Research Article

Access this article online
Quick Response Code:
Website:
https://journals.lww.com/pjhrd
DOI:
10.4103/PJHRD.PJHRD_35_25

A pilot study assessing the groundwater quality in selected regions of the Philippines using the Philippine groundwater health index project

John Christian R. Rances[1], Romeo R. Quizon[1], Rose Abigail Enoveso Duarte[1], Francis Sebastian Magbanua[2], Gemalyn L. Tenoc[3], Jhomee Fe F. Sapitan[4], Ismael P. Geroza[5,6], Jeremy Peregrino Mondejar[7], Judee N. Nogodula[8], Marian Fe Theresa C. Lomboy-Capino[1]

[1]Department of Environmental and Occupational Health, College of Public Health, University of the Philippines, Ermita, Manila, Philippines, [2]Institute of Biology, University of the Philippines, Quezon City, Philippines, [3]College of Teacher Education, Ilocos Sur Polytechnic State College - Tagudin Campus, Tagudin, Ilocos Sur, Philippines, [4]Department of Chemistry, College of Natural Sciences, Benguet State University, La Trinidad, Benguet, Philippines, [5]College of Fisheries, Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines, [6]Bureau of Fisheries and Aquatic Resources - National Freshwater Fisheries Technology Center, CLSU Compound, Science City of Muñoz, Nueva Ecija, Philippines, [7]Institute of Agricultural and Biosystems Engineering, Cebu Technological University - Barili Campus, Barili, Cebu, Philippines, [8]Department of Natural Sciences, University of Southeastern Philippines, Davao City, Davao Del Sur, Philippines

Address for correspondence:
Mr. John Christian R. Rances, Department of Environmental and Occupational Health, College of Public Health, University of the Philippines, Ermita, Manila 1000, Philippines.
E-mail: jrrances@up.edu.ph

Received: 16-06-2025
Accepted: 28-10-2025
Published: 22-12-2025

Abstract:

BACKGROUND: Groundwater is an essential resource for domestic use, agricultural needs, and economic activities, yet it is increasingly threatened by contamination and overextraction. To evaluate groundwater quality and identify associated health risks, the Philippine Groundwater Health Index (PGHI) project conducted a comprehensive assessment of selected sites across various regions in the country.

METHODS: The study analyzed groundwater samples from multiple locations to determine compliance with the Philippine National Standards for Drinking Water. Parameters assessed included organochlorines, heavy metals, microbial indicators, and physical and nonmetal characteristics such as phosphate and ammonia levels. Results were compiled to evaluate overall groundwater safety and identify areas of concern.

RESULTS: No organochlorines were detected in any of the samples, and all heavy metals complied with national drinking water standards. However, significant noncompliance was observed in other parameters. Microbial contamination was widespread, with 79.25% of samples failing to meet microbial standards due to the presence of fecal coliforms and Escherichia coli. Elevated levels of physical and nonmetal parameters were also noted, with 21 of 27 sites exceeding phosphate limits and 8 sites exceeding ammonia levels. These findings indicate substantial health risks associated with fecal contamination and nutrient pollution.

CONCLUSION: The PGHI project underscores the urgent need for enhanced groundwater treatment processes, regular monitoring, and strengthened policy-making to ensure safe drinking water. While the study provides critical insights, limitations such as lack of seasonal data, absence of emerging contaminant analysis, and limited spatial coverage highlight the necessity for continued improvements in groundwater management. Addressing these gaps is essential to protect public health, preserve environmental quality, and ensure the sustainable availability of safe groundwater for future generations..

Keywords:

Contamination, fecal, groundwater, monitoring, public health, water safety

Introduction

Water is fundamental to all life forms, and humans rely on it for essential functions. Although the Earth is covered by approximately 71% water, only 2.5% is freshwater suitable for drinking, with 30.1% stored as groundwater. Water availability and quality should be guaranteed as fundamental human rights.[1-3]

How to cite this article: Rances JC, Quizon RR, Duarte RA, Magbanua FS, Tenoc GL, Sapitan JF, *et al*. A pilot study assessing the groundwater quality in selected regions of the Philippines using the Philippine groundwater health index project. Philipp J Health Res Dev 2025;29(4):53-62.

Groundwater also plays a vital role in agriculture, which accounts for 70% of total global extraction and supports approximately 40% of global food production.[4-6] Agricultural practices contaminate groundwater with nitrates and other chemicals through fertilizers and pesticide runoff. Techniques such as "no-till," planting buffer strips, and strategic timing of fertilizer application to avoid rainfall events can mitigate runoff, although effects remain detectable.[3]

In Southeast Asia, pesticide use is rising annually, with significant consumption in Cambodia, Laos, and Vietnam, and India being a major producer of organochlorine pesticides such as benzene hexachloride and dichlorodiphenyltrichloroethane. This increase in pesticide use raises concerns about its potential health and environmental consequences.[7-10] After application, pesticides break down into various metabolites, which can be toxic. Residue levels are highest immediately postapplication but gradually decline as crops grow, and environmental factors contribute to their degradation. However, improper handling can lead to pesticide dispersion into nontarget areas and contamination of groundwater and surface water.[11-13]

Aside from this, pesticides leach into groundwater over time, particularly in sandy soils with low organic content. Leaching is influenced by soil properties, agricultural practices, and environmental conditions, leading to higher risks of water pollution.[14-18] Chronic exposure to pesticides can cause severe health issues, including cancer and neurological disorders, affecting both those directly handling pesticides and the general population relying on contaminated groundwater.[19,20]

Naturally occurring heavy metals such as antimony, arsenic, cadmium, and lead pose significant health risks when they accumulate in high concentrations. Cadmium and lead from industrial discharge and runoff can cause widespread contamination and severe health issues, including poisoning and neurological damage. Arsenic and antimony, which can enter water sources through mineral dissolution and industrial emissions, pose risks including cancer and respiratory problems.[21] These metals are persistent in the environment and bioaccumulate in vegetables, which are the primary source of human exposure, accounting for about 90% of exposure, with the remaining 10% coming from skin contact and inhalation of polluted dust.[22-24] The nonbiodegradable nature of these metals means they pose long-term health risks, with even low-level, prolonged exposure potentially causing serious health problems.[25-28]

