National Assessment Report in the Philippines

Chapter 1. Basic Information on National Monitoring Activities

1.1. Outline of activities on acid deposition and National Monitoring Plan

The Acid Deposition Monitoring Network in East Asia (EANET) was created in 2001 aiming to create a common understanding of the state of acid deposition problems in East Asia, provide useful inputs for decision-making at national and regional levels to prevent or reduce adverse impacts on the environment and promote cooperation on the issue of acid deposition among its Participating Countries.

The Philippines through the Department of Environment and Natural Resources - Environmental Management Bureau (DENR- EMB), the National Center for EANET, has been participating in the various activities of the EANET which include (1) annual implementation of National Monitoring Plan for wet deposition and dry deposition, soil and vegetation, inland aquatic environment and catchment-scale, (2) participation in the following activities implemented by the Asia Center for Air Pollution Research (ACAP), the Network Center for the EANET, such as inter-laboratory comparison exercises, technical support and capacity building activities, conduct and promotion of research and studies related to acid deposition issues, promotion of public awareness, and cooperation and information exchange in national and regional levels.

The EMB-DENR annually submits the monitoring data to ACAP as the EANET Network Center, where the compilation, evaluation, storage and provision of data, promotion of quality assurance and quality control (QA/QC) activities are implemented.

1.2. Monitoring Program

All EANET monitoring sites in the Philippines were established with the assistance of experts from the formerly Acid Deposition and Oxidant Research Center (ADORC), now the ACAP. Table 1 shows the EANET monitoring sites, intervals, and parameters while Figure 1.1 shows the location map of EANET sites and Figure 1.2 shows the photographs of the monitoring stations.

In reference to the Quality Assurance/Quality Control (QA/QC) Guidebook for Acid Deposition Monitoring Network in East Asia – 2016, the National Monitoring Plan (NMP) had been prepared and is updated annually for the implementation of the annual national monitoring activities. Monitoring activities have been conducted using QA/QA protocols.

The EMB-CO Environmental Research and Laboratory Services Division conducts the monitoring activities on wet deposition, dry deposition, inland aquatic environment and catchment-scale that are located at the urban and rural sites while the EMB-Cordillera Administrative Region (CAR) conducts monitoring activities located at the remote sites. The meteorological data respective to the deposition monitoring sites are being provided by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) of the Department of Science and Technology

(DOST). Recently, national air pollution monitoring activities were integrated into the EANET NMP.

Table 1 EANET monitoring components, sites, intervals, and parameters

Component	Monitoring Site/s	Latitude	Longitude	Monitoring Interval	Measured Parameters
Dry and Wet Deposition	Urban site: Metro Manila (MM) at Manila Observatory, Ateneo de Manila University Campus, Quezon City	14°38' N	121°04' E	Weekly	Dry Deposition: • SO_2 concentration converted from SO_4^{2-} concentration; • NO_2 concentration converted from NO_3^- concentration; • HCl concentration converted from Cl^- concentration; • NH3 concentration converted from NH_4^+ concentration; and • Na^+, K^+, Ca^{2+}, Mg^{2+}) Wet Deposition: • pH; Electric Conductivity (EC); • Concentration of cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}); and • Concentration of anions (SO_4^{2-}, NO_3^-, Cl^-)
	Rural site: Los Baños (LB) at PAGASA Agromet Station, UP Los Baños, College, Laguna	14°09' N	121°15' E		
	Remote site: Mt. Sto. Tomas (MST) at PAGASA Baguio Radar Station, Mt. Sto. Tomas, Tuba, Benguet	16°25' N	120°36' E		
Catchment-scale	La Mesa Watershed in Lagro, Quezon City			Monthly	• pH; Electric Conductivity (EC); Alkalinity • Concentration of cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}); and • Concentration of anions (SO_4^{2-}, NO_3^-, Cl^-)
Inland Aquatic Environment	Rural site: Pandin Lake in San Pablo, Laguna	14°7' N	121°22' E	Quarterly	• pH; Electric Conductivity (EC); Alkalinity • Concentration of cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}); and • Concentration of anions (SO_4^{2-}, NO_3^-, Cl^-)
	Remote site: Ambulalakao Lake in Kabayan, Benguet	16°66' N	120°89' E		
$PM_{2.5}$ Monitoring	MM Site at Ateneo de Manila University Campus, Quezon City	14°38' N	121°04' E	Continuous (Weekly downloading of data)	• $PM_{2.5}$
Soil and Vegetation	Urban site: La Mesa Watershed in Lagro, Quezon City			Every 3 - 5 years (No monitoring data in 2015-2019)	Soil Monitoring: • Moisture content; pH (H_2O) and pH (KCl); • Exchangeable base cations (Na^+, K^+, Ca^{2+}, Mg^{2+}); • Exchangeable acidity; • Effective cation exchangeable capacity (ECEC); • Carbonate content (when pH (H_2O) > 7); Vegetation Monitoring: • General description of the forest: Description of the tree (name of species, diameter at breast height and height of tree) and understory vegetation survey • Survey of tree decline: Observation of tree decline, photographic record of tree decline, and estimation of decline causes
	Rural site: Mt. Makiling Forest Reserve in UP Los Baños College, Laguna				
	Rural site: UP Quezon-Laguna Land Grant in Siniloan, Quezon				
	Remote site: Boneco Long Term Ecological Research Site in Itogon, Benguet				

1.3 Monitoring Sites/Stations

The established monitoring sites are shown in Figure 1.1 and in Figure 1.2 are photographs of the monitoring stations

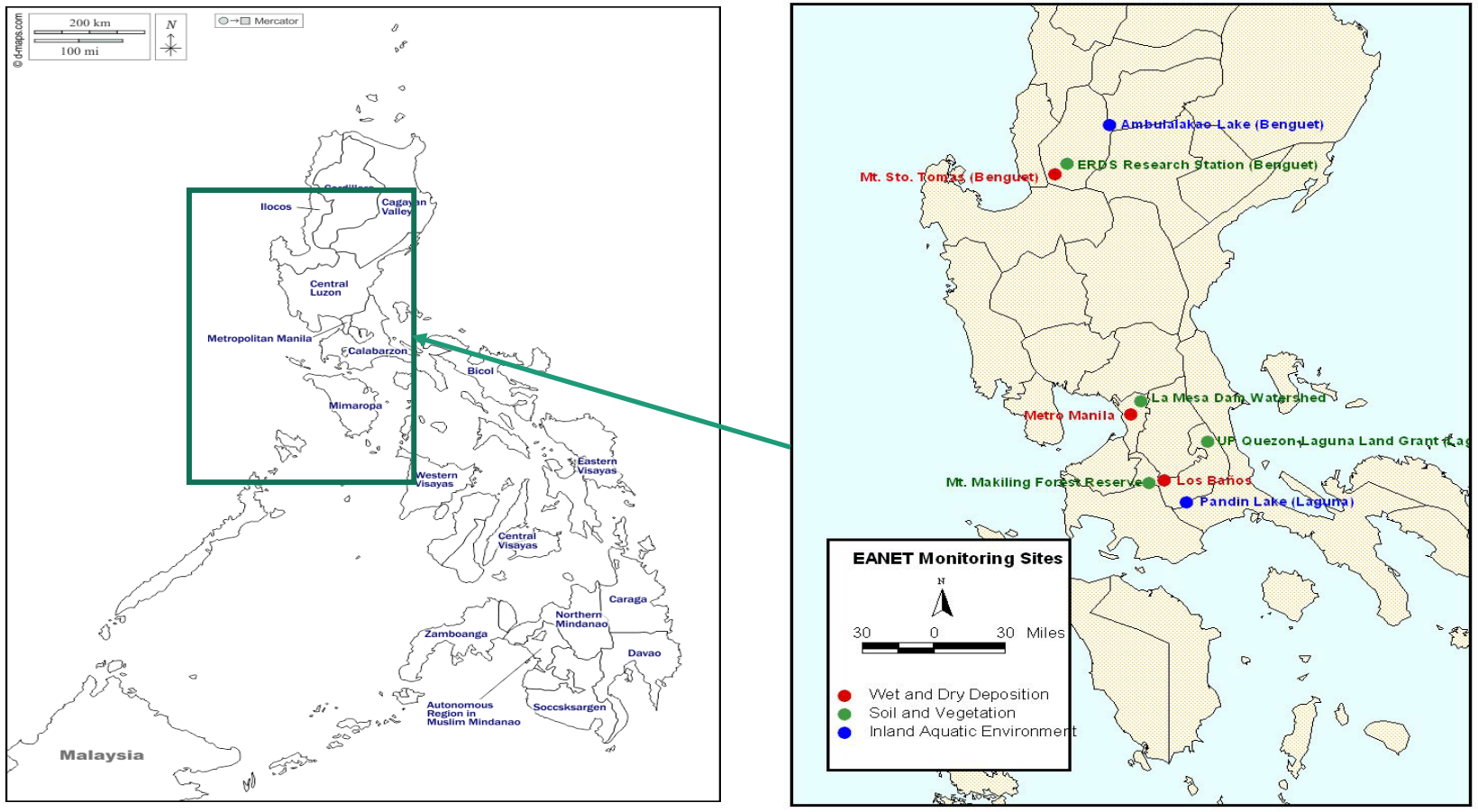


Figure 1.1 EANET monitoring sites (Catchment–scale study site is located in La Mesa Watershed).



Figure 1.2. Photographs of the monitoring stations and activities.

1.4 Sampling and Measurements

Wet and dry deposition monitoring are implemented to measure concentrations and fluxes of acidic substances deposited to the ground, while soil and vegetation and inland aquatic environment monitoring are carried out to assess the adverse impacts on terrestrial and aquatic ecosystems. Catchment-scale is an integrated monitoring activity which purpose is to evaluate both the quantitative and qualitative effects of acid deposition on ecosystems.

1.4.1 Wet and Dry Deposition Monitoring

Rainwater samples for Wet Deposition (WD) monitoring had been collected weekly using automatic rainwater sampler (Ogasawara Keiki US-330) installed at the sites. Measurements for the required parameters had been done in reference to the Technical Manuals on WD and on DD published by the EANET.

During 2020-2024 monitoring period, the previous issues on the worn-out sensors of the rainwater samplers were addressed through procurement of replacement sensors. Additionally, considering the current state of the operation of the samplers, the EMB Central Office also procured two (2) new wet only samplers to replace defective units and ensure continuity of monitoring activities.

On Dry Deposition (DD) monitoring, samples had been collected weekly using the Filter Pack method where gas and aerosols are trapped in a filter pack. Regular monitoring activities for DD continued in the urban and rural sites in 2020-2024. The required parameters were measured based on the Technical Manual for Dry Deposition on Filter Pack Method, also published by the EANET. Some enhancements and repairs were also conducted for the dry deposition samplers, including the acquisition of new pumps and dry gas meters, and improvements in the overall site installations.

However, in the case of the 2020 data, sampling activities were considerably affected by the implementation of various quarantine protocols due to the COVID-19 pandemic. However, these gradually improved over time to permit regular sampling work.

1.4.2 Inland Aquatic Environment Monitoring

Monitoring activities for IAE had been conducted in accordance with the EANET Technical Manual for Inland Aquatic Environment Monitoring in East Asia (2010). On a quarterly basis, surface water with replicates were sampled directly at the center of the lake. For reference, measurements of electric conductivity (EC), water temperature, pH and dissolved oxygen were done in situ using a portable water quality checker. Replicate samples were collected through grab sampling by using polyethylene bottles. The samples are preserved with ice in a chest while in transit to the corresponding Laboratory for analyses of the required parameters such EC, pH, alkalinity, cations and anions.

