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Mangrove Biodiversity Assessment and Heavy Metals Analysis at Uacon Lake, Candelaria, Zambales, Philippines

Daryl A. Juganas[1], Marietta Pakaigue-Valera[1], John Wayne A. Villen[1], Kathrina Mapanao-Villar[1] and Gella Patria L. Abella[1]

[1]Institute for Climate Change and Environmental Management, College of Science, Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines

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Corresponding Author:
Kathrina Mapanao-Villar
(kathrinamapanao@clsu.edu.ph)

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Abstract

Mangroves provide essential ecosystem goods and services, including shoreline stabilization and protection against soil erosion caused by storm surges, currents, and tides. Despite their importance, mangrove ecosystems are rapidly declining due to human-induced threats. This study assessed the condition of the mangrove ecosystem at Lake Uacon in the province of Zambales, Philippines, by identifying and quantifying mangrove species, examining their distribution and regeneration status, and evaluating their ecological and economic significance to the local community. Heavy metal concentrations in water and sediment were also analyzed to determine potential environmental contamination. Two sampling stations were established, recording 15 mangrove species and 225 individual trees. *Sonneratia alba* was the dominant species in both stations, with 76 individuals. However, overall species diversity was low, with a Shannon-Weiner Diversity Index (H') of 1.983. Heavy metal analysis showed that concentrations in water samples were within permissible limits set by the Department of Environment and Natural Resources, but the sediment samples exhibited elevated levels of chromium, iron, nickel, and copper, all above the permissible limit. The findings indicate a degraded mangrove ecosystem with low species biodiversity and heavy metal sediment contamination, highlighting the urgent need for targeted conservation and management interventions of the mangrove ecosystem in Lake Uacon.

Introduction

Mangrove forests provide a wide range of ecosystem services that are essential for environmental sustainability and human well-being, including in lake environments where mangrove stands are present. In lakes, mangroves help stabilize shorelines, reduce erosion, and filter sediments and pollutants, thereby improving water quality. They also serve as vital nursery habitats for freshwater and brackish-water species, supporting fish populations that local communities rely on for food and livelihood (Arceo-Carranza *et al.*, 2024). By acting as natural buffers, nutrient filters, and biodiversity hotspots, mangroves in lake ecosystems play a crucial role in enhancing ecological balance and promoting climate resilience and sustainable resource use (Bimrah *et al.*, 2022).

Despite their ecological and socio-economic importance, mangrove ecosystems across the Philippines continue to experience widespread degradation driven by rapid coastal development, pollution, and unsustainable resource extraction. Numerous studies have documented declining mangrove cover and deteriorating habitat conditions in several regions, emphasizing the urgent need for science-based conservation and improved management strategies (Camacho *et al.*, 2020). Strengthening rehabilitation programs, enhancing community engagement, and promoting habitat protection remain critical steps in safeguarding the long-term health and resilience of the country's mangrove ecosystems (Paz-Alberto *et al.*, 2021).

Beyond ecological degradation, mangrove ecosystems are increasingly threatened by heavy metal contamination, which poses significant ecotoxicological risk (Yeasmin *et al.*, 2025). As industrial activities continue to expand, industries such as textile manufacturing, tanning, petrochemical production, pesticide formulation, and pharmaceutical processing generate increasing amounts of industrial by-products containing heavy metals and other toxic compounds, contributing to environmental pollution (Xu *et al.*, 2024). Metals such as chromium, iron, nickel, and copper enter coastal environments through mining operations, industrial effluents, agricultural runoff, and natural erosion of mineral-rich soils (Daripa *et al.*, 2023). Once released, these pollutants tend to accumulate in sediments where they are absorbed and concentrated by mangrove root systems over time (Rozirwan *et al.*, 2025).

Mangroves can naturally retain, absorb, and trap heavy metals within their tissues and surrounding sediments, allowing them to act as effective agents of phytoremediation (Rahman *et al.*, 2024). However, prolonged exposure to high concentrations of heavy metals can adversely affect mangrove growth, reproduction, and survival, and also impair the health of associated fauna (Nguyen *et al.*, 2020). Such contamination poses additional risks to nearby communities that rely on aquatic resources for food and livelihoods (El-Sharkawy *et al.*, 2025). Moreover, sediment-bound metals can also be remobilized during flooding or storm events, further threatening water quality and compromising ecosystem health (Alfee and Bloor, 2024).

Uacon Lake in Candelaria, Zambales, is a 112-hectare inland lake bordered by mangrove forests. It receives cold, clear water from the Zambales mountains and drains into the West Philippine Sea through a 2-km river. Recognized as an ecotourism area in the early 2000s, the site remains minimally developed, with only a boardwalk near the barangay hall and several unfinished eco-trail and birdwatching structures.

However, water quality in the lake deteriorates after heavy rainfall, during which the lake becomes turbid. Intense rains in July 2021 caused the lake water to turn reddish-brown, a condition local residents attributed to upstream mining activities by Yinglong Steel Corp (Aglibot, 2021). A recent survey by the Department of Environment and Natural Resources (DENR) found that three main tributaries are now silted (Aglibot, 2021). Despite orders to cease operations, mining activities reportedly continue, posing ongoing risks to the lake and surrounding farmland.

Given these issues, this study aims to assess the heavy metal concentrations in the water, sediment, and mangrove samples of Uacon Lake and to evaluate the physical and chemical characteristics of the mangrove ecosystems. The study also examines the distribution, abundance, diversity, and regeneration status of mangrove species, as well as their ecological functions and economic importance. Understanding these factors is essential for determining the extent of environmental degradation and for identifying appropriate conservation and management interventions for the mangrove ecosystem of Uacon Lake.