It is also important to consider the impact of anions such as chlorides, nitrates, and phosphates. These anions are essential for plant growth and are commonly found in fertilizers, but their presence in polluted food and water sources raises significant health concerns.[29] Nitrates, for example, can lead to methemoglobinemia in children, potentially causing developmental issues or mental retardation. In addition, nitrates can be converted to nitrites in the body to form nitrosamines, a known group of carcinogens.[30] Moreover, chlorides, phosphates, and sulfates, being acidic anions, can alter the acid–base balance when ingested in high concentrations, leading to acidity and potentially causing acidosis.[31]

The increasing demand for pristine groundwater quality underscores the need for effective protection, monitoring, and sustainable management. Groundwater analysis is crucial for safeguarding public health and protecting the environment by identifying possible contaminants that pose significant health risks.[32,33] Unfortunately, current monitoring tools offer limited insight into these conditions.[34] To address these challenges, the Philippine Groundwater Health Index (PGHI) was developed, and this study serves as a pilot application of the index, incorporating a wide range of indicators, including physical, chemical, bacteriological, and biological factors, to provide a holistic assessment of groundwater resources.

Groundwater analysis characterizes specific contaminants, such as heavy metals, such as arsenic, lead, and cadmium, that can lead to serious health concerns, including cancer, kidney damage, and developmental problems in children.[35] Meanwhile, microbial contaminants, including fecal coliforms and *Escherichia coli*, indicate fecal contamination, which can cause severe gastrointestinal diseases, such as cholera, gastroenteritis, and hepatitis A.[36,37]

Studies across the Philippines have consistently detected nitrate and pesticide leaching in groundwater, with some locations even showing trace amounts of pesticide residues and trace metals.[38,39] These include heavy metals and nonmetal runoffs, which contribute to eutrophication and the formation of dead zones in aquatic ecosystems.[21,40,41] In response to these concerns, key regulations have been established to maintain and protect water quality. The Philippine Clean Water Act of 2004 (Republic Act 9275) was enacted to combat pollution from domestic, industrial, and agricultural sources, aiming to protect water bodies from significant pollutants. However, it falls short in addressing nonpoint sources, such as runoff and lacks a comprehensive approach to overall water quality.[42,43,44] To complement RA 9275, the Department of Environmental and Natural Resources (DENR) issued Department Administrative Order 2016–2008,[45] which introduced the Water Quality Guidelines and General Effluent Standards of

2016. These standards classify water bodies and set monitoring requirements but do not address drinking water parameters. This led to the Philippine National Standards for Drinking Water (PNSDW) being amended in 2017. The PNSDW incorporates guidelines from the World Health Organization and the US Environmental Protection Agency to ensure safe drinking water. However, challenges such as microbial contamination and fluctuations in water quality remain, highlighting the need for ongoing efforts to improve drinking water safety in the Philippines.

In line with these, the Department of Environmental and Occupational Health of the University of the Philippines Manila together with the University of the Philippines Diliman, University of the Philippines Los Baños, and state colleges utilized the newly developed PGHI to pilot its utility and gauge the groundwater quality in selected regions of the Philippines in accordance with the 2017 PNSDW. The main objective of this study is to assess the groundwater quality in selected agriculture and control areas across the Philippines using the PGHI project to ensure compliance with the 2017 PNSDW. Specifically, the study aims to: determine the physical, chemical (including heavy metals and nonmetal parameters), and microbiological quality of groundwater samples collected from selected sites in Luzon, Visayas, and Mindanao; identify the contaminants posing the most significant health risks in the groundwater resources, particularly by comparing the results against the PNSDW; and provide relevant information and data to policymakers and regulatory bodies to improve water quality standards and management strategies, especially concerning the use of groundwater as a source by different communities in the country. This, in turn, will be used to further provide information for policymakers and regulatory bodies to improve the water quality standards, highlighting the use of groundwater as a source by different communities in the country.

Methodology

Study sites

The PGHI project, a collaboration among the University of the Philippines Diliman, Los Baños, and Manila, comprehensively examined groundwater samples from agricultural areas across the Philippines. The project covers groundwater reservoirs in selected agricultural areas in the country. In addition, relatively undisturbed reference sites were surveyed in the following study areas: Ilocos Sur, Benguet, and Nueva Ecija in Luzon; Cebu in Visayas; and Davao del Norte in Mindanao [Figure 1]. These study areas were selected based on the Philippine groundwater systems monitored by the National Irrigation Administration, groundwater availability and potential maps generated by the Mines and Geosciences Bureau and Bureau of Soils and Water Management, and on the recommendations of the Local Government Units.

Within each study area, a matched pair of 3 reference (control) sites and 3 test (within agricultural area) sites was sampled for replication. However, only one and two control sites were established in Ilocos Sur and Nueva Ecija, respectively, due to accessibility and safety concerns. Hence, only 12 control sites and 15 test sites were covered. Wells, pipe groundwater pumps, or springs were randomly selected within each study area. Sampling was also conducted during both the dry and wet seasons. Seasonal variation is one factor that results in changes in groundwater physicochemical parameter values; hence, a total variation in groundwater quality in dry and wet seasons was accounted for.[44] Sampling also considered the different crops suitable for a specific season, as crop rotation may utilize different agrochemicals applicable for a specific crop that may affect the groundwater quality.

Reconnaissance surveys were conducted in Nueva Ecija, Benguet, and Ilocos Sur (22–23 November 2022); Davao del Norte (1–4 February 2022); and Cebu (20–24 February 2022). Water samples for physicochemical and microbiological parameters were collected during the dry season in Ilocos Sur, Benguet, and Nueva Ecija (22–24 April 2023), in Davao (14–16 April 2023), and in Cebu (18–20 April 2023). For the wet season, samples were gathered in Ilocos Sur, Benguet, and Nueva Ecija (15–17 January 2024), in Cebu (11–13 February 2024), and in Davao (15–17 February 2024).