1.4.3 Catchment-scale Monitoring

Monitoring of some streams at the La Mesa Watershed had been done before so that during the said

Technical Mission in January 2019, the Mission Team identified the catchment area at Tower 1 in the La Mesa Watershed in Lagro, Quezon City as the site for catchment-scale study of EANET in the Philippines. This is an important consideration because the La Mesa Watershed is the major source of water for the Metro Manila populace. Monitoring on a monthly basis had started on Catchment-scale through the collection of water sample from the stream at Tower 1 for the analysis of mandatory parameters in accordance with the Guideline for Catchment-scale Monitoring in East Asia. La Mesa Watershed has a total area of 26.59 square kilometers and the catchment area is 0.186 square kilometers, which is of loamy-sand soil. In the same Watershed the urban site for Soil and Vegetation monitoring had been earlier established. The Catchment-scale study site is around 9 km away from the MM site for wet and dry deposition monitoring. Data form these monitoring sites could be used for evaluation.

1.4.4 Soil and Vegetation Monitoring

The Philippines, as a member of the network, monitors and reports changes in vegetation and soil periodically at a selected location in the country to determine the extent and impact of acid deposition in this part of the East Asian region. The frequency of S&V monitoring is 3-5 years. Currently, there are four established monitoring sites, namely, La Mesa Watershed in Quezon City, the Mt. Makiling Forest Reserve in the University of the Philippines, Los Baños College in Laguna; the UP Quezon-Laguna Land Grant in Siniloan, Quezon, both representing rural sites, and the Boneco Long Term Ecological Research Station in Itogon, Benguet, which represents a remote site.

For 2023, the EMB with the technical assistance provided by Dr. Wilfredo Carandang (Vegetation Expert) and Dr. Marco Galang (Soil Expert) have successfully conducted the S&V monitoring activities at the Mt. Makiling Forest Reserve and at the UP Quezon-Laguna Land Grant in Laguna.

Chapter 2. Acid Deposition and Air Pollution in the Philippines and Their Environmental Impacts

2.1 State of acid deposition and air pollution

2.1.1 Wet deposition

Wet deposition is one form of acid deposition which is normally associated with acid rain. This happens when the sulfuric and nitric acid formed in the atmosphere mixed with rain, snow or fog and fell to the ground. Wet deposition has a substantial effect on ecosystem.

Long-term wet-deposition monitoring at the Philippine EANET sites in Metro Manila, Los Baños, and Mt. Sto. Tomas demonstrates persistent spatial differences and pronounced interannual variability in precipitation chemistry. Using the actual, unscaled analytical values, Metro Manila showed the highest median concentrations of non-sea-salt sulfate (nss-SO_4^{2-}), nitrate (NO_3^-), and ammonium (NH_4^+), followed by Los Baños and Mt. Sto. Tomas. A statistically significant long-term decrease was detected for nss-sulfate concentration in Metro Manila (Kendall's $\tau = -0.391$, $p = 0.007$; Theil–Sen slope = -0.363 μmol L^{-1} y^{-1}), whereas nitrate and ammonium did not exhibit significant monotonic trends. Annual precipitation pH also showed no significant long-term trend, despite

values below the 5.6 reference level in most Metro Manila observations. The high ammonium concentrations recorded during several years, particularly 2011–2012, indicate that reduced nitrogen is a major component of precipitation chemistry and may partially neutralize sulfuric and nitric acidity. These findings suggest that declining sulfur deposition does not necessarily translate into declining atmospheric deposition pressure because reactive nitrogen remains important. Continued monitoring should therefore evaluate sulfur together with both oxidized and reduced nitrogen, supported by meteorological, trajectory, and ecosystem-response information.

The assessment used annual wet-deposition data covering 2000–2025 from the three Philippine EANET monitoring environments: Metro Manila (Manila Observatory), Laguna (Los Baños), and Benguet (Mt. Sto. Tomas). The evaluation focused on nss-sulfate, nitrate, ammonium, precipitation pH, and selected major ionic constituents. Missing monitoring years were retained as missing values and were not interpolated or imputed.

For this write-up, all quantitative analyses and newly generated figures use the actual analytical values from the source data containing the published annual data for the Philippines as approved by the EANET Intergovernmental Meetings for the past years. Selected concentrations in presentation-oriented worksheets had been intentionally reduced to improve graphical readability; these scaled values were not used in the statistical analysis. The high values in the source dataset were retained, including the pronounced ammonium observations in Metro Manila during 2011 and 2012. The parameter labeled "Ammonia" is referred to here as ammonium (NH_4^+), which is the dissolved ionic form relevant to precipitation chemistry.

Long-term monotonic trends were evaluated using Kendall rank correlation, with the Theil–Sen estimator used to quantify the median rate of change. A significance level of 0.05 was used. Spatial differences were assessed for the 13 years with concurrent observations at all three monitoring sites using the Friedman test, followed by paired Wilcoxon comparisons. Wet-deposition fluxes were recalculated from the unscaled concentration and precipitation data using deposition (mmol m^{-2} y^{-1}) = concentration (µmol L^{-1}) × annual precipitation (mm y^{-1}) / 1000. This approach avoids the use of presentation-scaled values in deposition calculations.

Summary of Observed Concentrations

Parameter	Metro Manila	Los Baños	Mt. Sto. Tomas
nss-SO_4^{2-} (µmol L^{-1})	17.48 (9.10–25.40; n=24)	9.13 (5.22–17.02; n=20)	4.54 (1.20–7.31; n=13)
NO_3^- (µmol L^{-1})	14.62 (8.68–50.46; n=24)	8.22 (4.87–38.55; n=20)	3.94 (1.87–8.47; n=13)
NH_4^+ (µmol L^{-1})	35.49 (16.48–272.98; n=24)	18.67 (11.59–84.82; n=20)	5.91 (0.80–14.12; n=13)
pH	5.29 (4.44–6.28; n=24)	5.53 (4.49–6.29; n=21)	5.84 (5.29–6.70; n=13)

Table 2.1. Median, observed range, and number of annual observations for selected wet-deposition parameters. Values are based on the unscaled source data

The median concentrations demonstrated a consistent spatial gradient for the three principal species examined. Metro Manila recorded the highest median nss-sulfate, nitrate, and ammonium concentrations, Los Baños was intermediate, and Mt. Sto. Tomas generally recorded the lowest levels. When analysis was restricted to 13 years with data available at all three sites, the spatial differences were significant for nss-sulfate, nitrate, and ammonium (Friedman test, $p < 0.001$ for each parameter). Pairwise comparisons were likewise significant, supporting a persistent site-to-site gradient rather than a pattern caused solely by unequal temporal coverage.

Long-term Behavior of nss-Sulfate

Metro Manila exhibited a statistically significant decrease in annual nss-sulfate concentration over the monitoring period. Kendall's τ was -0.391 ($p = 0.007$), and the Theil–Sen estimator indicated an average monotonic decrease of approximately 0.363 µmol L^{-1} per year. The decline is visible despite substantial year-to-year variability and indicates that the long-term sulfur-related wet-deposition burden has decreased at the urban monitoring site.

No statistically significant monotonic trend was detected in Los Baños ($\tau = 0.221$, $p = 0.186$) or Mt. Sto. Tomas ($\tau = 0.154$, $p = 0.510$). These sites therefore should not be assumed to follow the same temporal trajectory as Metro Manila. The lack of significance in Mt. Sto. Tomas should also be interpreted in light of the shorter and more discontinuous monitoring record.

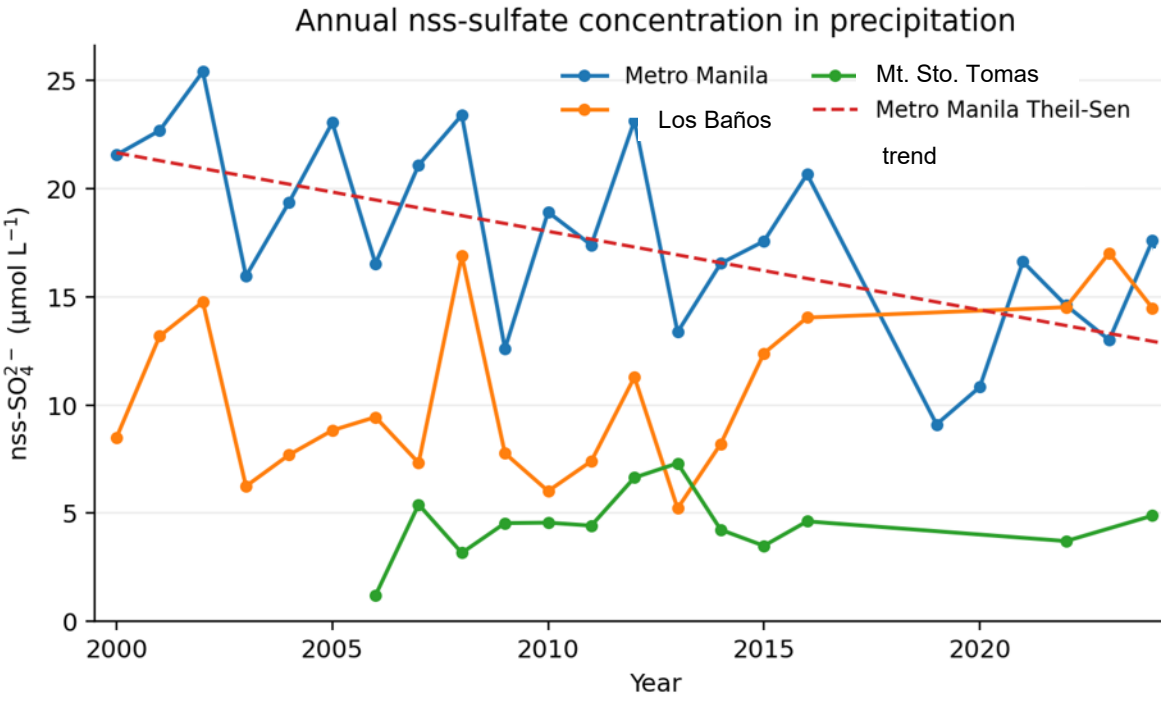


Figure 2.1. Annual nss-sulfate concentrations at the three Philippine EANET monitoring sites from 2000 to 2024. The dashed line represents the Theil–Sen trend for Metro Manila. Actual, unscaled concentrations are shown.

Long-term Behavior of Nitrate

Nitrate exhibited a different temporal behavior from nss-sulfate. Metro Manila showed essentially no monotonic long-term trend (τ = 0.000, p = 1.000), although several individual years were characterized by high nitrate concentrations, including approximately 50.46 µmol L^{-1} in 2010 and 36.44 µmol L^{-1} in 2016. These episodic elevations strongly influence the annual variability but do not constitute a sustained increase or decrease across the full monitoring record.

Laguna showed a positive tendency (τ = 0.305; Theil–Sen slope ≈ +0.135 µmol L^{-1} y^{-1}), but the trend did not reach the 0.05 significance level (p = 0.064). It is therefore more appropriate to describe the Laguna pattern as a possible upward tendency requiring continued observation rather than as a statistically established increase. Benguet showed no significant nitrate trend (τ = 0.077, p = 0.765).