Materials and Methods

Study Area

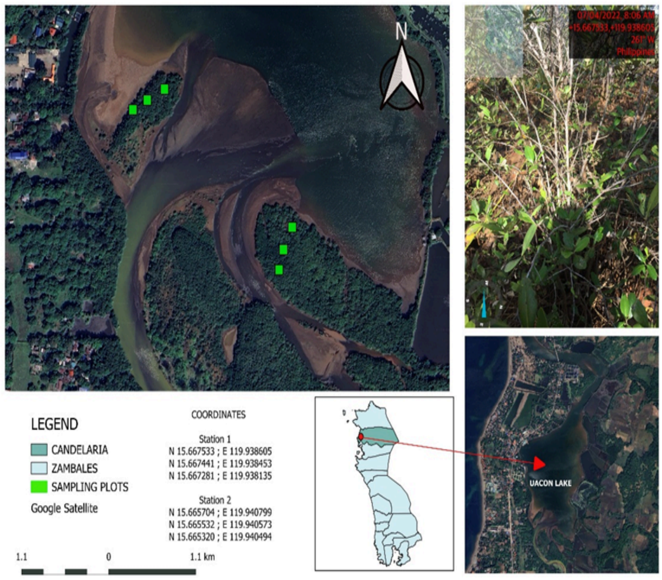

Figure 1. Study site and sampling locations of the mangrove ecosystem in Brgy. Uacon, Candelaria, Zambales, Philippines.

Uacon Lake, located in Barangay Uacon, Candelaria, Zambales, is a freshwater lake that receives runoff from surrounding upland areas, including drainage from a nearby mining site, which increases its risk of sedimentation and heavy metal contamination. The lake is located at 15°40'16.72"N, 119°56'27.14"E. A mangrove stand occurs along the lake's outlet and riverbanks, where two sampling stations were established, each containing three 10×12 quadrats (Figure 1). The locations of the sampling sites were determined using a Global Positioning System (GPS) device. True mangrove species were recorded at each station, and both water and sediment samples were collected from the mangrove forest for heavy metal analysis.

Assessment of mangrove species

Field sampling was conducted during the dry season in April 2022. Two sampling stations were established within the mangrove area, with transects positioned extending from the shoreline toward open water to assess vegetation distribution. All mangrove individuals within each quadrat were identified and measured for diameter at breast height (dbh), canopy cover, and height. To assess regeneration, 1 m × 1 m subplots were established within each quadrat to count seedlings and saplings. Mangrove species were identified using the *Field Guide to Philippine Mangroves* by Primavera (2009).

In this study, the Shannon-Weiner Diversity Index developed by Smith and Smith (1998) was used to assess the mangrove species diversity of Uacon Lake:

Species Diversity
Shannon-Weiner Diversity Index:

$$H = -\sum_{i=1}^{S} (p_i \times \ln(p_i))$$

Where;
H' = Shannon index of diversity
S = total number of species in the community
pi = proportion of species from the total species
ln = Naperian logarithm or natural logarithm

The conservation status and population trends of mangrove species were determined using the online tool database of the International Union for Conservation of Nature (IUCN) red list.

Physical and Chemical Characteristics of the Mangrove Ecosystem

Physical characteristics

In situ analysis of physical parameters was conducted at each sampling station. Water temperature was measured using a portable thermometer submerged below the water surface for five minutes. Readings were taken while the instrument remained in the water to minimize measurement error. Temperature measurements were recorded three times per station at varying depths within the sampling area, and the average was calculated.

Chemical characteristics

Water pH was measured using a digital pen-type pH meter, with the average of three readings recorded for each station. Salinity was measured using a refractometer and expressed in parts per thousand (ppt). Water samples for the analysis of ammonia, nitrite, phosphate, and total suspended solids (TSS) analysis were collected in sterilized bottles from each station at a depth of 6 inches below the surface. All samples were labelled, stored in a cooler at 4°C, and transported to CRL Laboratory, Clark Freeport Zone, Pampanga, Philippines, for laboratory analysis within 24 hours. Sulfate concentration was determined using the turbidimetric method, phosphate was analyzed using the stannous chloride method, and nitrite was measured using the brucine colorimetric method.

Heavy Metal Analysis in Mangrove Ecosystem

Collection of water for heavy metal analysis

Heavy metal analysis of Uacon Lake water was conducted to determine the concentrations of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), mercury (Hg), and nickel (Ni). Composite water samples were collected at each sampling site using 1-liter sterilized plastic bottles. All water samples were analyzed for heavy metal content using Inductively Coupled Plasma-Optimal Emission Spectroscopy (ICP-OES) at the CRL Laboratory, Clark Freeport Zone, Pampanga, Philippines.

Collection of sediment for heavy metal analysis

Sediment samples were also analyzed for heavy metals (As, Cd, Cr, Cu, Fe, Pb, Hg, Ni) using a composite sampling method. Samples were collected with a stainless-steel dipper, transferred to a stainless-steel bowl, and thoroughly homogenized. The homogenized samples were packed in labelled zip-lock bags and analyzed for heavy metal content using Inductively Coupled Plasma-Optimal Emission Spectroscopy (ICP-OES) at the CRL Laboratory, Clark Freeport Zone, Pampanga, Philippines.