Water quality parameters

Water quality assessment was conducted at each site to determine the condition of the groundwater. This activity ensured that the conditions satisfy the standards set by the DENR,[45,46] the Department of Health Administrative Order 10, 2017,[47] Korbel and Hose,[48] and the Food and Agriculture Organization (FAO) of the United Nations.[49] Water parameters were categorized into physical, chemical, and microbiological variables [Figure 2]. These variables were selected due to their known importance to the groundwater ecosystem[50,51] and their legal requirement by Philippine law. Results were compared to the Philippine water quality guidelines and national standards for drinking water. In addition, the FAO guidelines[49] for water quality for agriculture were used to assess the water suitability for irrigation.

Sample collection, preservation, and processing

Sampling methods were based on the work of Hancock and Boulton[52] as modified by Korbel and Hose.[48,51] Samples collected during these periods were analyzed in adherence to the Standard Methods for the Examination

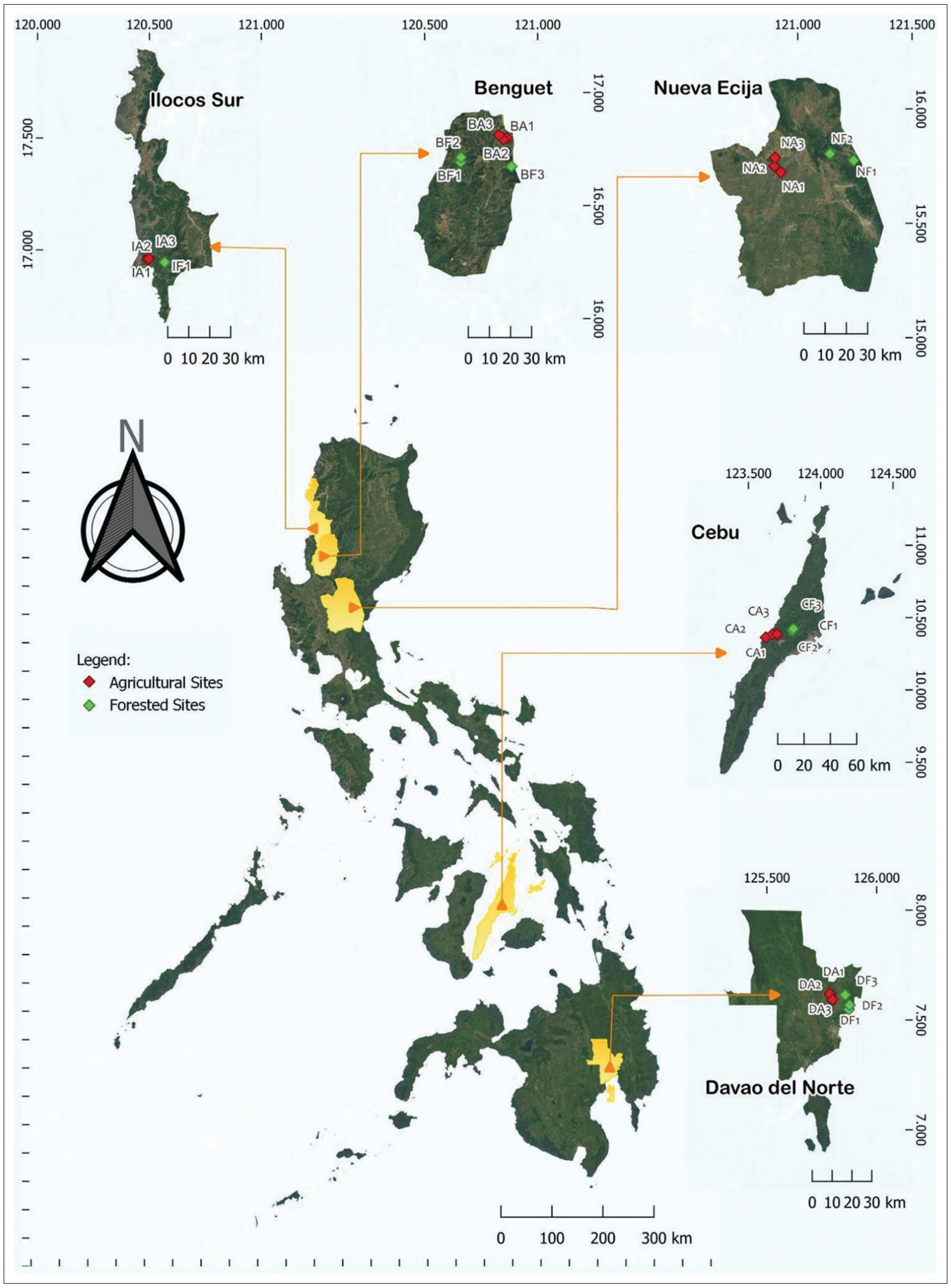

Figure 1: Map showing the location of the study sites for the Philippine groundwater health Index pilot study, highlighting the provinces in Luzon (Ilocos Sur, Benguet, Nueva Ecija), Visayas (Cebu), and Mindanao (Davao del Norte)

of Water and Wastewater (SMEWW), ensuring accurate and reliable water quality assessments. The SMEWW protocols include comprehensive tests for detecting a wide range of contaminants. These samples were analyzed by CRL Environmental Corporation, a laboratory testing firm.

Methodological framework

The overall methodology employed in this pilot study, utilizing the PGHI framework, is summarized in the research flowchart [Figure 2]. This visual representation outlines the steps from site selection and sampling design to laboratory analysis and data assessment against the established PNSDW.

