Retrieved from https://ph02.tci-thaijo.org/index.php/gskku/article/view/242231/164403

Pinder, A.M., Halse, S.A., McRae, J.M., & Shiel, R.J. (2005). Occurrence of aquatic invertebrates of the wheatbelt region of Western Australia in relation to salinity. Hydrobiologia, 543, 1–24. https://doi.org/10.1007/s10750-004-5712-3

Piotrowski, J., Wagner, K., & Gibson, R. (2011). Nitrogen and phosphorus pollution and harmful algal blooms in lakes. U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/system/files/documents/2021-10/nutrients-and-algal-blooms-v2-nxpowerlite.pdf

Poveda, J. (2022). The use of freshwater macrophytes as a resource in sustainable agriculture. Journal of Cleaner Production, 369, 133247. https://doi.org/10.1016/j.jclepro.2022.133247

Prasad, R., & Chakraborty, D. (2019, April 19). Phosphorus basics: Understanding phosphorus forms and their cycling in the soil. Alabama Cooperative Extension System. Retrieved from https://www.aces.edu/blog/topics/crop-production/understanding-phosphorus-forms-and-their-cycling-in-the-soil

Preiner, S., Dai, Y., Pucher, M., Reitsema, R.E., Schoelynck, J., Meire, P., & Hein, T. (2020). Effects of macrophytes on ecosystem metabolism and net nutrient uptake in a groundwater-fed lowland river. Science of The Total Environment, 721, 137620. https://doi.org/10.1016/j.scitotenv.2020.137620

Queensland Government. (2013). Impacts of salinity. Retrieved from https://www.qld.gov.au/environment/land/management/soil/degradation/salinity/impacts

R Core Team. (2021). R: A language and environment for statistical computing [Computer software]. Vienna, Austria: R Foundation for Statistical Computing.

Ravbar, N., Mulec, J., Mayaud, C., Blatnik, M., Kogovšek, B., & Petrič, M. (2023). A comprehensive early warning system for karst water sources contamination risk: Case study of the Unica springs, SW Slovenia. Science of The Total Environment, 885, 163958. https://doi.org/10.1016/j.scitotenv.2023.163958

Rekrak, A.Z., Fellah, A., & Boulefred, S. (2020). Dependability and purification performance of a semi-arid zone: A case study of Algeria's wastewater treatment plant.

The Egyptian Journal of Aquatic Research. Retrieved from https://www.researchgate.net/publication/339381887

Restificar, S., Day, M., & Urich, P. (2006). Protection of karst in the Philippines. Acta Carsologica, 35, 1–9. https://doi.org/10.3986/ac.v35i1.248

Rice, E.W., Baird, R.B., & Eaton, A.D. (2017). Standard methods for the examination of water and wastewater (23rd ed.). American Public Health Association, American Water Works Association, Water Environment Federation. Retrieved from https://yabesh.ir/wp-content/uploads/2018/02/Standard-Methods-23rd-Perv.pdf

Rosa, D.M., Sampaio, S.C., Pereira, P.A.M., Mauli, M.M., & Reis, R.R. (2017). Swine wastewater: Impacts on soil, plant, and leachate. Engenharia Agrícola, 37(5), 928–939. https://doi.org/10.1590/1809-4430-eng.agric.v37n5p928-939/2017

Rubalcaba, J.G. (2024). Metabolic responses to cold and warm extremes in the ocean. PLOS Biology, 22(1), e3002479. https://doi.org/10.1371/journal.pbio.3002479

Rudic, Z., Vujovic, B., Jovanovic, L., Kiković, D., Kljujev, I., Bozic, M., & Raicevic, V. (2018). Potential and constraints of macrophyte manipulation for shallow lake management. In N. Shiomi (Ed.), Advances in bioremediation and phytoremediation. InTech. https://doi.org/10.5772/67970

Safe Drinking Water Foundation. (2025). TDS and pH fact sheet. Retrieved from https://www.safewater.org/fact-sheets-1/2017/1/23/tds-and-ph

Sallenave, R. (2019). Understanding water quality parameters to better manage your pond (Publication No. W-104). New Mexico State University. Retrieved from https://pubs.nmsu.edu/_w/W104/index.html

Sandoval, K.L. (2024). Assessment of physicochemical parameters in selected water bodies in Laguna, Philippines. Journal of Electrical Systems, 20(5s), 1463–1466. https://doi.org/10.52783/jes.2477

Scheffer, M. (1999). The effect of aquatic vegetation on turbidity: How important are the filter feeders? Hydrobiologia, 408–409, 307–316. https://doi.org/10.1023/A:1017011320148

Schneider, S.C., Coetzee, J.A., Galvanese, E.F., Harpenslager, S.F., Hilt, S., Immerzeel, B., Köhler, J., Misteli, B., … & Vermaat, J.E. (2024). Causes of macrophyte mass development and management recommendations. Science of The Total Environment, 931, 172960. https://doi.org/10.1016/j.scitotenv.2024.172960

Shen, X., Sun, T., Su, M., Dang, Z., & Yang, Z. (2019). Short-term response of aquatic ecosystem metabolism to turbidity disturbance in experimental estuarine wetlands. Ecological Engineering, 136, 55–61. https://doi.org/10.1016/j.ecoleng.2019.06.005

Singer, M.J., George, H.A., Childers, C.D., & Merrill-Davies, M.L. (2012). What is pH and why do we care? University of California Agriculture and Natural Resources. Retrieved from https://anrcatalog.ucanr.edu/pdf/8488.pdf