Results and Discussion

Table 1. List of mangrove species observed in the mangrove ecosystem of Barangay Uacon, Candelaria, Zambales.

Family	Species	Frequency	
		Station 1	Station 2
Rhizophoraceae	*Bruguiera cylindrica*	2	-
	Bruguiera parviflora	1	-
	Ceriops zippeliana	-	23
	Rhizophora mucronata	4	-
	Rhizophora apiculata	8	47
Avicenniaceae	*Avicennia officinalis*	1	-
	Avicennia marina	8	-

	Avicennia rumphiana	-	18
	Avicennia alba	-	2
Lythraceae	*Sonneratia ovata*	2	3
	Sonneratia caseolaris	14	-
	Sonneratia alba	55	21
Combretacea	*Lumnitzera racemosa*	5	1
Euphorbiaceae	*Excoecaria agallocha*	7	1
Myrtaceae	*Osbornia octodonta*	2	-
	Total	**109**	**116**

A total of 15 mangrove species, belonging to six families, were recorded in the mangrove ecosystem of Uacon Lake. The community was dominated by species from the family Rhizophoraceae, which accounted for 5 species, followed by Avicenniaceae. Within Rhizophoraceae, the genus *Rhizophora* was the most represented, which is considered a key tree species that shapes the mangrove ecosystem globally (Mantiquilla *et al.*, 2021). The species richness reported in this study is based on vegetation data collected from three 10 m × 12 m quadrats in each sampling station. A detailed account of species composition is presented in Table 1.

The mangrove community at Uacon Lake exhibited higher species richness compared to those reported by Serrano *et al.*, (2022) at Botolan and Iba, Zambales and Paz-Alberto *et al.*, (2020) at Sta. Cruz, Candelaria, Masinloc and Palauig. Station 1 had 12 species, while Station 2 had eight species. However, Station 2 had a higher total number of individuals (116) compared to Station 1 (109), indicating greater species richness but lower abundance in Station 1. Station 1 was dominated by *S. alba*, whereas Station 2 was dominated by *R. apiculata*. Both species are known to thrive in muddy and sandy sediments, with *Rhizophora* species being more adaptable to stressed or hypoxic environments due to their extensive root systems (Sudhir *et al.*, 2022).

Correct taxonomic identification of *Ceriops* species was applied in this study. Morphological and molecular evidence confirmed that *C. decandra* and *C. zippeliana* are distinct species, with *C. zippeliana* being the species present in the Philippines (Sheue *et al.*, 2009). Following the taxonomic revision by Primavera *et al.* (2016a, as cited in Agduma and Cao, 2023), the species previously identified as *Ceriops decandra* was herein reported as *C. zippeliana*, ensuring accuracy in the mangrove species inventory for Uacon Lake.

Sonneratia alba was recorded in all quadrats surveyed and was the most dominant and densest species in both sampling stations. This suggests that the current environmental conditions of the mangrove ecosystem at Uacon Lake, Candelaria, Zambales, are particularly conducive to the growth of *S. alba*. The species is well adapted to the muddy sediments characteristic of the study site. Likewise, *R. apiculata* was also found to be well suited to the local environmental conditions.

Sonneratia species are known to adapt well to the environment with soils rich in organic matter (Costa *et al.*, 2019), while members of the family *Rhizophora* exhibit optimal growth in core mangrove soils (Numbere, 2018). The aerial prop roots of *R. apiculate*, which descend from the branches and extend downward toward the substrate, likely contribute to the species' adaptability to the existing environment of the study site. Also, *Sonneratia* species have been reported to exhibit higher average vegetation resistance (VR) to typhoons, further supporting their resilience in dynamic coastal and near-coastal environments (Dumalan, 2023).

Species distribution, abundance, and diversity

All data collected on mangrove species were subjected to vegetation analysis such as relative frequency (RF), relative density (RD), relative dominance (RDo), importance value index (IVI), and species diversity, to characterize the mangrove community of Uacon Lake, Candelaria, Zambales.

When data from the two sampling stations was combined, a total of 225 individual mangrove trees were recorded within the sampled plots. *Sonneratia alba* emerged as the ecologically dominant species, with the highest relative frequency, relative density, relative dominance, and importance value index, indicating its strong adaptive advantage and resistance to typhoons. *Rhizophora apiculata* also showed substantial abundance, indicating its tolerance to contaminated sediment conditions. In contrast, *Avicennia officinalis* and *Bruguiera parviflora* were represented by only a single individual each, suggesting that these species are either rare or less competitive under the prevailing environmental conditions at the study site.

Species diversity

The Shannon-WeinerDiversity Index of the mangrove ecosystem in Barangay Uacon, Candelaria, Zambales, exhibited very low diversity, with a computed value of 1.983 (Table 2). Both sampling stations recorded a limited number of species and individuals. This low diversity is likely attributed to anthropogenic activities, including mining, timber extraction, wildlife exploitation, and household waste run-off, all of which contribute to coastal pollution. Local communities also attributed the heavy siltation observed in the mangrove areas to ongoing mining activities in the upland areas.

Table 2. Relative Frequency, Relative Density, Relative Dominance, and Importance Value Index.