Results

The findings indicated no detectable levels of organochlorines in any of the groundwater samples tested. This suggests that the groundwater samples complied with bans and restrictions imposed as early as 1989[53] to control and eliminate these harmful chemicals. These results indicate that efforts to regulate

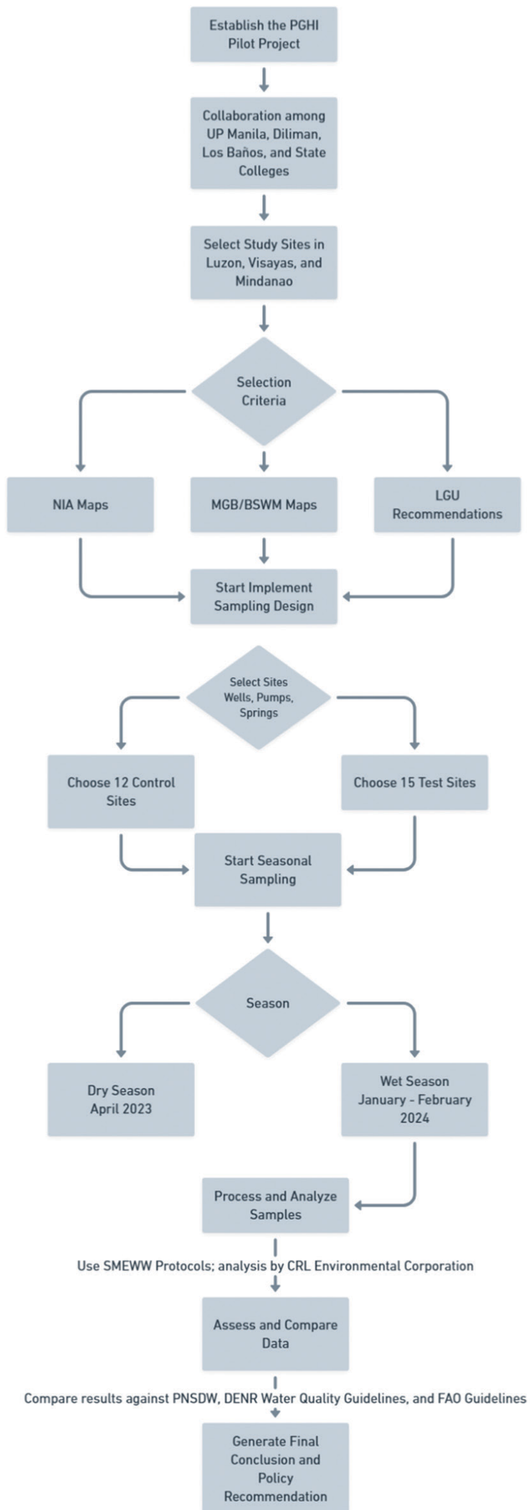

Figure 2: Flow chart of the Philippine groundwater health index pilot study methodology. PGHI = Philippine groundwater health index, NIA = National Irrigation Administration, MGB = Mines and Geosciences Bureau, BSWM = Bureau of Soils and Water Management, LGU = Local government unit, PNSDW = Philippine national standards for drinking water, DENR = Department of Environmental and Natural Resources, SMEWW = Standard methods for the examination of water and wastewater, FAO = Food and Agriculture Organization,

organochlorines have been effective, as far as the study sites are concerned.

Furthermore, the concentrations of other chemical parameters, including heavy metals, were found to comply with the stringent criteria set by the PNSDW.[54] This compliance signifies that these particular contaminants were within safe limits for drinking water.

However, the data showed varied results for nonmetal, physical, and microbiological parameters. Out of the 27 sites, eight exceeded ammonia parameter limits, with four consistently over the limit in both dry and wet seasons [Table 1a]. Twenty-one sites exceeded phosphate levels, with 12 sites consistently high in both seasons [Table 1b]. Physical parameters also showed noncompliance, with 10 sites exceeding color standards (4 consistently across both seasons), 9 sites exceeding turbidity, and 1 site exceeding total dissolved solids during the wet season [Table 2a-c]. Of these samples, four control sites exceeded ammonia and turbidity parameter levels, nine control sites exceeded phosphate parameter levels, and three control sites exceeded color levels.

To quantify the central tendency and variability of the noncompliant parameters, descriptive statistics, including the mean, standard deviation (SD), minimum, and maximum concentrations, were computed across all sites for both the dry and wet seasons. This analysis focused on key nonmetal chemicals (ammonia, phosphate, chloride, and nitrate) and physical parameters (color, turbidity, and total dissolved solids) to demonstrate the range of contamination levels encountered across the sampled areas [Table 3].

The study revealed that most sites in both dry and wet seasons failed to meet microbial and chemical standards, with only around 20.75% compliance. However, physical and chemical parameters were consistently met by a significantly higher percentage of sites, reaching over 85.18% and 79.17%, respectively, in both seasons [Table 4].

Based on the findings, a significant portion of the sites and samples exceeded microbial standards set by PNSDW[54] and DENR.[45] Thus, further investigation and corrective actions are necessary to address fecal coliforms and *E. coli* contamination. Ensuring water safety and compliance with regulatory standards is crucial to protect public health and prevent waterborne diseases.

The study also explored the relationships driving the observed contamination. This approach allows for a visual understanding of how temporal factors and site characteristics influence the concentration of key pollutants. Specifically, the interseasonal variability of ammonia and phosphate helps determine if wet season mobilization (runoff) or dry season concentration significantly affects groundwater quality [Figures 3 and 4].