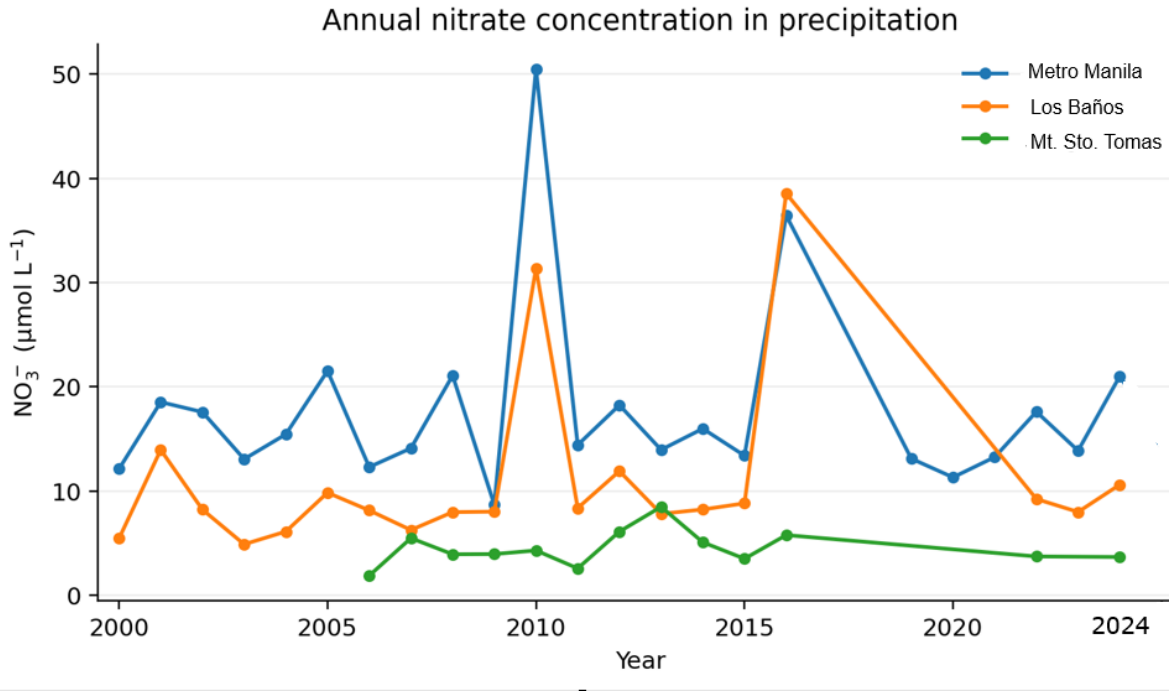


Figure 2.2 Annual nitrate concentrations at the three Philippine EANET monitoring sites from 2000 to 2024. Actual, unscaled concentrations are shown.

Importance of Reduced Nitrogen

Ammonium was a major component of precipitation chemistry, particularly in Metro Manila. The median Metro Manila concentration was approximately 35.49 µmol L^{-1}, but the distribution was strongly influenced by several high observations. Concentrations reached about 182.50 µmol L^{-1} in 2011 and 272.98 µmol L^{-1} in 2012, with another high value of approximately 112.32 µmol L^{-1} in 2016. These actual concentrations are substantially higher than the presentation-scaled values used in some graphical worksheets and materially strengthen the evidence that reduced nitrogen can be an important component of wet deposition.

Despite the large episodic peaks, ammonium did not show a statistically significant monotonic trend in Metro Manila (τ = −0.152, p = 0.313), Los Baños (τ = 0.221, p = 0.186), or Mt. Sto. Tomas (τ =

0.026, p = 0.952). This pattern indicates that the major feature of the reduced-nitrogen record is episodic variability rather than a simple long-term increase or decrease.

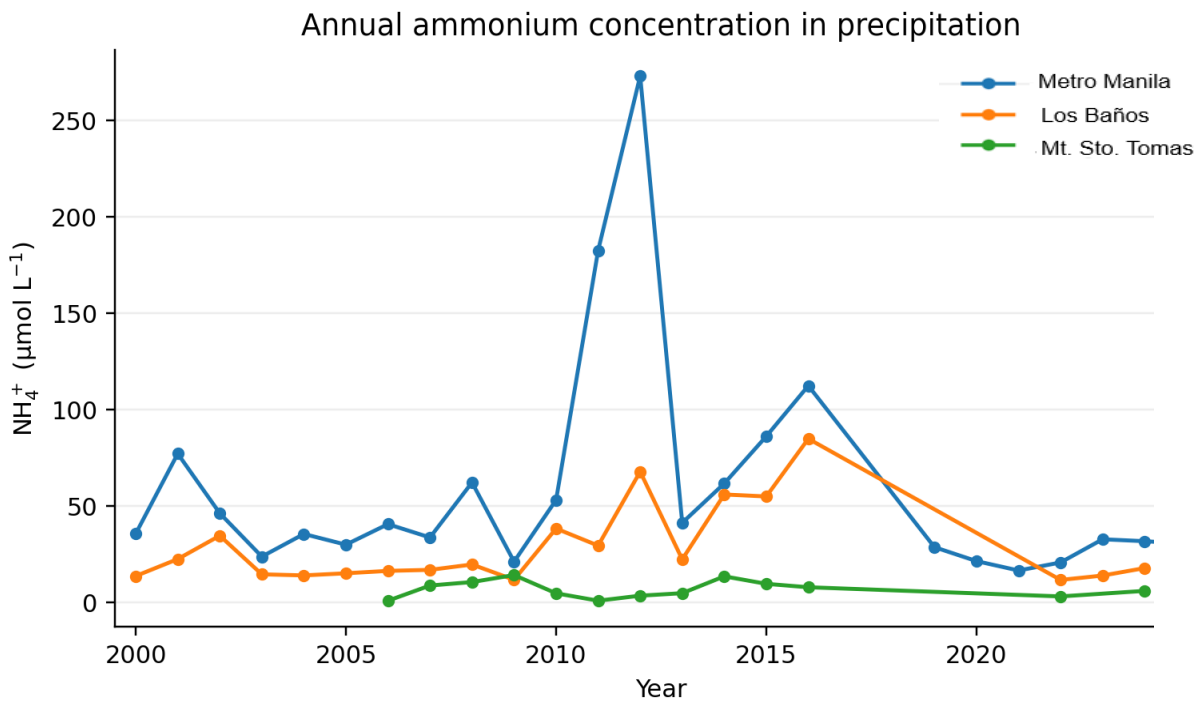


Figure 2.3. Annual ammonium concentrations at the three Philippine EANET monitoring sites for 2000-2024. The pronounced Metro Manila values in 2011–2012 are shown at their actual magnitudes.

Rainwater pH and Acid–Base Balance

Annual precipitation pH was variable at all three sites. Median pH was approximately 5.29 in Metro Manila, 5.53 in Los Baños, and 5.84 in Mt. Sto. Tomas. Relative to the 5.6 reference level used in the monitoring presentation, 19 of 24 Metro Manila observations and 14 of 21 Laguna observations were below 5.6, compared with 4 of 13 observations in Benguet. Nevertheless, no site exhibited a statistically significant monotonic long-term pH trend.

The absence of a clear pH trend despite the significant decline in Metro Manila nss-sulfate demonstrates that precipitation acidity cannot be interpreted from sulfate alone. Rainwater pH reflects the net balance among acid-forming species and neutralizing constituents. Changes in nitrate, ammonium, alkaline cations, rainfall amount, and atmospheric transport can therefore offset or obscure the pH response expected from changes in sulfate.

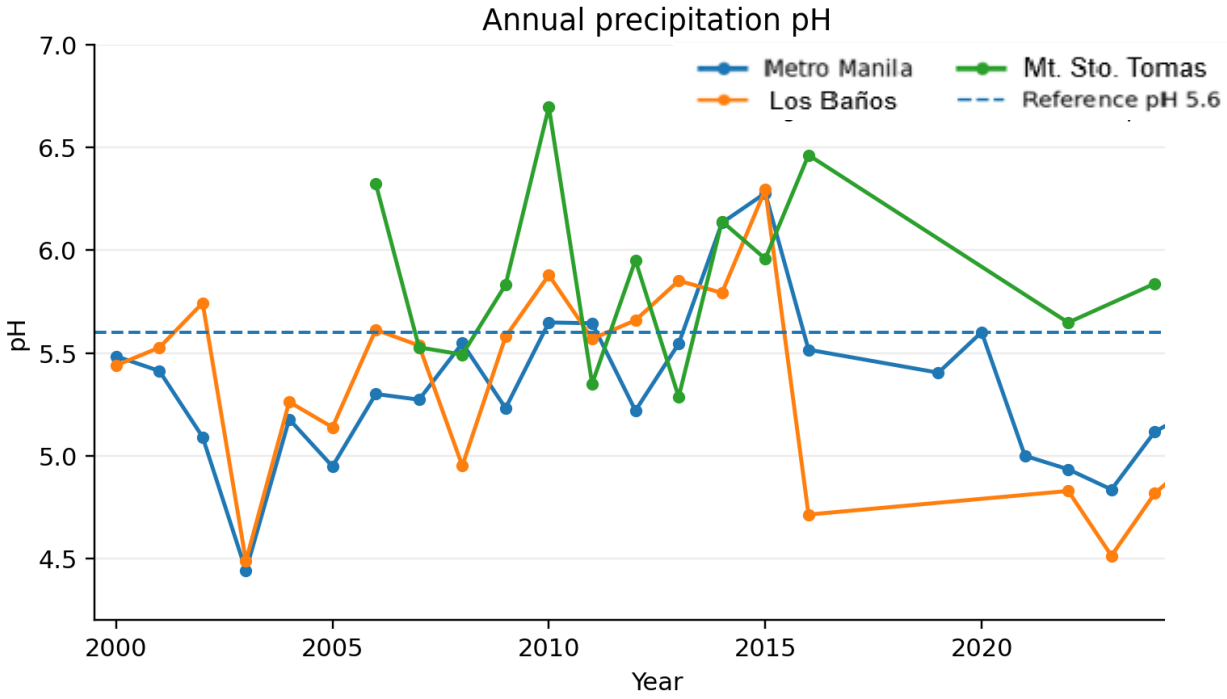


Figure 2.4. Annual precipitation pH at the three Philippine EANET monitoring sites from 2000 to 2024. The dashed line shows the pH 5.6 reference level used in the monitoring dataset.

Ionic Composition and the Neutralizing Role of Ammonium

The charge-equivalent composition of Metro Manila precipitation further highlights the importance of ammonium. When ionic concentrations are expressed in μeq L^{-1}, ammonium constitutes a substantial portion of the cationic charge in many years and dominates the cation balance during the 2011–2012 episodes. Evaluating ions on an equivalent-charge basis is important because divalent species contribute two equivalents of charge per mole, whereas ammonium, nitrate, sodium, and potassium are monovalent.

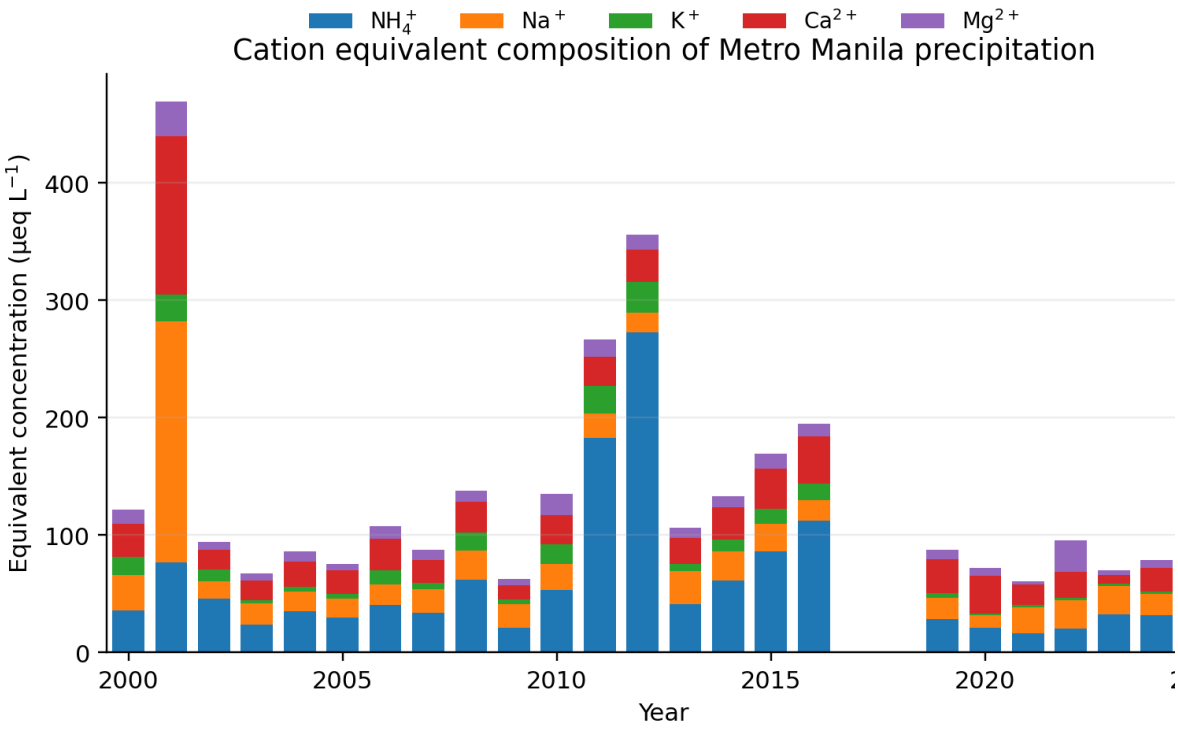


Figure 2.5. Cation equivalent composition of Metro Manila precipitation. Values are expressed as charge equivalents to support acid–base interpretation.