Species name	F	RF	D	RD	Do	RDo	IVI	No. of individual	H′
Bruguiera cylindrica	0.17	2.94	0.009	0.89	0.004	0.413	4.24	2	
Bruguiera parviflora	0.17	2.94	0.004	0.44	0.001	0.134	3.52	1	
Ceriops zippeliana	0.17	2.94	0.102	10.2	0.052	5.234	18.4	23	
Rhizophora mucronata	0.5	8.82	0.018	1.78	0.021	2.052	12.65	4	
Rhizophora apiculata	0.83	14.71	0.244	24.4	0.214	21.4	60.55	55	
Avicennia officinalis	0.17	2.94	0.004	0.44	0.0009	0.088	3.47	1	
Avicennia marina	0.17	2.94	0.036	3.56	0.018	1.834	8.33	8	
Avicennia rumphiana	0.17	2.94	0.08	8	0.115	11.5	22.44	18	1.98
Avicennia alba	0.17	2.94	0.009	0.89	0.019	1.864	5.69	2	
Sonneratia ovata	0.33	6.67	0.022	2.22	0.032	3.19	12.08	5	
Sonneratia caseolaris	0.33	5.88	0.062	6.22	0.054	5.36	17.46	14	
Sonneratia alba	1	20	0.338	33.8	0.386	38.62	92.4	76	
Lumnitzera racemosa	0.33	5.88	0.027	2.67	0.022	2.177	10.73	6	
Excoecaria agallocha	0.5	8.82	0.036	3.56	0.048	4.845	17.22	8	
Osbornia octodonta	0.17	2.94	0.009	0.89	0.013	1.299	5.13	2	
Total	**5**	**100**	**1**	**100**	**1**	**100**	**300**	**225**	

Note. F = frequency; RF = relative frequency; D = density; RD= relative density; Do = dominance; RDo = relative dominance; IVI = importance value index; H′ = Shannon-Wiener Diversity Index

The Philippines is home to at least 50% of the world's approximately 65 mangrove species, making it one of the most mangrove-diverse countries in the world. Despite this remarkable biodiversity, mangrove ecosystems in the country continue to decline due to human activities and natural disturbances, resulting in the loss of valuable biodiversity assets (Caballero *et al.*, 2025).

Sediment accretion and accumulation of heavy metals, oil residues, herbicides, and untreated wastewater can reduce mangrove photosynthetic capacity, growth, and biomass, ultimately increasing plant mortality (Nguyen *et al.*, 2020). For example, tin mining activities in South Bangka, Indonesia, were shown to reduce mangrove density between 1997 and 2014, as revealed by Normalized Difference Vegetation Index analysis (Sari & Rosalina, 2016). Such activities threaten mangrove ecosystems that are critical for maintaining coastal stability.

Mining-related activities like dredging and land filling can cause flooding in mangrove habitats, depriving aerial roots of oxygen and leading to mangrove tree deaths. In addition, pollution, oil spills, urban development, and other human activities contribute further to mangrove destruction. Globally, land-use change accounted for approximately 62% of mangrove losses between 2000 and 2016, primarily driven by conversion to aquaculture and agriculture. Southeast Asia was disproportionately affected, experiencing up to 80% of these losses (Goldberg, 2020).

Regeneration rate

Table 3. Regeneration rate of mangrove ecosystem at Uacon Lake, Candelaria Zambales, Philippines.

Site	*Number of regeneration*			Total	Regeneration rate (m^2)
	Quadrat 1	Quadrat 2	Quadrat 3		
1	5	8	11	24	0.07
2	4	3	7	14	0.04

The natural regeneration rate of mangrove forests in the mangrove ecosystem at Uacon Lake was also assessed. The average regeneration rates at Sites 1 and 2 were 0.07 and 0.04 per square meter, respectively (Table 3). According to the habitat criteria chart for mangroves, the overall computed regeneration rate of the mangrove ecosystem at Uacon Lake is poor, indicating limited production of new seedlings at both study sites.

Site 1 exhibited a higher regeneration rate (0.07 individuals per square meter) than Site 2 (0.04 individuals per square meter), as shown in Table 4. This difference is likely due to the greater species diversity and composition of Site 1. According to Das *et al.* (2019), natural recruitment densities of mangroves follow the order: *A. marina* > *C. tagal* > *A. corniculatum* > *R. mucronata*. The low regeneration of the mangrove ecosystem at Uacon Lake may be linked to pollution from nearby mining activities, which can hinder seed sprouting and natural recruitment processes (Waters, 2016). Similar threats - such as urban development, logging, land conversion, tourism, waste pollution, and mine drainage (Romañach *et al.*, 2018) have contributed to declining mangrove populations worldwide.

Ecological and conservation status of mangrove species

Table 4. Ecological and conservation status of mangrove species at Barangay Uacon, Candelaria, Zambales.

Scientific name	Conservation status and population trend	
	IUCN status	Population trend
Bruguiera cylindrica	Least Concern (LC)	Decreasing
Bruguiera parviflora	Least Concern (LC)	Decreasing
Ceriops zippeliana	Near Threatened (NT)	Decreasing
Rhizophora mucronata	Least Concern (LC)	Decreasing
Rhizophora apiculata	Least Concern (LC)	Decreasing
Avicennia officinalis	Least Concern (LC)	Decreasing
Avicennia marina	Least Concern (LC)	Decreasing
Avicennia rumphiana	Vulnerable (VU)	Decreasing
Avicennia alba	Least Concern (LC)	Decreasing
Sonneratia ovata	Near Threatened (NT)	Decreasing
Sonneratia caseolaris	Least Concern (LC)	Decreasing
Sonneratia alba	Least Concern (LC)	Decreasing
Lumnitzera racemosa	Least Concern (LC)	Decreasing
Excoecaria agallocha	Least Concern (LC)	Decreasing
Osbornia octodonta	Least Concern (LC)	Decreasing

Table 4 summarizes the ecological and conservation status of mangrove species assessed in Barangay Uacon. According to the IUCN Red List of Threatened Species (2022-1), most mangrove species observed were classified as Least Concern (LC) species. However, *S. ovata* and *C. zippeliana* were classified as Near Threatened (NT), and *A. rumphiana* was classified as a Vulnerable (VU) species. Notably, all observed mangrove species exhibited decreasing population trends.