Table 1a: Ammonia concentrations at four sites consistently exceeding parameter standards

Site	Standard	Dry	Wet
IIIC2	0.03	0.20	0.60
XIT1		1.00	1.00
XIT2		0.60	1.10
XIT3		2.40	1.20

Table 1b: Phosphate concentrations at 12 sites consistently exceeding parameter standards

Site	Standard	Dry	Wet
IC1	0.025	0.070	0.070
IC2		0.030	0.030
IIC1		0.080	0.080
IIC2		0.050	0.060
IIT1		0.050	0.040
IIIT3		0.050	0.070
VIIC1		0.030	0.100
VIIC2		0.100	0.030
VIIC3		0.200	0.080
XIT1		0.060	0.070
XIT2		0.090	0.100
XIT3		0.100	0.200

Table 2a: Color standards at four sites consistently exceeding parameter standards

Site	Standard	Dry	Wet
IIIT1	5	10	32
XIT1		20	20
XIT2		60	60
XIT3		4000	32

Table 2b: Turbidity concentrations at nine sites exceeding parameter standards

Site	Standard	Measure
IT1	5	5.8
IT2		6.6
IIIC1		20.0
IIIC2		39.0
IIIT1		9.9
IIIT3		17.0
VIIT2		5.9
VIIT3		6.1
XIT3		1500

Table 2c: Total dissolved solids concentrations at one site exceeding parameter standards

Site	Standard	Measure
IIIT1	600	694

Discussion

In this study, groundwater analysis was conducted at test sites (agricultural areas) and control sites (pristine water bodies). Notably elevated levels of nonmetal chemicals, specifically ammonia and phosphate, were unexpectedly detected in the control sites, suggesting the presence of unique factors such as hydrogeological variations influencing groundwater chemistry at these locations. These highlight the need to distinguish site-specific characteristics between control and test locations, as such differences may impact data interpretation. Investigating potential sources of contamination or natural variations specific to these sites is critical for more accurate analysis and for understanding the broader implications of the study. Additional sampling and site-specific assessments are recommended to identify the potential origins of these nonmetal chemicals.

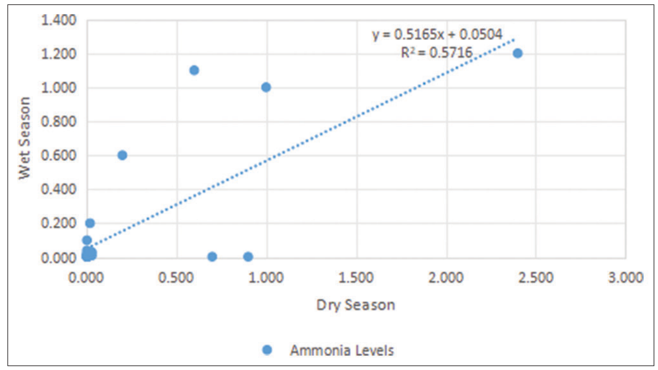

Figure 3: Temporal distribution of ammonia levels between sites in dry and wet seasons

Analysis of the statistical compliance provided crucial insight into the severity and heterogeneity of contamination. The large SDs for ammonia and phosphate, particularly compared to the national standards, confirm that the contamination is highly variable across the study sites. This suggests a nonuniform, localized pattern of pollution. The extreme maximum values recorded on color and turbidity, on the other hand, demonstrate poor physical water quality at certain points, highlighting significant localized infrastructure or water integrity failure. While mean concentrations for parameters such as chloride and nitrate remained well below the PNSDW limits, their detection and variability underscore the pervasive influence of anthropogenic activity across the sampled areas.

In addition, the examination of temporal trends reinforces the complexity of groundwater dynamics. Distribution of ammonia between dry and wet seasons indicates a moderately positive relationship ($R = 0.5716$). However, the distribution of phosphate between dry and wet seasons shows a much weaker correlation ($R = 0.1401$). This difference suggests that while ammonia levels may be somewhat sustained throughout the year, phosphate contamination is more ephemeral and highly responsive to seasonal factors. The data points generally falling above the regression line in both figures visually indicate a slight tendency

Table 3: Statistical compliance with physical and chemical parameters

Parameter	Standard	Dry	Wet	Minimum	Maximum
Ammonia	0.03	0.22±0.52	0.16±0.36	0.003	2.400
Nitrate	50	5.53±9.03	2.79±4.57	0.006	9.900
Chloride	250	7.54±7.69	7.36±9.21	0.900	38.00
Phosphate	0.025	0.049±0.044	0.047±0.044	0.0064	0.2000
Color	5	3	3	3	4000
Turbidity	5	58.91±288.0	2.87±7.61	0.05	1500
TDS	600	227.2±156.9	268.6±171.6	4.72	694
Bacteriological	1.1	2034±5088	2098±4798	1	16,000

TDS=Total dissolved solids

Table 4: Percentage of sites compliant with the Philippine national standards for drinking water standards for both seasons

Parameters	Dry (%)	Wet (%)	Average (%)	Average (%)
Ammonia	77.78	77.78	77.78	79.17
Nitrate	100.00	100.00	100.00	
Chloride	100.00	100.00	100.00	
Phosphate	37.04	40.74	38.89	
Color	66.67	81.48	74.07	85.18
Turbidity	81.48	85.19	83.33	
TDS	100.00	96.30	98.15	
Bacteriological	22.22	19.23	20.75	20.75

TDS=Total dissolved solids

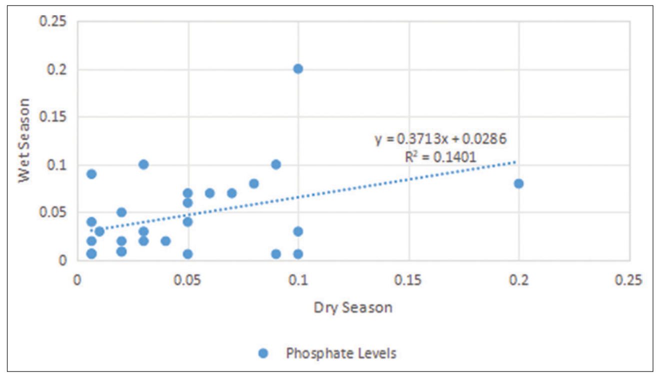

Figure 4: Temporal distribution of phosphate levels between sites in dry and wet seasons

for higher contamination levels during the wet season, which is likely due to the mobilization and rapid transport of surface pollutants (runoff) into the shallow aquifers.[55]