The calculated wet-deposition fluxes provide an even clearer indication of the magnitude of reduced nitrogen input. Using the actual concentrations and annual precipitation, ammonium deposition in Metro Manila was exceptionally high during 2011 and 2012, reaching approximately 667 and 1,218 mmol m^{-2} y^{-1}, respectively. These values were not reduced for graphical presentation in the present analysis. At the same time, annual pH did not decline proportionally to the magnitude of sulfate and nitrate deposition.

This pattern is consistent with partial neutralization of sulfuric and nitric acidity by atmospheric ammonia following conversion to ammonium salts. The term “neutralization,” however, should not be interpreted as removal of the environmental loading. Ammonium sulfate and ammonium nitrate may reduce free hydrogen-ion activity and thereby moderate measured pH, but they continue to deliver reactive nitrogen and, in the case of ammonium sulfate, sulfur to receiving ecosystems. Consequently, relatively moderate precipitation pH can coexist with substantial atmospheric deposition.

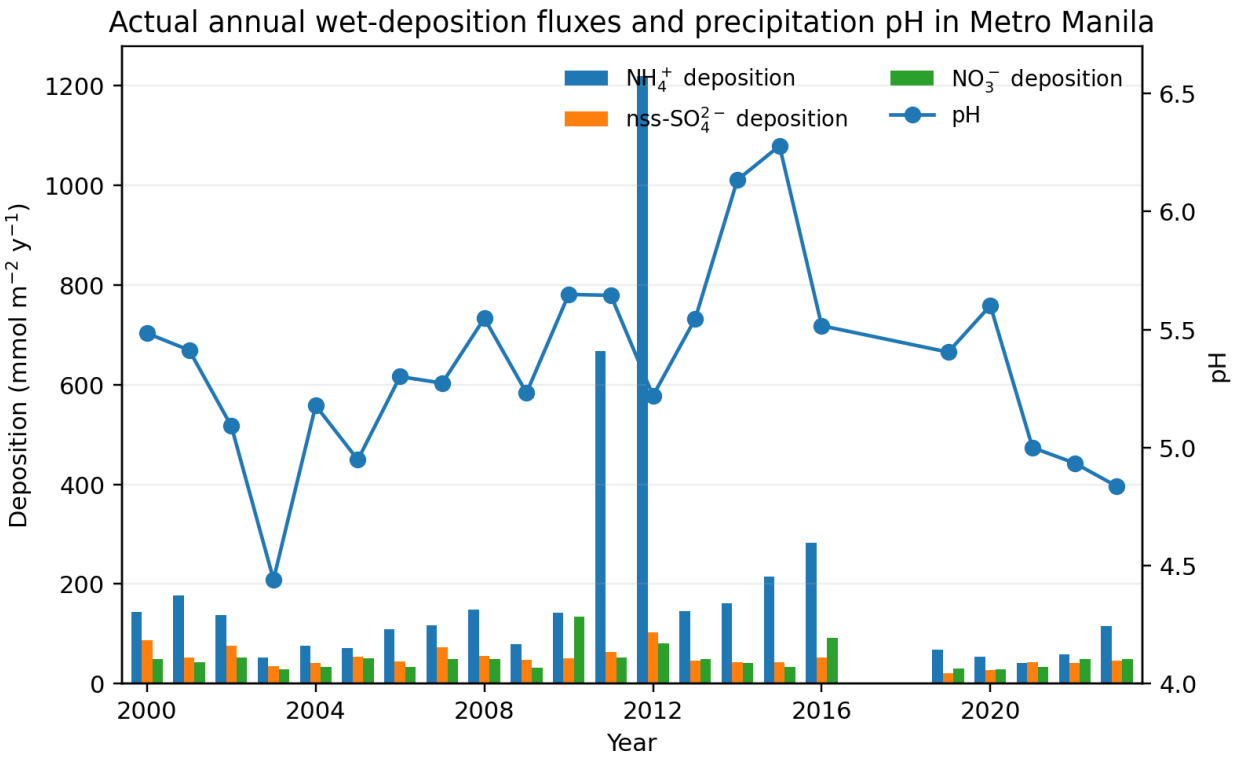


Figure 2.6. Actual annual ammonium, nss-sulfate, and nitrate wet-deposition fluxes in Metro Manila with annual precipitation pH. Fluxes were recalculated from unscaled concentration and precipitation data.

Seasonal Variation in Wet Deposition

The seasonal assessment supplied for Metro Manila for 2019–2024 shows that nss-sulfate and nitrate deposition generally increased during the wetter part of the year, particularly from approximately May or June through October. The correspondence between precipitation and deposition illustrates the distinction between concentration and flux: a high deposition amount may result from efficient scavenging and large rainfall volume even when the chemical concentration of individual rain events is not at its annual maximum.

This seasonal behavior is environmentally important because wet-deposition flux represents the actual amount of sulfur or nitrogen transferred from the atmosphere to terrestrial and aquatic surfaces. Monsoon-season rainfall can therefore produce substantial cumulative loading even when precipitation chemistry is diluted by large rainfall volumes. The supplied seasonal figure is retained as a qualitative representation because the workbook does not provide a single clearly labeled monthly summary table corresponding exactly to the plotted 2019–2024 averages.

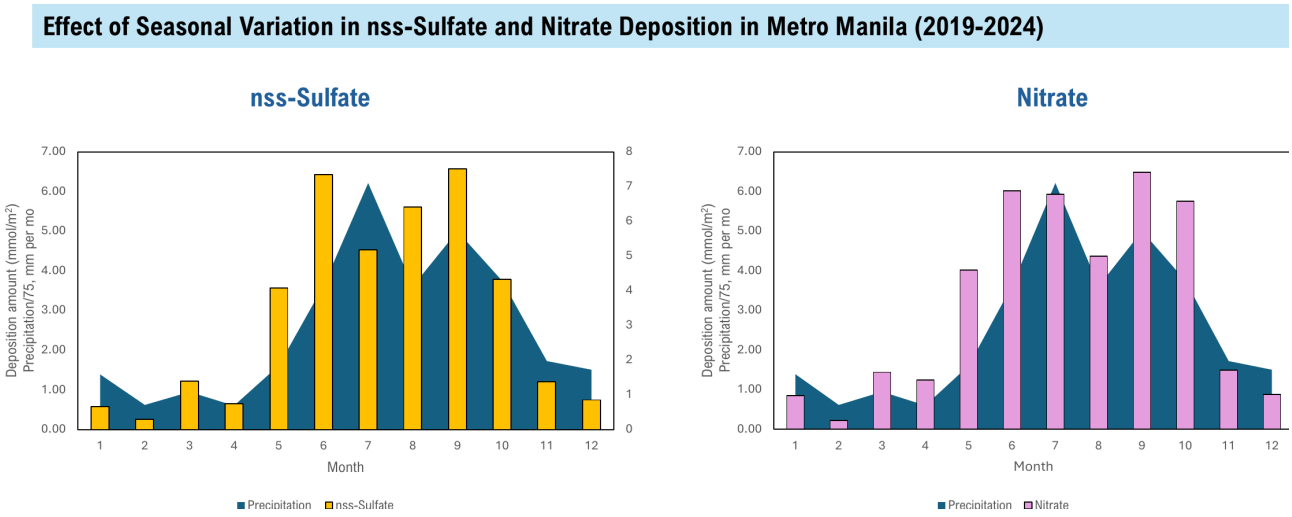


Figure 2.7. Supplied graphical representation of seasonal variation in Metro Manila nss-sulfate and nitrate deposition for 2019–2024, shown together with precipitation. Source: EANET STM 27 presentation.

Statistical Summary of Long-Term Trends

Parameter / Site	Kendall τ	p-value	Sen slope	Interpretation
nss-SO_4^{2-} – Metro Manila	-0.391	0.007	-0.363	Significant decrease
nss-SO_4^{2-} – Laguna	0.221	0.186	+0.251	No significant trend
nss-SO_4^{2-} – Benguet	0.154	0.510	+0.032	No significant trend
NO_3^- – Metro Manila	0.000	1.000	-0.001	No significant trend
NO_3^- – Laguna	0.305	0.064	+0.135	Positive tendency; not significant
NO_3^- – Benguet	0.077	0.765	+0.032	No significant trend
NH_4^+ – Metro Manila	-0.152	0.313	-0.429	No significant trend
NH_4^+ – Laguna	0.221	0.186	+0.682	No significant trend
NH_4^+ – Benguet	0.026	0.952	+0.013	No significant trend
pH – Metro Manila	0.000	1.000	-0.000	No significant trend
pH – Laguna	-0.029	0.882	-0.008	No significant trend
pH – Benguet	0.051	0.858	+0.005	No significant trend

Table 2.2. Mann–Kendall/Theil–Sen summary for annual concentration and pH series. Slopes are per year; concentration slopes are in μmol L^{-1} y^{-1} and pH slopes are pH units y^{-1}.

2.1.2 Dry deposition

Dry deposition is another form of acid deposition in which airborne acids are removed from the air during fine and cloudy days. If inhaled dry deposition can cause health problems on humans. For the period 2020 to 2024, continuous implementation of dry deposition monitoring activities at the Metro Manila site was implemented, except only during the implementation of community quarantine protocols at the height of the COVID-19 pandemic. Meanwhile, dry deposition sampling in Los Baños resumed in 2022. Considering the gaps in the available data on dry deposition across all sites, trends cannot be accurately described at this time. Nevertheless, the resumption of the sampling activities in Metro Manila and in Los Baños marks an important step in obtaining critical long-term monitoring data on dry deposition in the country. The plots below show the accumulated data for key anions and cations bound in particles for the period 2000 to 2024.