Economic Importance and Function of the Mangrove Species at Barangay Uacon, Candelaria, Zambales

Mangroves of Barangay Uacon provide a wide range of ecosystem services and resources for the local communities (Table 5). These include materials for construction and handicrafts, fuelwood, medicines, and food for humans and animals. Specifically, nine species are used for construction and handicrafts, eight for fuel and food, and six for medicinal purposes. Additionally, species such as *S. caseolaris* and *B. cylindrica* serve as raw materials for chemical manufacturing (IUCN Red List of Threatened Species 2022-1).

Table 5. Economic importance and function of the mangrove species at Barangay Uacon, Candelaria, Zambales.

Scientific Name	Economic Importance (IUCN Red List 2022-1)				
	Source of Food	Source of Medicine	Source of Construction Materials, Handicrafts	Source of Fuel	Others (Chemicals)
Bruguiera cylindrica					
Bruguiera parviflora					
Ceriops zippeliana					
Rhizophora mucronata					
Rhizophora apiculata					
Avicennia officinalis					
Avicennia marina					
Avicennia rumphiana					
Avicennia alba					
Sonneratia ovata					
Sonneratia caseolaris					
Sonneratia alba					
Lumnitzera racemosa					
Excoecaria agallocha					
Osbornia octodonta					

Water Quality Parameters of the Mangrove Ecosystem

Table 6. Physico-chemical parameters assessment of mangrove ecosystem at Barangay Uacon, Candelaria, Zambales.

Parameters	Site 1			Site 2			Limit	
							DAO (2016-08)	
	Q1	Q2	Q3	Q1	Q2	Q3	Class C	Class SC
Temp (°C)	29.2	28.18	30.29	35.6	32.12	32.0	25-31	25-31
pH	7.9	8.12	8.16	7.89	7.67	7.85	6.5-9.0	6.5-8.5
Conductivity (µs/cm)	-	-	-	-	2.2	0.5	0-800*	-

DO (mg/L)	11.07	12.11		11.72	6.7	9.3	5.0	5.0
Salinity	2	2	2	2	2	2	-	-
Nitrate (mg/L)		<0.017			0.30		7.0	10
Phosphate (mg/L)		<0.0064			<0.0064		0.5	0.5
Sulfate (mg/L)		1,720			1,800		275	275

DAO 2016-08- DENR Administrative Order 2016-08: Water Quality Guidelines and General Effluent Standards
CLASS C (Freshwaters) – 1. Fishery waters for the propagation and growth of fish and other aquatic resources; 2. Recreational Waters Class II – for boating, fishing, or similar activities; for agriculture, irrigation, and livestock watering.
CLASS SC (Marine waters) - Fishery Water Class III- For the propagation and growth of fish and other aquatic resources and intended for commercial and sustenance fishing; 2. Recreational waters II – For boating, fishing, or similar activities; 3. Marshy and/or mangrove areas declared as fish and wildlife sanctuaries.
** - Water Quality Standards (https://mrccc.org.au/wp-content/uploads/2013/10/Water-Quality-Salinity-Standards.pdf)*

Physico-chemical parameters such as temperature, pH, conductivity, dissolved oxygen (DO), salinity, total dissolved solids (TDS), nitrate, phosphate and sulfate were analyzed to assess the water quality conditions at the two study sites. Most parameters including pH, conductivity, salinity, nitrate and phosphate were within or below the normal ranges. However, temperature at Site 2, as well as dissolved oxygen and sulfate concentrations, exceeded the standard values (Table 6).

The high temperature recorded at Site 2 can be attributed to the time of measurement, which was conducted at midday, as well at the relatively low water level at the site (Table 7). Moreover, sulfate concentrations exceeded the allowable limits at both study sites, with measured values of 1,720 mg/L at Site 1 and 1,800 mg/L at Site 2. These values far exceed the acceptable sulfate limit for coastal waters, which is 275 mg/L. Overall, sulfate was the only water quality parameter that exceeded permissible limits.

Sulfate is a naturally occurring chemical that is highly soluble in water and commonly found at high concentrations in both surface and groundwater. Elevated sulfate concentrations in water may originate from several sources, including gypsum-rich deposits and mining activities involving sulfide minerals. Because sulfate is highly mobile in soils, inputs to the soil can impact shallow groundwater systems (Minnesota Pollution Control Agency 2022).

According to these findings, the water column within the mangrove ecosystem of Uacon Lake exhibited low concentrations of harmful chemicals. In contrast, sediment analysis revealed measurable concentrations of heavy metals (HMs), including iron (Fe), nickel (Ni), and chromium (Cr). Heavy metals are naturally occurring elements characterized by high atomic weight and density (Tchounwou *et al.*, 2012). Various physical and chemical processes can cause these metals to accumulate in sediments, thereby reducing their concentrations in the water column. Seasonal variations, such as increased rainfall during the wet season, may also influence HM concentrations through dilution (Ahmed *et al.*, 2019). Although sediment accumulation of HMs may temporarily limit their availability in the water column, sediment disturbance or resuspension events could potentially reintroduce HMs into the aquatic environment, posing long-term environmental concerns for aquatic organisms and human health.