Data also show that one control site exceeded ammonia and seven control sites exceeded phosphate standards, suggesting contamination is not strictly limited to the agricultural sites. This observation is supported by the highly heterogeneous data and large SD values. This visual overlap in contamination severity across site types strongly points to diffuse, nonagricultural sources, such as leakage from septic tanks or poorly managed sewage systems, as major contributors to nonmetal contamination. These factors, possibly combined with hydrogeological variations, are likely influencing groundwater chemistry even in areas considered relatively pristine.[41]

Moreover, the contamination of water with fecal coliforms and *E. coli* poses significant risks to both human health and the environment. *E. coli* is a bacterium commonly found in the intestines of warm-blooded animals, and its presence in water is indicative of fecal contamination.[56,57] When water contaminated with *E. coli* is consumed, it can cause various gastrointestinal illnesses, such as diarrhea, abdominal cramps, nausea, and vomiting.[56] These symptoms can be particularly severe in vulnerable populations, including children, the elderly, and individuals with compromised immune systems.[58]

In addition, the detection of *E. coli* in water serves as a warning sign for potential contamination by other pathogenic microorganisms, including bacteria (such as Salmonella and Campylobacter), viruses (such as rotavirus and hepatitis A virus), and parasites (such as Giardia and Cryptosporidium).[56,57] This increases the risk of waterborne diseases, which can spread through water consumption, recreational activities, or inadequate hygiene practices.[58]

Public health authorities respond swiftly to the detection of *E. coli* in water by issuing advisories or warnings to the affected communities. These alerts advise against using or consuming the contaminated water until it is deemed safe through remediation measures. Outbreaks of waterborne diseases linked to *E. coli* contamination can strain healthcare systems, leading to increased healthcare costs due to medical treatments, hospitalizations, and public health interventions.[57]

Despite its comprehensive scope and adherence to rigorous analytical methods, the PGHI project faces several limitations that warrant consideration. As a pilot study, its design involves inherent constraints. First, the project's temporal sampling approach, conducted over specific periods such as from April 15–24, 2023, and January to February 2024, may not capture seasonal variations or long-term trends in groundwater quality. Variations in agricultural activities, rainfall patterns, and land use changes can significantly influence groundwater quality over time. Second, while the PGHI project focused on a diverse range of chemical and bacteriological parameters, the study did not comprehensively assess all potential contaminants present in groundwater. Emerging contaminants, such as pharmaceuticals, personal care products, and industrial chemicals, may pose risks that were not fully addressed within the scope of the project.

Furthermore, due to the pilot nature of this assessment, the spatial coverage of the PGHI project, although sampling was done in Luzon (Benguet, Ilocos Sur, Nueva Ecija), Visayas (Cebu), and Mindanao (Davao), may not represent all groundwater conditions nationwide. Regional differences in geology, hydrology, and anthropogenic activities could influence the presence and distribution of contaminants, limiting the generalizability of findings to other geographical areas.

Addressing groundwater contamination requires advanced treatment technologies to remove harmful bacteria like *E. coli* and ensure adherence to water quality standards. Timely detection, public awareness, and regular monitoring are vital to prevent health risks and environmental harm. Stakeholder collaboration and strong policies will enhance water resource management and ensure sustainable groundwater quality.

Conclusion

Groundwater quality analysis is essential for safeguarding public health, protecting the environment, and managing water resources effectively. Through comprehensive analysis, it is possible to identify contaminants and take proactive measures to prevent their adverse effects. The PGHI project exemplifies this commitment, examining groundwater samples across various regions to ensure compliance with quality standards.

The results of the analysis revealed critical noncompliance, highlighted by the severe failure rate of 79.25% of samples exceeding microbial standards. This microbial contamination, coupled with the frequent exceedances of nonmetal chemicals, with phosphate levels being noncompliant in 21 out of 27 sites, underscores a widespread pollution problem likely driven by inadequate sanitation and sewage management. Moreover, the study also shows undetectable levels of organochlorines, indicating compliance with regulatory bans and restrictions. Further analysis revealed the high variability of contaminants, with seasonal distribution showing that wet season runoff contributes to pollutant mobilization. The visual evidence of noncompliance extending into control sites necessitates a policy shift focusing on robust septic and sewage management. In addition, the presence of fecal coliforms and/or *E. coli* above permissible thresholds warrants further investigation and corrective actions to ensure water safety and prevent further contamination. *E. coli* contamination poses significant risks to human health and the environment, underscoring the importance of timely detection and effective water treatment. By adhering to quality standards and promoting public awareness, the impact of contamination can be mitigated, and the availability of safe drinking water for all can be ensured.

Acknowledgments

The authors are grateful for the permission to use the PGHI as the backbone of the study. The authors would also like to acknowledge Dr. Kathryn Korbel and Dr. Grant Hose from Macquarie University, New South Wales, Australia, for their contribution to shaping the protocol used by the PGH index and the eventual involvement of stakeholders in describing the current landscape of groundwater quality in the Philippines.

This work was made possible through the financial support of the Department of Science and Technology – Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development Grants-in-Aid (DOST-PCAARRD-GIA) funding award.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Mitchell HH, Hamilton TS, Steggerda FR, Bean HW, *et al*. The chemical composition of the adult human body and its bearing on the biochemistry of growth. J Biol Chem 1945;158:625-37.
2. Sargen M. (n.d.). Biological roles of water: Why is water necessary for life? Engage with Nature-Based Solutions. Available from https://engagewithnbs.ca/resource/biological-roles-of-water-why-is-water-necessary-for-life/. [Last retrieved on 2025 Sep 12].
3. U.S. Geological Survey. Agricultural contaminants. U.S. Department of the Interior. 2019. Available from: https://www.usgs.gov/mission-areas/water-resources/science/agricultural-contaminants. [Last accessed 2025 Aug 10].
4. Shiklomanov IA. Comprehensive assessment of the freshwater resources of the world: Assessment of water resources and water availability in the world. Stockholm Environment Institute. 1997.
5. Margat J, van der Gun J. Groundwater Around the World: A Geographic Synopsis. Boca Raton, FL, USA: CRC Press Taylor and Francis Group; 2013. p. 376.
6. Yang X, Liu J. Assessment and valuation of groundwater ecosystem services: A case study of Handan City, China. Water 2020;12:1-11.