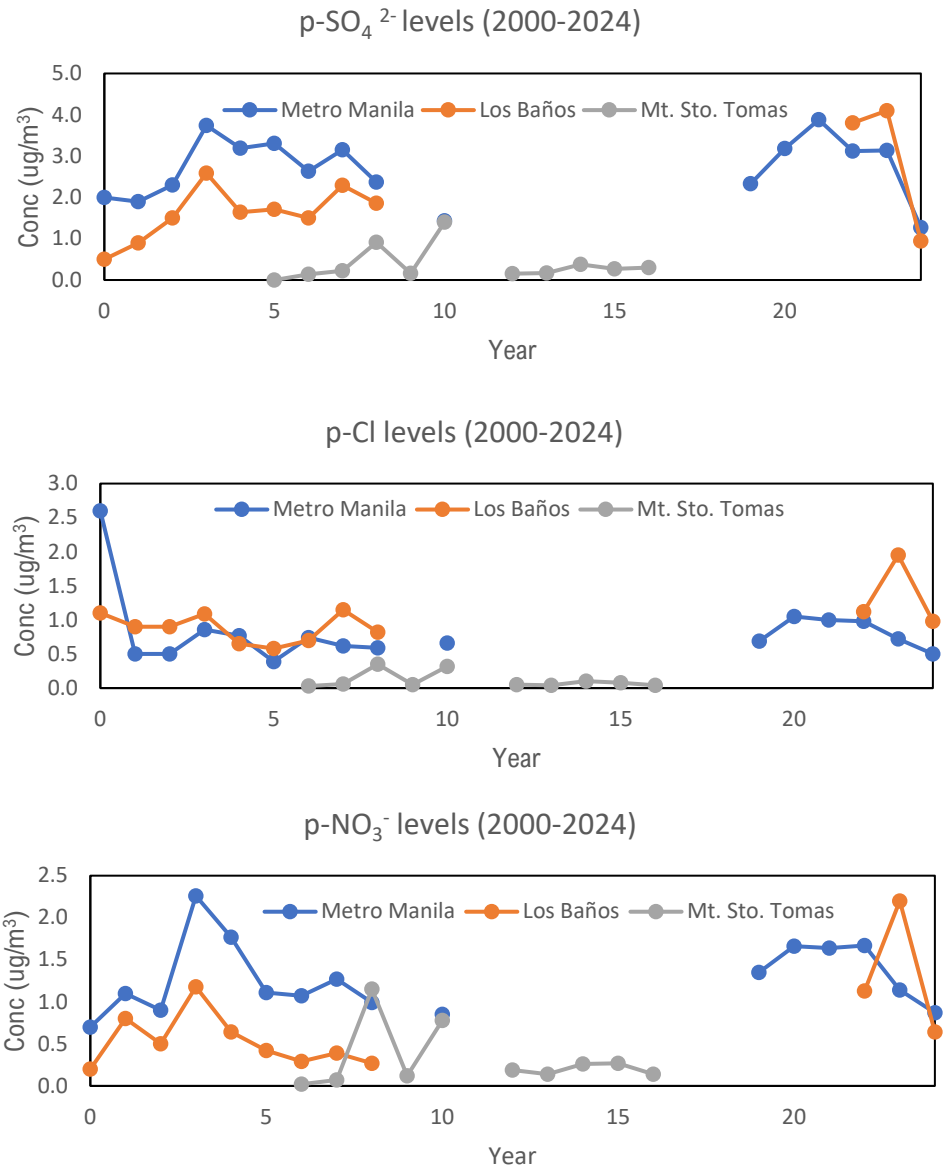


Figure 2.8. Annual Mean Concentration for particulate-bound sulfate, chloride, and nitrate for all monitoring sites from 2000 to 2024.

As can be seen from Figures 2.8 and 2.9, there are considerably large gaps in the data available for dry deposition monitoring activities across all the monitoring sites from 2000 to 2024. Among the three EANET dry deposition monitoring sites, only the Metro Manila Station was able to accumulate continuous data from 2020 to 2024. All of the anions measured show a relatively decreasing trend from 2020 to 2024. Meanwhile the cations from the Metro Manila station varies in trends, with potassium noticeably having the highest concentration in 2020 as compared to other cations. This trend will further be studied in the next monitoring and reporting cycles, and efforts will be made to enable data collection again at Mt. Sto. Tomas station. Los Baños station also resumed regular monitoring in 2022 with continuous data collection until 2024.

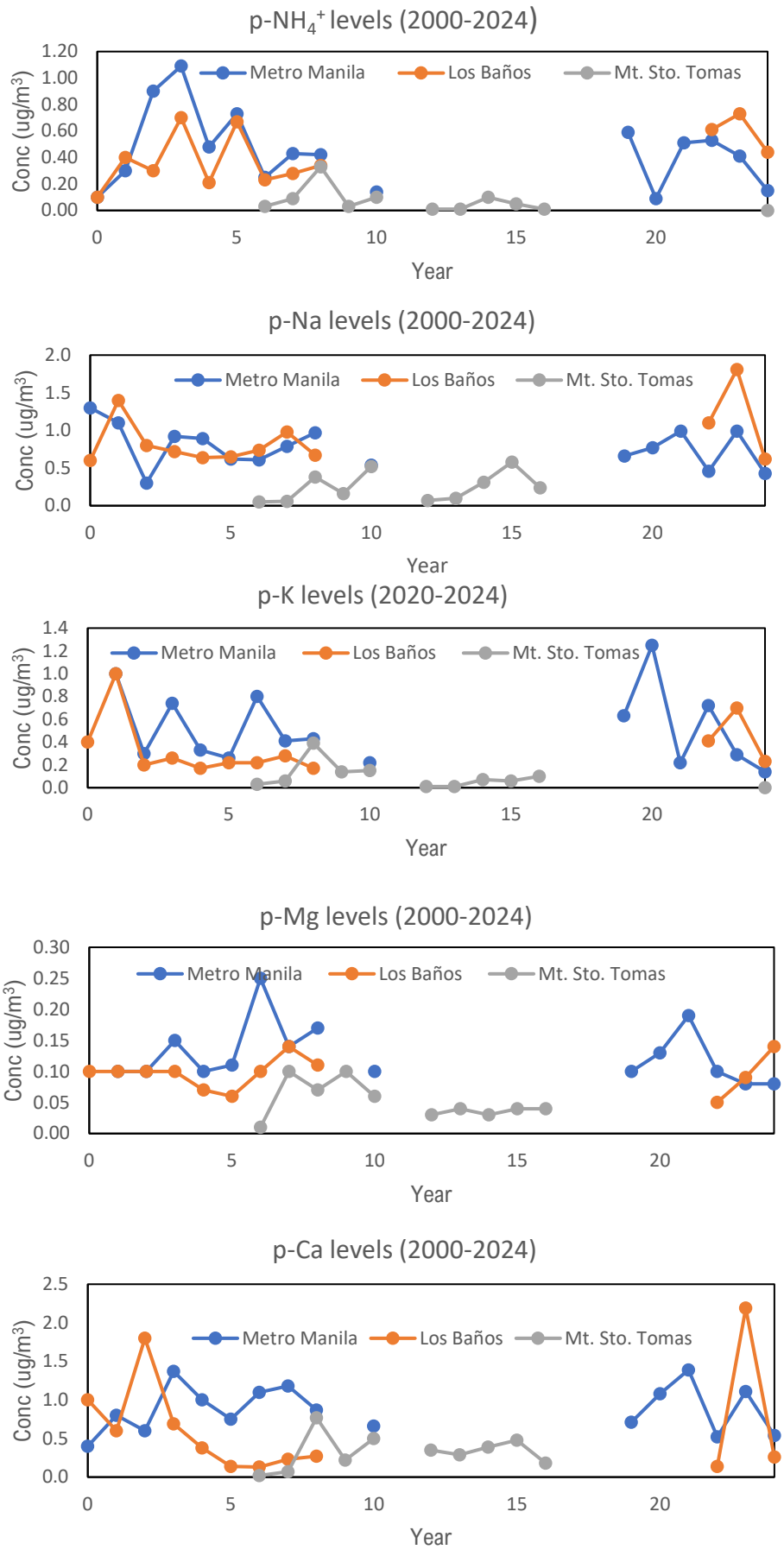


Figure 2.9. Annual Mean Concentration for particulate-bound cations for all monitoring sites from 2000 to 2024.

2.2 State of inland aquatic environment

Currently, the Philippines has two sites for Inland Aquatic Environment Monitoring, namely, Pandin Lake (rural site), located in San Pablo, Laguna, and Ambulalakao Lake (remote site), located in Kabayan, Benguet province. Pandin Lake is part of the Seven Lakes System in the area, which are of low-profile volcanic craters. As one of the best kept lakes, Pandin Lake is the most pristine of the Seven Lakes. It is considered oligotrophic because of the abundant plant and aquatic fauna surrounding the area. The Lake has no inlet while its outlet water drains into the Laguna de Bay through the Prinsa River while its recharge water comes from rainwater and underground. The Ambulalakao Lake in Kabayan Benguet is located in a sheltered valley with tall forest around it and is said to be the cleanest body of water in the Cordillera Mountains.

For this report, the regular data gathering at Lake Pandin is summarized by the following graphs for representative anions and pH from 2000 to 2024.

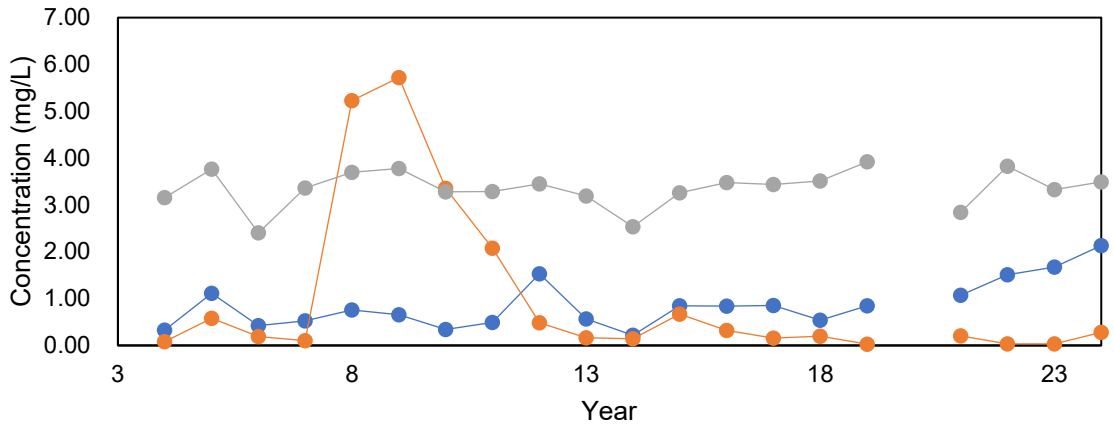


Figure 2.10. Long-term trends of sulfate, nitrate, and chloride from 2000 to 2024 from Lake Pandin.

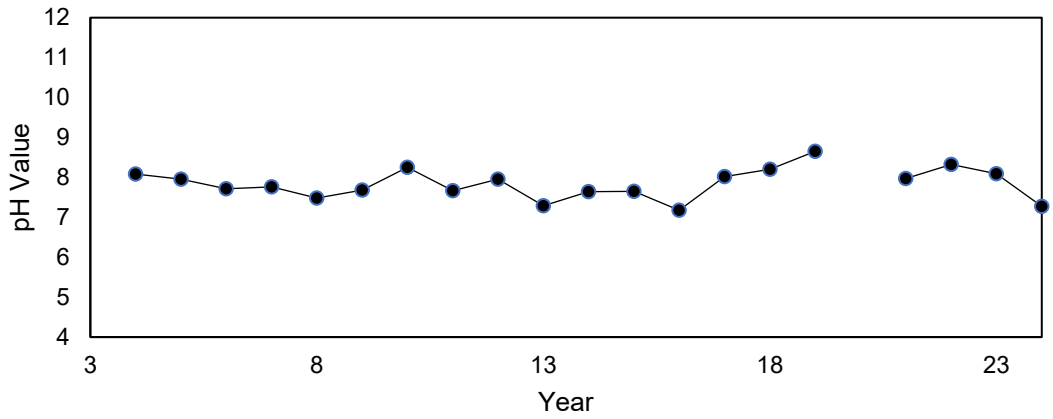


Figure 2.11. Long-term pH trends of of Lake Pandin from 2000 to 2024.

The long-term monitoring data for Lake Pandin (2000–2024) indicate that the lake has maintained a generally neutral to slightly alkaline pH, ranging mostly from about 7.2 to 8.6, with no evident trend toward acidification and with occasional increases in recent years. Among the measured anions, chloride consistently shows the highest concentrations (approximately 2.5–4.0 mg/L) and remains relatively stable throughout the monitoring period, suggesting a steady background source. Sulfate concentrations are generally low (<1 mg/L) during the early years but exhibit a gradual increase in the later monitoring period, reaching around 2 mg/L, which may indicate changing atmospheric inputs or watershed influences. In contrast, nitrate displays a pronounced but short-lived peak around the mid-2000s (reaching approximately 6–7 mg/L) followed by a sharp decline to near-background levels, suggesting a transient nutrient input event rather than a sustained trend. Overall, the data suggest that Lake Pandin remains well-buffered against acidification, with stable pH conditions despite fluctuations in anion concentrations, reflecting generally good water quality and no clear signs of long-term acid deposition impacts.