Heavy metal analysis in mangrove ecosystem

Table 7. Heavy metal analysis of water at mangroves ecosystem.

Heavy Metals	Location		Limit		
	Site 1	Site 2	DAO 2016-08		DAO 2021-19
	(mg/L)	(mg/L)	C (mg/L)	SC (mg/L)	
Arsenic	<0.005	<0.005	0.02	0.02	
Cadmium	<0.001	<0.001	0.005	0.005	
Copper	<0.003	<0.003	0.02	0.02	
Lead	<0.005	<0.005	0.05	0.05	
Nickel	0.03	0.009	0.20	0.06	0.20
Mercury	<0.0002	<0.0002	0.002	0.002	
Chromium	0.009	<0.005	0.01	0.05	
Iron	0.70	0.07	1.5	1.5	

Note. C =Class C (inland/surface water); SC = class SC (coastal/marine water)

Results in Table 7 indicate that the concentrations of HMs in the water samples were within normal ranges and fell below the maximum allowable limits established by regulatory standards.

Table 8. Heavy metal content in the sediments of mangrove ecosystem.

Heavy metals	Location		Limit
	Site 1 (mg/kg)	Site 2 (mg/kg)	USEPA (mg/kg)
Arsenic	ND	ND	1.0
Cadmium	2.8	2.8	0.05
Copper	19	21	0.20
Lead	1.6	2.0	0.30
Nickel	3,100	2,970	1.50
Mercury	ND	ND	0.10
Chromium	1,050	1,080	2.50
Iron	72,700	91,300	250

USEPA – United States Environmental Protection Agency
ND- Not Detected

Table 8 shows sediment samples from the mangrove ecosystems at Uacon Lake, Candelaria, Zambales, containing Fe, Ni, Cr, and Cu levels exceeding USEPA standards, while As and Hg were not detected.

Our study found extremely high concentrations of Fe (72,700 mg/L in Site 1 and 91,300 mg/L in Site 2) and elevated levels of Ni and Cr in the mangrove sediments. These elevated concentrations are likely due to ferronickel mining activities from the Zambales Ferro-Nickel Mining Project, which produces Fe-Ni pellets. Likewise, presence of solid waste observed at both study sites during field assessments, highlight additional anthropogenic pressures on the mangrove ecosystem.

Chemical contaminants in marine and estuarine waters tend to settle into seabed sediments through processes like sedimentation, complexation, and adsorption onto clay particles (Mohamed *et al.*, 2014). As a result, HMs often accumulate in sediments, significantly increasing their availability within the food chain and making sediment a key indicator of aquatic HM pollution (Gunes, 2021). Prolonged exposure to high HM concentrations can reduce species richness, impair mangrove growth, and alter nutrient cycling, thereby affecting overall ecosystem productivity and resilience. Mangrove trees, which provide critical nursery habitats and coastal protection, may experience physiological stress and increased mortality under chronic heavy metal exposure, affecting both ecological services and local livelihoods that depend on these resources.

These findings emphasize the need for careful dredging practices, continuous sediment monitoring, effective pollution mitigation strategies and improved river management practices to prevent HM mobilization and downstream contamination of aquatic habitats (Pari-Huaquisto *et al.*, 2020). Similar findings were reported in a study along the Alinsaog River, where high concentrations of Fe, Cr, and Ni in sediments were linked to ecological stress in local mangrove and aquatic communities (Sazon & Migo, 2019)

Conclusion

The mangrove ecosystem at Uacon Lake, Candelaria, Zambales was found to be partially degraded, as evidenced by low species diversity and poor generation rates. Anthropogenic activities were identified as the primary drivers of this degradation, including improper solid waste disposal from the nearby communities, water pollution, and increased sedimentation and siltation resulting from mining run-off during heavy rains. Other contributing factors include cutting of mangrove trees, and hunting or wildlife trade.

Elevated concentrations of heavy metals, particularly Fe, Ni, and Cr in the sediments may further exacerbate stress on the mangrove ecosystem by affecting tree growth, reducing survival rates, and negatively affecting overall health of associated aquatic organisms. Continued degradation of the mangrove ecosystem may lead to loss of critical habitats and food sources for many species, resulting in reduced biodiversity within the coastal ecosystem and decreasing fish catches for local fisherfolk.

Future research should prioritize long-term monitoring of water quality and sediment heavy metal concentrations, as well as evaluating the effectiveness of restoration efforts. We recommend conservation efforts, formulation and strict implementation of local policies that support community-based solid waste management programs, controlled reforestation or enrichment planting using native mangrove species, regular monitoring of sediment and water quality, and stricter regulation and enforcement of mining and industrial runoff controls.

Ethical Statement

This study was conducted in accordance with ethical standards for research. Prior permission was obtained from the local government units and concerned authorities before conducting field surveys and data collection. Data collection activities were carried out in a manner that minimized disturbance to the mangrove ecosystem.

Conflict of Interest Statement

The authors declare no conflict of interest related to the conduct and publication of this research. All procedures followed were in accordance with institutional and ethical standards, and there were no financial or personal relationships that could have influenced the outcomes of this study.

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Declaration of Generative AI and AI-Assisted Technologies

This work was prepared entirely by the author(s) without the use of generative AI or AI-assisted technologies.

Data Availability

All data supporting the findings of this study are available within the paper.