Souza, C.S., Weirich, C.E., Feiden, A., Klosowski, E.S., Aleixo, V.E.S., & Marchetti, M.E. (2021). Temperature influences swine wastewater treatment by aquatic plants. Scientia Agricola, 78(4), e20190325. https://doi.org/10.1590/1678-992X-2019-0325

Swistock, B. (2022). Interpreting irrigation water tests: Basic interpretation of how various water quality parameters can influence plant growth during irrigation. Penn State Extension. Retrieved from https://extension.psu.edu/interpreting-irrigation-water-tests

Suter, G.W. II, Cormier, S., Schofield, K., Gilliam, J., & Barbour, C. (2025). pH. U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/caddis/ph

Ho, T.L.T., Cao, T.S., Nguyen, H.N., & Bui, P.K.H. (2016). Comparison of two pig-farming systems in impact on the quality of surface and groundwater in Hanoi, Vietnam. International Journal of Agriculture Innovations and Research, 5(3), 2319–1473. Retrieved from https://ijair.org/administrator/components/com_jresearch/files/publications/IJAIR_1996_FINAL.PDF

Tokrishna, R. (1992). Integrated livestock-fish farming systems in Thailand. In T.K. Mukherjee (Ed.), Proceedings of the FAO/IPT Workshop on Integrated Livestock-Fish Production Systems, Institute of Advanced Studies, University of Malaya, Kuala Lumpur, Malaysia. FAO. Retrieved from https://www.fao.org/4/ac155e/ac155e13.htm

Tonog, M.N., & Poblete, M.M. (2015). Drinking water quality assessment in selected barangays in Laoang, Northern Samar, Philippines. International Journal of Environmental Science and Development, 6(1), 29–32. https://doi.org/10.7763/IJESD.2015.V6.556

Tymczyna, L., Chmielowiec-Korzeniowska, A., & Saba, L. (2000). Effect of a pig farm on the physical and chemical properties of a river and groundwater. Polish Journal of Environmental Studies, 9(2), 97–102. Retrieved from https://www.pjoes.com/pdf-87283-21142?filename=Effect%20of%20a%20Big%20Pig%20Farm.pdf

Ueno, H., Jige, M., Sakamoto, T., Balce, G.R., & Deguchi, I. (2008). Geology and clay mineralogy of the landslide area in Guinsaugon, Southern Leyte Island, Philippines. Retrieved from https://www.semanticscholar.org/paper/Geology-and-Clay-Mineralogy-of-the-Landslide-Area-Ueno-Jige/d72af6625458992e94e30a9978606e7873340031

U.S. Environmental Protection Agency [EPA]. (2012). Nitrates. Retrieved from https://archive.epa.gov/water/archive/web/html/vms57.html

U.S. Environmental Protection Agency [EPA]. (2025). Indicators: Phosphorus. Retrieved from https://www.epa.gov/national-aquatic-resource-surveys/indicators-phosphorus

Venglovsky, J., Sasakova, N., Gregova, G., Papajova, I., Toth, F., & Szaboova, T. (2018). Devitalisation of pathogens in stored pig slurry and potential risk related to its application to agricultural soil. Environmental Science and Pollution Research International, 25(22), 21412–21419. https://doi.org/10.1007/s11356-017-0557-2

Vymazal, J., Švehla, J., Kröpfelová, L., & Chrastný, V. (2007). Trace metals in *Phragmites australi*s and *Phalaris arundinacea* growing in constructed and natural wetlands. Science of The Total Environment, 380(1–3), 154–162. https://doi.org/10.1016/j.scitotenv.2007.01.057

Wang, H., García Molinos, J., Heino, J., Zhang, H., Zhang, P., & Xu, J. (2021). Eutrophication causes invertebrate biodiversity loss and decreases cross-taxon congruence across anthropogenically-disturbed lakes. Environment International, 153, 106494. https://doi.org/10.1016/j.envint.2021.106494

Wei, I., Liang, Z., & Zhang, Y. (2022). Evolution of physicochemical properties and bacterial community in aerobic composting of swine manure based on a patent compost tray. Bioresource Technology, 343, 126136. https://doi.org/10.1016/j.biortech.2021.126136

Wetzel, R.G. (1996). Benthic algae and nutrient cycling in lentic freshwater ecosystems. In R.J. Stevenson, M.L. Bothwell, & R.L. Lowe (Eds.), Algal ecology: Freshwater benthic ecosystems (pp. 641–667). Academic Press. https://doi.org/10.1016/B978-012668450-6/50049-7

Widyastuti, M., & Haryono, E. (2017). Water quality characteristics of Jonge Telaga (doline pond) as water resources for the people of Semanu District Gunungkidul Regency. Indonesian Journal of Geography, 48(2), 157–167. https://doi.org/10.22146/ijg.17595

World Health Organization [WHO]. (2022). Guidelines for drinking-water quality (4th ed., incorporating the 1st and 2nd addenda). Retrieved from https://iris.who.int/bitstream/handle/10665/352532/9789240045064-eng.pdf?sequence=1

Wu, T., Zhu, G., Zhu, M., Xu, H., Zhang, Y., & Qin, B. (2020). Use of conductivity to indicate long-term changes in pollution processes in Lake Taihu, a large shallow lake. Environmental Science and Pollution Research, 27, 21376–21385. https://doi.org/10.1007/s11356-020-08590-x

Yanamadala, V. (2005). Calcium carbonate phosphate binding ion exchange filtration and accelerated denitrification improve public health standards and combat eutrophication in aquatic ecosystems. Water Environment Research: A Research Publication of the Water Environment Federation, 77(7), 3003–3012. https://doi.org/10.2175/106143005x73884