2.3 State of catchment monitoring

Stream water monitoring at Tower 1 in La Mesa Watershed started in 2017 with the recommendation of the 2016 ACAP Technical Mission Team that the stream at Tower 1 should be considered for catchment-scale monitoring. In January 2019, the ACAP Technical Mission Team confirmed that the said stream was suitable for Catchment-scale study. Consequently, collection of stream water from the site has been conducted on a monthly basis. Using the available data from 2019 to 2023 from the monthly catchment monitoring activities, this report presents the first comprehensive analysis of the catchment data since 2019. Figure 2.12 summarizes annual precipitation, sulfur and nitrogen deposition, stream-water concentrations, rainwater concentrations, and input-output budgets for sulfate and dissolved inorganic nitrogen. Collectively, these results provide insight into how atmospheric deposition is processed, retained, or exported within the watershed system.

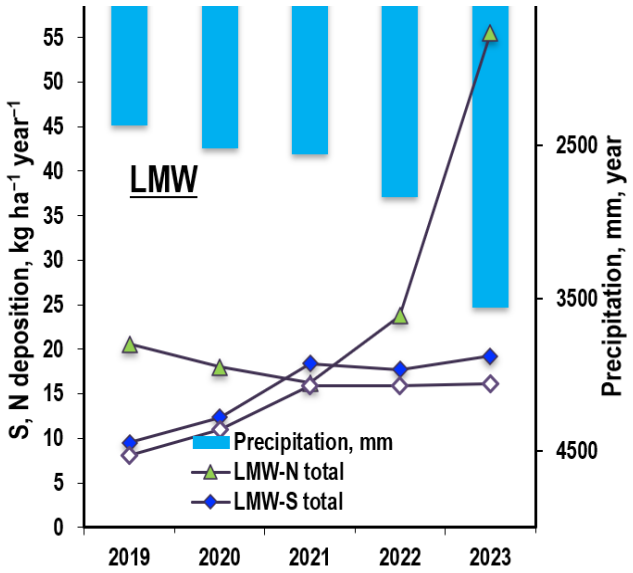


Figure 2.12. Annual Sulfur and Nitrogen Deposition in La Mesa Watershed (LMW) in relation to precipitation

The graph shows that precipitation generally increased toward 2023, with the highest rainfall observed during the final year of the monitoring period. This increase in precipitation was accompanied by a marked increase in total nitrogen deposition in 2023. Total nitrogen deposition showed moderate variation from 2019 to 2022 but increased substantially in 2023. This suggests that nitrogen deposition at La Mesa Watershed may be strongly influenced by wet deposition processes, particularly during years with higher precipitation. Increased rainfall can enhance the scavenging of atmospheric nitrogen species, including nitrate and ammonium, thereby increasing the total nitrogen load delivered to the watershed.

Total sulfur as well as non-sea salt sulfur deposition showed a more gradual increasing pattern over the monitoring period. Unlike nitrogen, sulfur deposition did not exhibit the same abrupt increase in 2023, although values remained generally higher in the latter part of the monitoring period compared with earlier years. This difference in behavior suggests that sulfur and nitrogen deposition may be influenced by different source strengths, atmospheric processes, or removal mechanisms.

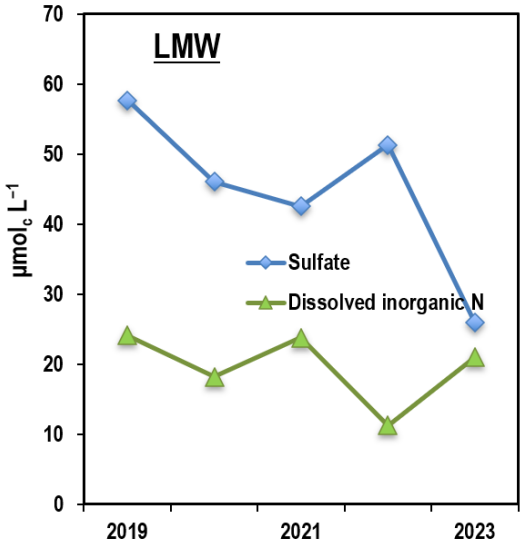


Figure 2.13. Annual Mean Sulfate and Dissolved Inorganic Nitrogen Concentrations in Stream Water

Figure 2.13 shows the annual concentrations of sulfate and dissolved inorganic nitrogen in stream water. Sulfate concentrations were generally higher than dissolved inorganic nitrogen concentrations throughout the monitoring period. Sulfate declined from 2019 to 2021, increased again in 2022, and then decreased sharply in 2023.

The relatively high sulfate concentrations in the earlier years may indicate the influence of accumulated sulfur within the catchment, geologic or soil-related contributions, or delayed release from previous deposition inputs. The increase in sulfate concentration in 2022 may reflect enhanced flushing or changes in hydrologic transport. However, the substantial decline in 2023 suggests that dilution from high precipitation, reduced sulfate availability for export, or changes in catchment flow pathways may have affected stream-water sulfate concentration.

Dissolved inorganic nitrogen, represented by nitrate plus ammonium, showed a fluctuating pattern. Concentrations decreased from 2019 to 2020, increased in 2021, decreased markedly in 2022, and increased again in 2023. Despite these fluctuations, dissolved inorganic nitrogen concentrations remained lower than sulfate concentrations. This pattern suggests that nitrogen is more actively retained or transformed within the watershed compared with sulfate.

The observed stream-water chemistry indicates that La Mesa Watershed has internal processes that regulate the movement of deposited sulfur and nitrogen. These may include soil adsorption, biological uptake, microbial transformation, groundwater interaction, and hydrologic dilution.

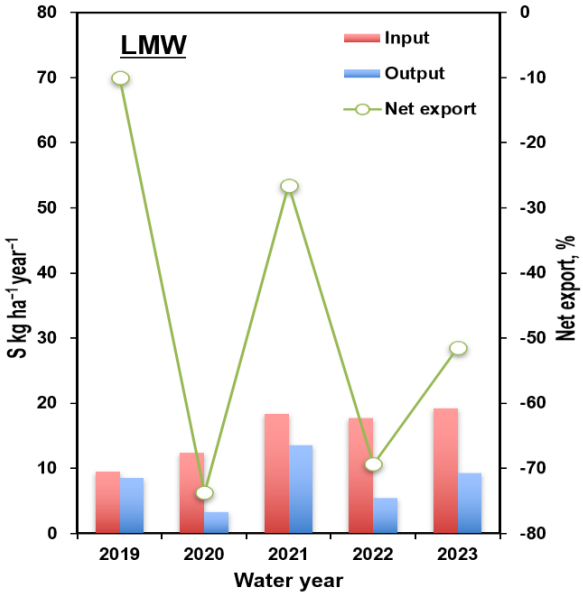


Figure 2.14. Sulfur Input, Output, and Net Export in LMW

Figure 2.14 presents the annual sulfur input, sulfur output, and net export percentage for La Mesa Watershed. Sulfur input represents atmospheric sulfur deposition, while output represents sulfur export through stream water. Across the monitoring period, sulfur input generally exceeded sulfur output, indicating that not all deposited sulfur was immediately exported from the catchment.

The sulfur input increased from 2019 to 2021, remained relatively high in 2022, and increased slightly in 2023. In contrast, sulfur output was generally lower and showed more variable behavior. Output was relatively low in 2020 and 2022, higher in 2021, and increased again in 2023 but remained below the corresponding input.

The net export values were negative across the monitoring years, indicating net retention of sulfur within the watershed. The degree of retention varied annually, with stronger retention observed in years when output was much lower than input. This suggests that La Mesa Watershed may store a portion of deposited sulfur in soils, vegetation, groundwater, or other internal catchment compartments.

The variation in sulfur export also highlights the role of hydrology. During wetter years, stream-water export may increase because of greater water movement through the catchment. However, high precipitation may also dilute stream-water concentrations, which can complicate the interpretation

of annual output. For this reason, future analysis should ideally include discharge data and flow-weighted loads to better separate dilution effects from actual changes in sulfur mobilization.

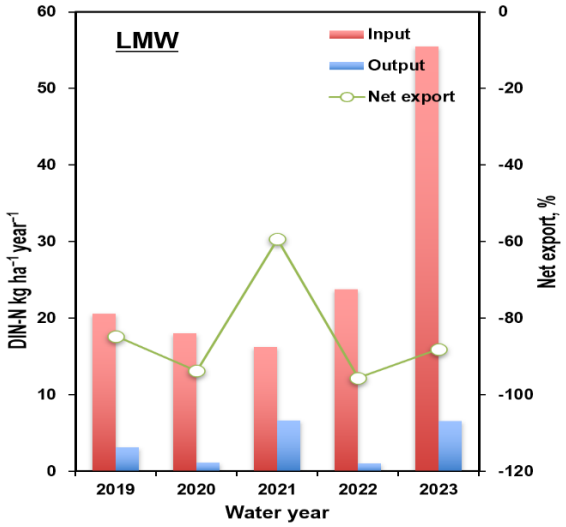


Figure 2.15. Dissolved Inorganic Nitrogen Input, Output, and Net Export

Figure 2.15 presents the input, output, and net export of dissolved inorganic nitrogen. The results show that nitrogen input consistently exceeded nitrogen output throughout the monitoring period. This indicates that La Mesa Watershed retained or transformed a substantial proportion of deposited inorganic nitrogen before it could be exported through stream water. The most notable feature of Figure 2.15 is the large increase in nitrogen input in 2023. Despite this increase, nitrogen output remained comparatively low and did not increase proportionally. This suggests that the watershed continued to function as an effective sink for inorganic nitrogen during the monitoring period.

The consistently negative net export values indicate strong nitrogen retention. This retention may be attributed to uptake by vegetation, microbial immobilization, nitrification-denitrification processes, soil storage, and other biological or geochemical mechanisms. In forested catchments, nitrogen retention is often expected when biological demand remains high and the ecosystem has not reached nitrogen saturation.

However, the substantial increase in nitrogen input in 2023 warrants attention. If elevated nitrogen deposition continues over time, the watershed's capacity to retain nitrogen may eventually be reduced. This could lead to increased nitrate export, potential nutrient enrichment of receiving waters, and possible changes in soil and vegetation conditions. Continued monitoring is therefore necessary to determine whether the 2023 increase represents an isolated event or an emerging trend.

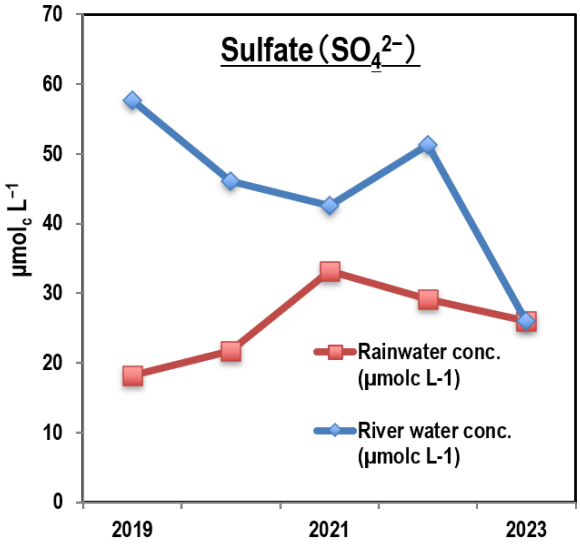


Figure 2.16. Comparison of Sulfate Concentrations in Rainwater and Stream Water

Figure 2.16 compares sulfate concentrations in rainwater and stream water. From 2019 to 2022, stream-water sulfate concentrations were higher than rainwater sulfate concentrations. This suggests that sulfate in stream water was not derived solely from current-year rainfall input. Instead, stream-water sulfate may also reflect stored sulfate within the catchment, mineral weathering, soil-water interaction, groundwater contribution, or delayed release from previous atmospheric deposition.

Rainwater sulfate concentrations increased from 2019 to 2021, followed by a gradual decrease toward 2023. Stream-water sulfate concentrations, on the other hand, declined from 2019 to 2021, increased in 2022, and then decreased sharply in 2023. By 2023, rainwater and stream-water sulfate concentrations became nearly similar.