7. Khan MJ, Zia MS, Qasim M. Use of pesticides and their role in environmental pollution. World Acad Sci Eng Technol 2010;72:122-8.
8. Pozo K, Harner T, Lee SC, Sinha RK, Sengupta B, Loewen M, *et al*. Assessing seasonal and spatial trends of persistent organic pollutants (POPs) in Indian agricultural regions using PUF disk passive air samplers. Environmental Pollution, 2011;159:646-653. doi: 10.1016/j.envpol.2010.09.025.
9. Schreinemachers P, Tipraqsa P. Agricultural pesticides and land use intensification in high, middle and low income countries. Food Policy 2012;37:616-26.
10. Schreinemachers P, Afari-Sefa V, Heng CH, Dung PTM, Praneetvatakul S, Srinivasan R. Safe and sustainable crop protection in Southeast Asia: Status, challenges and policy options. Environmental Science and Policy 2015;54:357-366.
11. Liu Y, Mo R, Tang F, Fu Y, Guo Y. Influence of different formulations on chlorpyrifos behavior and risk assessment in bamboo forest of China. Environ Sci Pollut Res Int 2015;22:20245-54.
12. Marie L, Sylvain P, Benoit G, Maurice M, Gwenaël I. Degradation and transport of the chiral herbicide S-metolachlor at the catchment scale: Combining observation scales and analytical approaches. Environ Sci Technol 2017;51:13231-40.
13. Riyaz M, Shah RA, Sivasankaran K. Pesticide residues: Impacts on fauna and the environment. IntechOpen. 2021. doi: 10.5772/intechopen.98379.
14. Bailey GW, White JL. Factors influencing the adsorption, desorption, and movement of pesticides in soil. In: Gunther FA, Gunther JD, editors. Single Pesticide Volume: The Triazine Herbicides. New York, NY: Springer; 1970. p. 29-92.
15. Gevao B, Semple KT, Jones KC. Bound pesticide residues in soils: A review. Pol J Environ Stud 2000;108:3-14.
16. Gupta S, Gajbhiye VT. Effect of concentration, moisture and soil type on the dissipation of flufenacet from soil. Chemosphere 2002;47:901-6.
17. Steffens K, Larsbo M, Moeys J, Jarvis N, Lewan E. Predicting pesticide leaching under climate change: Importance of model structure and parameter uncertainty. Agric Ecosyst Environ 2013;172:24-34. doi: 10.1016/j.agee.2013.03.018.
18. Pereira VJ, da Cunha JPAR, de Morais TP, de Oliveira JPR, de Morais JB. Physical-chemical properties of pesticides: Concepts, applications, and interactions with the environment. Bioscience J 2016;32(3). doi: 10.14393/BJ-v32n3a2016-31533.
19. Rosenfeld PE, Feng LGH. Mercury, BPA and pesticides in food. In Risks of hazardous wastes. William Andrew/Elsevier. 2011. p. 223–235.
20. Mieldazys A, Mieldazys R, Vilkevicius G, Tverijonas J, Otrusina A. Agriculture-Use of Pesticides/Plant Protection Products. Bilbao: EU-OSHA; 2015.
21. Mitra S, Chakraborty AJ, Tareq AM, Emran TB, Nainu F, Khusro A, *et al*. Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. J King Saud Univ Sci 2022;34:101865. doi.: 10.1016/j.jksus.2022.101865.
22. Kim H, Song B, Kim H, Park J. Distribution of trace metals at two abandoned mine sites in Korea and arsenic-associated health risk for the residents. Toxicology Environ Health Sci2009;1:83-90.
23. Martorell I, Perelló G, Martí-Cid R, Llobet JM, Castell V, Domingo JL. Human exposure to arsenic, cadmium, mercury, and lead from foods in Catalonia, Spain: Temporal trend. Biol Trace Elem Res 2011;142:309-22.
24. Khan S, Reid BJ, Li G, Zhu YG. Application of biochar to soil reduces cancer risk via rice consumption: A case study in Miaoqian village, Longyan, China. Environ Int 2014;68:154-161. doi: 10.1016/j.envint.2014.03.017.
25. Nabulo G, Black CR, Young SD. Trace metal uptake by tropical vegetables grown on soil amended with urban sewage sludge. Environ Pollut 2011;159:368-76.
26. Mitra S, Chakraborty AJ, Tareq AM, Emran TB, Nainu F, Khusro A, *et al*. Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. J King Saud Univ Sci 2022;34:101865.
27. Stasinos S, Zabetakis I. The uptake of nickel and chromium from irrigation water by potatoes, carrots and onions. Ecotoxicol Environ Saf 2013;91:122-8.
28. Khan A, Khan S, Khan MA, Qamar Z, Waqas M. The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: A review. Environ Sci Pollut Res Int 2015;22:13772-99.
29. Edeogu CO. Nitrate, sulfate, phosphate and chloride status of staple food crops, soils and water as indicator of environmental base anion pollution load in Ebonyi State, Nigeria. J Biol Sci 2007;7:745-51.
30. Moshoeshoe MN, Obuseng V. Simultaneous determination of nitrate, nitrite and phosphate in environmental samples by high performance liquid chromatography with UV detection. South Afr J Chem 2018;71:79-85.
31. Enyoh CE, Verla AW, Egejuru NJ. pH variations and chemometric assessment of borehole water in Orji, Owerri Imo State, Nigeria. Int J Environ Anal Chem 2018;5:1-9.
32. Lapong E, Fujihara M. Water resources in the Philippines : An overview of its uses, management, problems and prospects. J Rainwater Catchment Syst 2008;14:57-67.
33. Das S, Roy PK, Banerjee G, Mazumdar A. Water quality index is an important tool of groundwater: A case study. In: Roy PK, Roy MB, Pal S, editors. Advances in Water Resources Management for Sustainable Use. Lecture Notes in Civil Engineering. Singapore: Springer; 2021. p. 131.
34. Rola AC, Pulhin JM, Tabios GQ, Lizada JC, Dayo MHF. Challenges of water governance in the Philippines. Philippine J Sci 2015;144:197-208.
35. Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ. Heavy metal toxicity and the environment. Exp Suppl 2012;101:133-64.
36. Fewtrell L, Bartram J. (Eds.). Water quality: Guidelines, standards and health—Assessment of risk and risk management for water-related infectious disease. World Health Organization / IWA Publishing; 2001.
37. Medema GJ, Payment P, Dufour A, Robertson W, Waite M, Hunter P, *et al*. Assessing microbial safety of drinking water: Improving approaches and methods. Organisation for Economic Co-operation and Development (OECD) and World Health Organization (WHO). 2003. Available from: https://www.who.int/publications/i/item/9241562540. [Last accessed 2025 Sep 13].
38. Bouman BA, Castañeda A, Bhuiyan S. Nitrate and pesticide contamination of groundwater under rice-based cropping systems: Past and current evidence from the Philippines. Agric Ecosyst Environ 2002;92:185-99.
39. Ngidlo RT. Impacts of pesticides and fertilizers on soil, tail water and groundwater in three vegetable producing areas in the Cordillera Region, Northern Philippines. J Exp Agric Int 2013;3:780-93.
40. Camargo JA, Alonso Á. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environ Int 2006;32:831-49.
41. Jalil A, Luyun RA Jr., Delos Reyes AA Jr., *et al*. Assessment of groundwater quality for irrigation at Malawali Island, Basilan, Philippines. J Penelitian Pengelolaan Daerah Aliran Sungai 2020;4:187-200. [doi: 10.20886/jppdas. 2020.4.2.187-200].
42. Senoro DB, de Jesus KL, Mendoza LC, *et al*. Groundwater quality monitoring using in-situ measurements and hybrid machine learning with empirical Bayesian kriging interpolation method. Appl Sci 2022;12:132.
43. Andreen WL. Success and backlash: The remarkable story of the Clean Water Act. George Washington Journal of Energy & Environmental Law 2013;4:25–37:185–199.
44. Ganiyu SA, Badmus BS, Olurin OT, Ojekunle ZO. Evaluation of