Author Contributions

DAJ: Conceptualization, Methodology, Investigation, Data Curation and Writing (Original draft); **MPV:** Formal analysis, Investigation, and Data curation; **JWAV:** Formal analysis, Investigation, and Data curation; **KMV:** Investigation, Data curation and Writing (Review and editing); **GPLA:** Writing (Review and editing), Supervision, Project administration and Funding acquisition

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References

Agduma, A. R., & Cao, K. F. (2023). Species richness, extent and potential threats to mangroves of Sarangani Bay protected seascape, Philippines. *Biodiversity Data Journal*, *11*, e100050. https://doi.org/10.3897/BDJ.11.e100050

Ahmed, M., Matsumoto, M., Ozaki, A., Thinh, N. V., & Kurosawa, K. (2019). Heavy metal contamination of irrigation water, soil, and vegetables and the difference between dry and wet seasons near a multi-industry zone in Bangladesh. *Water*, *11*(3), 583. https://doi.org/10.3390/w11030583

Alfee, S. L., & Bloor, M. C. (2024). A global review of river sediment contamination and remobilization through climate change-induced flooding. *Sustainable Environment*, *11*(1). https://doi.org/10.1080/27658511.2024.2440957

Arceo-Carranza, D., Mendoza, L. C., Teutli-Hernandez, C., Herrera-Silveira, J. A., Vazquez, J. A., & Chiappa-Carrara, X. (2024). Mangrove ecosystems as fundamental habitats for fish from the Mexican Caribbean: An evaluation between a conserved and restoration zone. *Regional Studies in Marine Science*, *77*, 103650. https://doi.org/10.1016/j.rsma.2024.103650

Bimrah, K., Dasgupta, R., Hashimoto, S., Saizen, I., & Dhyani, S. (2022). Ecosystem services of mangroves: A systematic review and synthesis of contemporary scientific literature. *Sustainability*, *14*(19). https://doi.org/10.3390/su141912051

Caballero, J., Andog, J. M., Bacaling, I. J., Barrientos, M. N., Benito, A., Caballero, A. C., Sugabo, K., Tadlip, M. J., Mellor, J. N., Sumalinog, E. A., Panunca, F. R., Rubia, J., Negro, G. S., Abejo, M., Nudalo, A., Bayon, C. G., Colita, L., Rosales, R., & Cortes, S. T. (2025). Mangrove composition, economic valuation, and disturbances in Mactan Island, Cebu, Philippines. *Environmental Challenges*, *21*, 101361. https://doi.org/10.1016/j.envc.2025.101361

Camacho, L. D., Gevaña, D. T., Sabino, L. L., Ruzol, C. D., Garcia, J. E., Camacho, A. C. D., Oo, T. N., Maung, A. C., Saxena, K. G., Liang, L., Yiu, E., & Takeuchi, K. (2020). Sustainable mangrove rehabilitation: Lessons and insights from community-based management in the Philippines and Myanmar. *APN Science Bulletin*, *10*(1), 18–25. https://doi.org/10.30852/sb.2020.983

Daripa, A., Malav, L., Yadav, D.K., Chattaraj, S. (2023). Metal Contamination in Water Resources due to Various Anthropogenic Activities. *In book: Metals in Water* 111-127. https://doi.org/10.1016/B978-0-323-95919-3.00022-7

Das, L., Patel, R., Salvi, H., & Kamboj, R. D. (2019). Assessment of natural regeneration of mangrove with reference to edaphic factors and water in Southern Gulf of Kachchh, Gujarat, India. *Heliyon*, *5*(8), e02250. https://doi.org/10.1016/j.heliyon.2019.e02250

Dumalan, R. J. P. (2023). State of the mangrove in Ormoc City. In *State of the Mangrove Summit: Central and Eastern Visayas Proceedings* (pp. 34–44). https://www.researchgate.net/publication/371292489_State_of_the_Mangrove_in_Ormoc_City

El-Sharkawy, M., Alotaibi, M. O., Li, J., Du, D., & Mahmoud, E. (2025). Heavy metal pollution in coastal environments: Ecological implications and management strategies: A review. *Sustainability*, *17*(2), 701. https://doi.org/10.3390/su17020701

Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. *Global Change Biology*, *26*, 5844–5855. https://doi.org/10.1111/gcb.15275

Gunes, G. (2021). The change of metal pollution in the water and sediment of the Bartın River in rainy and dry seasons. *Environmental Engineering Research*, *27*(2): https://doi.org/10.4491/eer.2020.701

Mantiquilla, J. A., Shiao, M. S., Shih, H. C., Chen, W. H., & Chiang, Y. C. (2021). A review on the genetic structure of ecologically and economically important mangrove species in the Indo-West Pacific. *Ecological Genetics and Genomics*, *18*, 100078. https://doi.org/10.1016/j.egg.2020.100078

Minnesota Pollution Control Agency. (2022). *Sulfate impairments*. https://www.pca.state.mn.us.