The convergence of rainwater and stream-water sulfate concentrations in 2023 may indicate a change in catchment sulfate dynamics. The sharp decrease in stream-water sulfate could be associated with dilution under high precipitation conditions, reduced flushing of stored sulfate, or changes in water flow pathways. The result also suggests that current rainwater sulfate concentration alone is insufficient to explain stream-water sulfate behavior. Catchment storage and hydrologic processes must also be considered.

This finding supports the importance of catchment-scale monitoring because it demonstrates that atmospheric deposition data needs to be interpreted together with stream-water chemistry to understand actual ecosystem response.

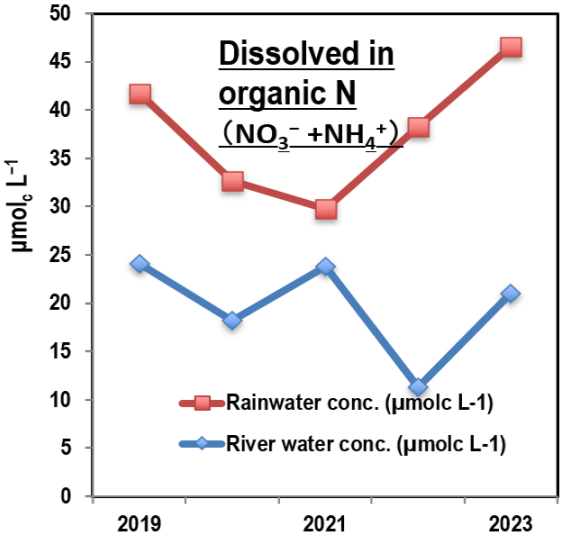


Figure 2.17. Comparison of Dissolved Inorganic Nitrogen Concentrations in Rainwater and Stream Water

Figure 2.17 compares dissolved inorganic nitrogen concentrations in rainwater and stream water. Rainwater concentrations were consistently higher than stream-water concentrations throughout the monitoring period. This pattern is different from sulfate and indicates stronger retention or transformation of nitrogen within the watershed.

Rainwater dissolved inorganic nitrogen concentrations decreased from 2019 to 2021 but increased substantially in 2022 and 2023. Stream-water concentrations fluctuated over the same period, with relatively higher values in 2019 and 2021, a notable decrease in 2022, and a partial increase in 2023. Despite the increase in rainwater nitrogen concentration in 2023, stream-water nitrogen concentration remained much lower than rainwater concentration.

This pattern indicates that deposited inorganic nitrogen was not directly exported to the stream in equivalent concentration. Instead, a large portion of nitrogen input was likely retained by vegetation, immobilized in soil organic matter, transformed through microbial processes, or lost through gaseous pathways such as denitrification.

The consistent difference between rainwater and stream-water dissolved inorganic nitrogen concentrations suggests that La Mesa Watershed currently maintains a relatively strong capacity to regulate nitrogen inputs. However, continued increases in atmospheric nitrogen deposition may alter this balance over time. Long-term monitoring is needed to detect possible early signs of nitrogen saturation, such as increasing nitrate concentration in stream water, reduced biological retention, or seasonal pulses of nitrogen export.

Integrated Discussion

The results from Figures 2.12 to 2.17 show that La Mesa Watershed acts as an important regulating system between atmospheric deposition and aquatic export. Both sulfur and nitrogen inputs from the atmosphere were not exported directly in proportion to deposition loads. Instead, the watershed retained or transformed a significant portion of these inputs.

Sulfur showed evidence of partial retention, with atmospheric input generally exceeding stream output. However, stream-water sulfate concentrations were often higher than rainwater sulfate concentrations, suggesting that sulfate dynamics are influenced by internal catchment sources, storage, and delayed release. The sharp decrease in stream-water sulfate in 2023, despite continued sulfur deposition, highlights the importance of hydrologic conditions and catchment processes in controlling sulfate export.

Nitrogen showed stronger retention than sulfur. Dissolved inorganic nitrogen input consistently exceeded output, and rainwater nitrogen concentrations were consistently higher than stream-water concentrations. This indicates that the watershed has an active capacity to retain or transform deposited nitrogen. Biological uptake and microbial processes are likely important mechanisms controlling nitrogen movement within the catchment.

The 2023 results are particularly important. The year was characterized by high precipitation and a marked increase in nitrogen deposition. Despite this increase, stream nitrogen export remained relatively low. This suggests continued nitrogen retention by the watershed. However, from a long-term environmental management perspective, sustained increases in nitrogen deposition could increase the risk of nitrogen saturation, nutrient imbalance, and downstream nitrogen export.

These findings demonstrate the value of the EANET catchment-scale monitoring approach. Monitoring precipitation chemistry alone provides information on atmospheric input, but it does not fully explain how the ecosystem responds. By linking deposition data with stream-water chemistry and input-output budgets, the catchment-scale approach provides a more complete understanding of pollutant behavior and ecosystem buffering capacity.

2.5 Overall analysis

The long-term Philippine EANET record demonstrates that wet-deposition chemistry is characterized by strong spatial differences and substantial interannual variability. Metro Manila consistently experienced higher nss-sulfate, nitrate, and ammonium concentrations than Laguna and Benguet during common monitoring years, indicating a stronger atmospheric loading at the urban site.
The clearest long-term change is the statistically significant decline in Metro Manila nss-sulfate. In contrast, nitrate did not decline significantly, and ammonium remained highly variable with pronounced episodic peaks. The difference in temporal behavior between sulfur and nitrogen species indicates that improvements in sulfur-related deposition should not be interpreted as an equivalent reduction in overall atmospheric deposition pressure.

The high ammonium concentrations and deposition fluxes emphasize the importance of reduced nitrogen in the Philippine atmospheric environment. Ammonium may partially neutralize sulfuric and nitric acidity and moderate precipitation pH, but this process does not eliminate nitrogen loading. Accordingly, pH alone is insufficient as an indicator of the status or ecological significance of atmospheric deposition.

Future monitoring and assessment should continue long-term wet-deposition measurements while placing greater emphasis on the integrated nitrogen cycle, including both oxidized and reduced nitrogen. Where feasible, wet-deposition data should be linked with atmospheric ammonia and nitrogen oxide

measurements, meteorological and trajectory analyses, and catchment- or ecosystem-scale observations. Such integration would improve the ability to distinguish local from regional influences and to evaluate how changing atmospheric composition translates into effects on soils, vegetation, and receiving waters.

In the case of dry deposition monitoring, the reinstated monitoring activities in Metro Manila and Los Baños stations have to be sustained for the next years in order to accumulate sufficient data to assess trends and correlate the same with other EANET monitoring activities. Issues on the implementation of the same activity in the Mt. Sto. Tomas Station will also be investigated for possible interventions to address the persistent data gaps in the monitoring activities in this site.

The inland aquatic environment monitoring activity in Lake Pandin shows no significant impacts of acidification based on the data gathered for this reporting period. However, further correlation of the data with those from wet and dry deposition monitoring results is also recommended in the next reporting cycle to verify relationship of atmospheric monitoring activities with ecosystem impacts.

Finally, the catchment-scale monitoring results for La Mesa Watershed demonstrate the importance of linking air pollution management with watershed and ecosystem protection. The presence of sulfur and nitrogen deposition indicates that pollutants emitted into the atmosphere may eventually be transferred to land and water systems through wet and dry deposition. This shows that air pollution control should not be evaluated only through ambient air concentrations, but also through actual pollutant loading to sensitive ecosystems.

From an air pollution management perspective, the results highlight the need to control precursor emissions of sulfur and nitrogen compounds. Sulfur deposition is generally associated with sulfur dioxide emissions from combustion and industrial sources, while nitrogen deposition may come from nitrogen oxides from vehicles, power generation, and fuel combustion, as well as ammonia from waste-related, agricultural, urban, and natural sources. These pollutants may be deposited directly or transformed in the atmosphere into sulfate, nitrate, and ammonium particles before reaching the watershed.

The marked increase in nitrogen deposition in 2023 is particularly relevant for air pollution policy. Although stream nitrogen export remained relatively low, suggesting continued retention within the watershed, sustained increases in atmospheric nitrogen input may eventually affect the nitrogen buffering capacity of the ecosystem. If deposition loads continue to increase, there may be a higher risk of nitrogen saturation, nutrient imbalance, soil acidification, and increased nitrogen export to receiving waters. This emphasizes the need to monitor and manage nitrogen-related air pollutants, including both oxidized nitrogen species from combustion sources and reduced nitrogen species such as ammonia.

The results also indicate that protected watersheds such as La Mesa may still be influenced by emissions from surrounding urban and regional sources. This supports the need to include sensitive ecological receptors, including watersheds, forests, reservoirs, and protected areas, in airshed management planning. Deposition monitoring can serve as a complementary tool for assessing whether air pollution control measures are reducing actual pollutant loading to ecosystems.

The findings support a more integrated and ecosystem-based approach to air pollution management. This includes strengthening monitoring of sulfur and nitrogen deposition, improving source assessment for sulfur dioxide, nitrogen oxides, ammonia, and secondary particulate matter, and linking air quality data with watershed, stream-water, soil, and vegetation monitoring. Such integration can improve the scientific basis for policy development and help identify priority sources and pollutants for control.

In general, the La Mesa Watershed results show that effective air pollution management contributes not only to improved ambient air quality but also to the protection of water resources and ecosystem services. Continued catchment-scale monitoring under EANET can provide important evidence for evaluating emission reduction strategies, enhancing airshed management plans, and supporting policy briefs on acid deposition, nitrogen deposition, and integrated air–water–ecosystem protection in the Philippines.

Chapter 3. Review of National Air Quality Management

3.1 Air Quality

The Philippine Clean Air Act of 1999 or Republic Act 8749 (RA 8749) aims to achieve and maintain healthy air for all. It contains the legal mandate of governmental agencies in managing the outdoor air quality in the Philippines, listing all potential sources of outdoor air pollution while providing ambient air quality guidelines and standards for emissions. Its implementation is a multisectoral undertaking, led by the Department of Environment and Natural Resources.

The DENR – EMB is the mandated lead agency in the implementation of RA 8749. DENR-EMB is mainly tasked to monitor the outdoor air pollution; prepare a National Air Quality Status Report which shall be used as a basis in formulating the Integrated Air Quality Improvement Framework; and issue rules and regulations in the implementation of the Act.

3.2 State of Air Quality

3.2.1 Air Quality Monitoring Data

Particulate Matter 10 (PM10) has significantly **improved by 48%** nationwide, decreasing from 60 µg/Ncm in 2012 to 31 µg/Ncm in 2024; in Metro Manila, PM10 improved by **30%**, decreasing from 70 µg/Ncm in 2012 to 30 µg/Ncm in 2024. This reduction is important because epidemiological evidence cited by the World Health Organization (WHO) links lower particulate-matter exposure with reduced premature mortality risk.

Based on WHO-cited health-risk relationships, every 10 µg/Ncm decrease in PM10 may correspond to an estimated 0.5% decrease in daily all-cause mortality risk. For Metro Manila, PM10 declined from 70 µg/Ncm in 2012 to 30 µg/Ncm in 2024, equivalent to a 40 µg/Ncm reduction.

From 2020 to 2024, the PM10 nationwide increased by 14.8% (27 to 31). The increase in PM10 levels from 2020 to 2024 may be linked to the reopening of businesses and the return to face-to-face

work, classes, and daily activities. As more people traveled, more vehicles were on the roads, and commercial and industrial activities resumed, all of which likely contributed to higher dust and pollution levels in the air. This suggests that while air quality improved in some areas, the recovery of economic and social activity may have led to a rise in particulate pollution.