seasonal variation of water quality using multivariate statistical analysis and irrigation parameter indices in Ajakanga area, Ibadan, Nigeria. Applied Water Science, 2018;8:1-15. doi: 10.1007/s13201-018-0677-y.

45. Department of Environment and Natural Resources. Water quality guidelines and general effluent standards of 2016 (DENR Administrative Order No. 2016-08). Department of Environment and Natural Resources. 2016 Available from: https://emb.gov.ph/wp-content/uploads/2019/04/DAO-2016-08_WATER-QUALITY-GUIDELINES-AND-GENERAL-EFFLUENT-STANDARDS.pdf. [Last accessed on 2025 Sep 15].
46. Department of Environment and Natural Resources. Department of Environmental, Natural Resources Administrative Order No. 2021-19: Updated water quality guidelines and general effluent standards for selected parameters. 2021. Available from: https://emb.gov.ph/wp-content/uploads/2021/07/DAO-2021-19-UPDATED-WQG-AND-GES-FOR-SELECTED-PARAM.pdf. [Last accessed on 2025 Sep 15].
47. Department of Health. Department of Health Administrative Order No. 2017-0010: Philippine National Standards for Drinking Water of 2017. 2017. Available from: https://doh.gov.ph/wp-content/uploads/2023/08/Administrative-Order-No.-2017-0010-Philippine-National-Standards-for-Drinking-Water.pdf. [Last accessed on 2025 Sep 15].
48. Korbel KL, Hose GC. A tiered framework for assessing groundwater ecosystem health. Hydrobiologia 2011;661:329-49.
49. Food and Agriculture Organization. Water quality for agriculture (FAO Irrigation and Drainage Paper No. 29). Food and Agriculture Organization of the United Nations. 1985.
50. Chapelle F. Groundwater Microbiology and Geochemistry. New York: Wiley; 2001.
51. Korbel KL, Hose GC. The weighted groundwater health index: Improving the monitoring and management of groundwater resources. Ecol Indic 2017;75:164-81.
52. Hancock PJ, Boulton AJ. Sampling groundwater fauna: Efficiency of rapid assessment methods tested in bores in Eastern Australia. Freshw Biol 2009;54:902-17.
53. Paulino V. National Labor Relations Commission, G.R. No. 176184, Supreme Court of the Philippines; 2006. Available from: https://elibrary.judiciary.gov.ph/thebookshelf/showdocs/1/41964. [Last accessed on 2025 Sep 10].
54. Department of Health. Philippine National Standards for Drinking Water 2017. Republic of the Philippines; 2017. Available from: https://doh.gov.ph/sites/default/files/publications/PNSDW-2017.pdf. [Last accessed on 2025 Sep 10].
55. Inson JG, Supsup CE, Flores MJ. Spatial mapping of groundwater quality in the municipality of Santa Ignacia, Tarlac, Philippines. Appl Water Sci 2021;11:174. 56. Centers for Disease Control and Prevention. About Escherichia coli infection. 2024. https://www.cdc.gov/ecoli/about/index.html. [Last accessed on 2025 Sep 15].
57. World Health Organization. Guidelines for drinking-water quality (4th ed.). World Health Organization. 2020. Available from https://www.who.int/publications/i/item/9789241548151. [Last retrieved 2025 Sep 12].
58. Environmental Protection Agency. Drinking water: Waterborne diseases and water quality (Report on the Environment). U.S. Environmental Protection Agency. 2021. Available from https://19january2021snapshot.epa.gov/report-environment/drinking-water_.html. [Last retrieved 2025 Sep 12].