Mohamed, K. N., Abd Karim, N. E., & Deraman, S. (2014). Heavy metals distribution in seabed sediment at Golok Central and Golok Barat gas fields, Sarawak. *Bulletin of Environmental Science and Sustainable Management*, *2*(2), 48–52. https://doi.org/10.54987/bessm.v2i2.196

Nguyen, A., Richter, O., Le, B. V. Q., & Thi, N. (2020). Long-term heavy metal retention by mangroves and effect on its growth: A field inventory and scenario simulation. *International Journal of Environmental Research and*

Public Health, *17*(23), 9131. https://doi.org/10.3390/ijerph17239131

Numbere, A. O. (2018). Mangrove species distribution and composition, adaptive strategies and ecosystem services in the Niger River Delta, Nigeria. In S. Sharma (Ed.), *Mangrove ecosystem ecology and function*. IntechOpen. https://doi.org/10.5772/intechopen.79028

Pari-Huaquisto, D. C., Alfaro-Alejo, R., Pilares-Hualpa, I., & Belizario, G. (2020). Seasonal variation of heavy metals in surface water of the Ananea River contaminated by artisanal mining, Peru. In *IOP Conference Series: Earth and Environmental Science*, *614*, 012167. https://doi.org/10.1088/1755-1315/614/1/012167

Paz-Alberto, A. M., Camaso, E. E., Alberto, R., Juganas, D. A., Mapanao, K. M., Ponce, C. D., & Genaro, C. R. (2021). Climate change vulnerability and disaster risk assessment using remote sensing technology and adaptation strategies for resiliency and disaster risk management in selected coastal municipalities of Zambales, Philippines. *American Journal of Climate Change*, *10*(1), 85–133. https://doi.org/10.4236/ajcc.2021.101005

Paz-Alberto, A. M., Mapanao, K. M., & Juganas, D. A. (2020). Status of mangrove ecosystems in selected coastal municipalities in Zambales, Philippines. *Asian Journal of Biodiversity, 11*(1). https://doi.org/10.7828/ajob.v11i1.1390

Primavera, J. H. (2009). *Field guide to Philippine mangroves*. Zoological Society of London-Philippines. https://repository.seafdec.org/handle/20.500.12066/6662

Rahman, S. U., Han, J. C., Zhou, Y., Ahmad, M., Li, B., Wang, Y., Huang, Y., Yasin, G., Ansari, M. J., Saeed, M., & Ahmad, I. (2024). Adaptation and remediation strategies of mangroves against heavy metal contamination in global coastal ecosystems: A review. *Journal of Cleaner Production*, *441*, 140868. https://doi.org/10.1016/j.jclepro.2024.140868

Romañach, S., DeAngelis, D., Koh, H. L., Li, Y., Teh, S. Y., Barizan, R. S. R., & Zhai, L. (2018). Conservation and restoration of mangroves: Global status, perspectives, and prognosis. *Ocean & Coastal Management*, *154*, 72–82. https://doi.org/10.1016/j.ocecoaman.2018.01.009

Rozirwan., Khotimah, N. N., Putri, W. A. E., Fauziyah., Aryawati, R., Diansyah, G., & Nugroho, R. Y. (2025). Biomarkers of heavy metals pollution in mangrove ecosystems: Comparative assessment in industrial impact and conservation zones. *Toxicology Reports*, *14*. https://doi.org/10.1016/j.toxrep.2025.102011

Sari, S. P., & Rosalina, D. (2016). Mapping and monitoring of mangrove density changes on tin mining area. *Procedia Environmental Sciences*, *33*, 436–442. https://doi.org/10.1016/j.proenv.2016.03.094

Sazon, R. R., & Migo, V. P. (2019). Accumulation of heavy metals in sediments and tissues of *Rhizophora apiculata*, *Sonneratia alba*, and *Avicennia* sp. in Alinsaog River, Zambales, Central Luzon, Philippines. *Social Science Research Network*. https://doi.org/10.2139/ssrn.3489099

Serrano, S. C., Tangtham, N., Bualert, S., & Janyasuthiwong, S. (2022). Species diversity of mangroves in Central Zambales, Philippines. *Journal of Environmental Management and Tourism*, *13*(3), 782–789. https://doi.org/10.14505/jemt.v13.3(59).17

Sheue, C. R., Liu, H. Y., Tsai, C. C., Rashid, S. M., Yong, J. W., & Yang, Y. P. (2009). On the morphology and molecular basis of segregation of *Ceriops zippeliana* and *C. decandra* (Rhizophoraceae) from Asia. *Blumea – Biodiversity, Evolution and Biogeography of Plants*, *54*(1), 220–227. https://doi.org/10.3767/000651909x476193

Sudhir, S., Arunprasath, A., & Sankara, V. (2022). A critical review on adaptations and biological activities of the mangroves. *Journal of Natural Pesticide Research*, *1*. https://doi.org/10.1016/j.napere.2022.100006

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metals toxicity and the environment. In A. Luch (Ed.), *Molecular, clinical and environmental toxicology*. *Experientia Supplementum*, *101*. Springer. Basel. https://doi.org/10.1007/978-3-7643-8340-4_6

Waters, H. (2016). Mangrove restoration: Letting mother nature do the work. *Smithsonian National Museum of Natural History*. https://ocean.si.edu/ocean-life/plants-algae/mangrove-restoration-letting-mother-nature-do-work

Xu, W., Jin Y., Zeng, G. (2024). Introduction of Heavy Metals Contamination in the Water and Soil: A Review on Source, Toxicity and Remediation Methods. *Green Chemistry Letters and Reviews*, 17(1). https://doi.org/10.1080/17518253.2024.2404235

Yeasmin, S. M., Luo, C., Rahman, M. H., Woalid, S. T., Hasan, Rahman, A., Rahman, M. A., Khan, H. R., & Kawsar, A. (2025). Heavy metal sources and associated ecological and human health risks in coastal islands of the Ganges-Brahmaputra-Meghna delta, Bangladesh. *Environmental Chemistry and Ecotoxicology*, *8*, 112-126. https://doi.org/10.1016/j.enceco.2025.11.010