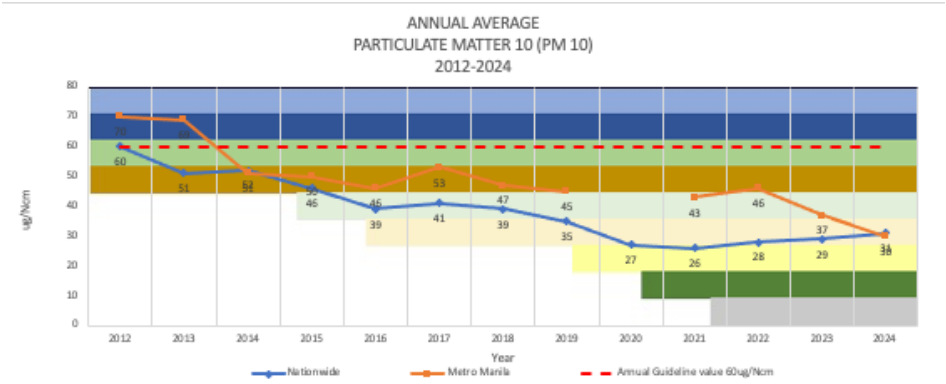


Figure 3.2. Particulate Matter 10 (PM 10) Annual Historical Data.

Particulate Matter 2.5 (PM2.5) has significantly **improved by 30%** nationwide, decreasing from 23 µg/Ncm in 2015 to 16 µg/Ncm in 2024; in Metro Manila, PM2.5 improved by **48%**, decreasing from 27 µg/Ncm in 2012 to 14 µg/Ncm in 2024. This improvement is highly relevant because WHO identifies fine particulate matter as a major contributor to premature mortality, particularly through cardiovascular and respiratory diseases.

Based on WHO-commissioned systematic-review evidence, long-term exposure to PM2.5 is positively associated with all-cause and cause-specific mortality. For Metro Manila, PM2.5 declined from 27 µg/Ncm in 2012 to 14 µg/Ncm in 2024, equivalent to a 13 µg/Ncm reduction.

From 2020 to 2024, the PM2.5 nationwide increased by 14.8% (27 to 31). The increase in PM2.5 levels from 2020 to 2024 may be attributed to the recovery of economic and social activities from the pandemic.

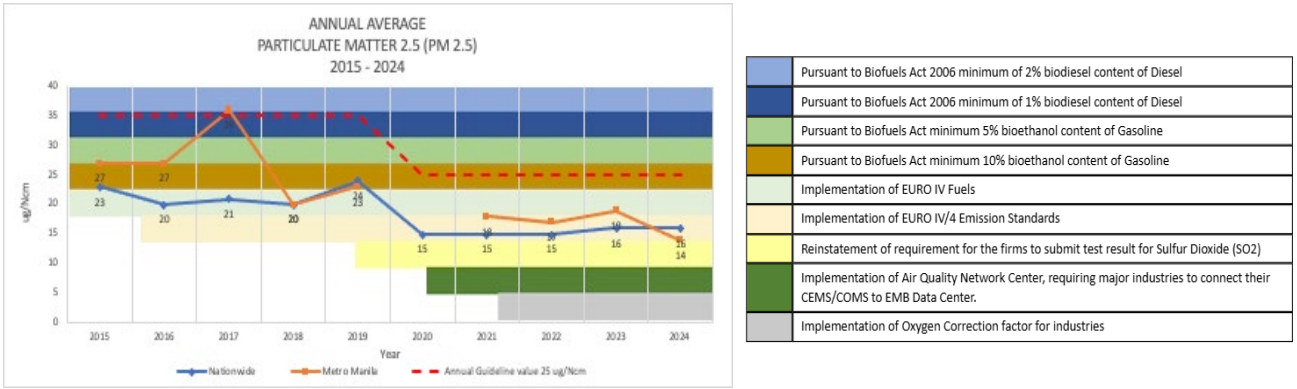


Figure 3.3. Particulate Matter 2.5 (PM 2.5) Annual Historical Data overlayed with years when policies relating to air quality management were implemented

Highlighted portions of Figure 3.3 show the inclusive years when specific policies and regulatory interventions were implemented to show the prevailing major regulatory frameworks during the period which can have potential impacts to the annual monitoring data for ambient air quality relative to PM2.5 levels.

3.2 Status of Management of Air Pollution Sources

The management of air pollution sources in the Philippines is implemented within the framework of the Philippine Clean Air Act of 1999 (RA 8749), which classifies emission sources into stationary, mobile, and area sources. This source-based approach enables the DENR–EMB and partner agencies to apply appropriate regulatory, permitting, monitoring, compliance, and public-awareness measures depending on the nature of the emission source and the responsible sector.

For stationary sources, management efforts focus on permitting, source-emission testing, compliance monitoring, and the progressive use of monitoring systems for major sources. Key mechanisms include the issuance and renewal of Permits to Operate, the conduct of stack-emission testing, the accreditation and oversight of third-party source-emission testing firms, and the use of Continuous Emission Monitoring Systems/Continuous Opacity Monitoring Systems where required. These measures are intended to strengthen accountability among regulated facilities and improve the reliability of emission data used for enforcement and policy development.

For mobile sources, management is carried out through the certification of new motor vehicles, monitoring of Private Emission Testing Centers, coordination with other national agencies, and enforcement-related activities such as anti-smoke belching operations. These interventions address emissions from the transport sector, which remains a significant contributor to national air pollution, particularly in urban areas affected by traffic congestion and increasing vehicle activity.

For area sources, management is generally shared with local government units through local ordinances, public-awareness activities, and community-level enforcement. Area-source concerns include open burning, smoke from small-scale activities, nuisance emissions, and seasonal pollution events such as fireworks-related emissions. Because these sources are dispersed and often community-based, effective management depends on sustained coordination among national agencies, local governments, and the public.

Overall, the status of air-pollution-source management shows that the country has established the core instruments needed to regulate major emission sources; however, implementation must continue to be strengthened through updated inventories, improved data quality, enhanced regional monitoring capacity, digital permitting and reporting systems, and stronger inter-agency coordination.

3.3 Public Awareness

EMB through its Environmental Education and Information Division conducted activities and developed Information, Education and Communication (IEC) and promotional materials for public awareness on air quality management. IEC materials such as infographics, brochures, flyers, audio-video presentations were developed, produced, and disseminated to other government offices, industry partners, civil societies, local government units, communities, schools, and academe.

EMB also provides learning bundles on air quality management which can be found on the EMB website and Facebook page. Regular FB posting of air related activities and infographics are being conducted by the Bureau to heighten its awareness campaign.

Among the IEC and promotional materials include the following:

Infographics, Brochures, Flyers and Exhibit Materials

1. Ambient Air Pollution and Its Health Impact;
2. Household Air Pollution and Its Health Impact;
3. Clean Air Act- Implications to Local Government Units, Women and Small Business Establishments;
4. Right to Breathe Clean Air: Step up Act Now flyer and exhibit material; and
5. Fact Sheets on Clean Air Act.

Audio-Video Presentations

1. *Halina Sama Tayo* song and music video production to call for public awareness and actions for clean air;
2. Virtual tour of the Air Quality Management Section office and demonstration of its air quality monitoring equipment;
3. *Hangin ay Ingatan Tungo sa Malinis na Kalikasan* AVP on air quality status, air pollution and its negative impacts on our health and environment;
4. *Malinis na Sasakyan para sa Malinis na Hangin*: A video on promoting proper vehicle maintenance; and
5. Virtual tour of the Environmental Research and Laboratory Services Division of the EMB Central Office. The video featured the capabilities of the EMB Central Laboratory related to the implementation of the Philippine Clean Air Act .

EMB also regularly conducted special event activities in celebration of National Clean Air Month in November every year. These activities have been in partnership with various stakeholders such as youth and community leaders, academe, technical experts, national government agencies and local government units.

Major activities conducted are as follows:

1. Conduct of National Clean Air Forum
2. “Kilos para sa Kalikasan” clean air concert and exhibits
3. Painting and Art Contests on Clean Air

4. Video Blog Contest on Greening my Lifestyle for Blue Skies
5. Bayanihan sa Daan Award- Philippine Bikable and Walkable Communities Award
6. Forum for Higher Educational Instiutuions on the Clean Air Act and Air Quality Management

Chapter 4. Conclusion and Summary

The Philippines Center for EANET, the DENR-EMB has continued to implement the various activities of the EANET which include (1) annual implementation of National Monitoring Plan for wet and dry deposition, soil and vegetation, inland aquatic environment and catchment-scale, (2) participation in the inter-laboratory comparison exercises, technical support and capacity building activities, promotion of research and studies related to acid deposition issues, promotion of public awareness, and cooperation and information exchange in national and regional levels. The DENR-EMB annually submits the monitoring data to the Network Center, the Asia Center for Air Pollution Research (ACAP) where the compilation, evaluation, storage and provision of data, promotion of quality assurance and quality control (QA/QC) activities are implemented. Acid deposition monitoring activities in the Philippines have been summarized by using data for the last five years as well as data since the year 2000.

The national assessment of acid deposition and air pollution in the Philippines from 2020 to 2024 highlights both encouraging progress and persistent challenges. The monitoring results underscore the importance of sustained, multi-pollutant management and continued investment in long-term environmental monitoring.

Conclusions

1. **Declining Sulfur Deposition in Metro Manila.** A statistically significant decrease in non-sea-salt sulfate concentrations was observed at the Metro Manila site, reflecting improvements in sulfur-related emissions. However, this decline has not translated into a consistent improvement in precipitation pH, indicating that other pollutants continue to exert pressure on ecosystems.

2. **Persistent Role of Reactive Nitrogen.** Ammonium concentrations, particularly the episodic peaks in 2011–2012 and 2016, demonstrate that reduced nitrogen remains a major component of wet deposition. While ammonium partially neutralizes sulfuric and nitric acidity, it continues to deliver reactive nitrogen and sulfur to ecosystems, sustaining environmental loading.

3. **No Significant Long-Term Trends in Nitrate and pH.** Nitrate concentrations showed episodic variability without a sustained trend, while precipitation pH across all sites remained variable but generally below the 5.6 reference level in Metro Manila and Los Baños. This highlights the complex interplay of acid-forming and neutralizing species in precipitation chemistry.

4. **Seasonal Fluxes Driven by Monsoon Rainfall.** Wet deposition fluxes of sulfate and nitrate increased during the monsoon season, emphasizing that deposition loads are strongly influenced by rainfall volume. This seasonal pattern underscores the need to evaluate fluxes alongside concentrations to fully understand ecosystem impacts.

5. **Dry Deposition Monitoring Gaps.** Continuous dry deposition data were available only for Metro Manila during 2020–2024, with Los Baños resuming in 2022. While decreasing trends in particulate-bound sulfate, nitrate, and chloride were observed in Metro Manila, data gaps at other sites limit comprehensive national trend analysis.

6. **Ecosystem and Public Health Implications.** Catchment-scale monitoring at La Mesa Watershed confirmed the vulnerability of critical water resources to acid deposition. Soil and vegetation monitoring at multiple sites revealed early signs of stress, while particulate-bound deposition continues to pose respiratory health risks in urban areas.

Recommendations

1. **Strengthen Multi-Pollutant Management.** Policies should address sulfur, oxidized nitrogen, and reduced nitrogen simultaneously, recognizing their combined influence on precipitation chemistry and ecosystem health.

2. **Expand and Sustain Monitoring Coverage.** Efforts must be made to restore continuous dry deposition monitoring at Mt. Sto. Tomas and Los Baños, and to maintain wet deposition, soil, vegetation, and aquatic monitoring across all sites.

3. **Enhance Catchment-Scale Studies.** The La Mesa Watershed study should be expanded and replicated in other critical watersheds to better understand acid deposition impacts on water resources and ecosystem services.

4. **Integrate Deposition Data into Public Health Policy.** Findings on particulate-bound deposition should inform air quality management strategies, particularly in Metro Manila, to mitigate respiratory health risks.

5. **Promote Regional Cooperation and Capacity Building.** Continued participation in EANET activities, inter-laboratory comparisons, and technical missions will strengthen national capacity and ensure alignment with regional best practices.

6. **Support Expert-Led Ecosystem Assessments.** Regular soil and vegetation monitoring, guided by technical experts, remains essential to detect subtle but significant ecological changes and to inform adaptive management.

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