Journal of Environmental Science and Management 27-1: 80-89 (June 2024) ISSN 0119-1144

Mangroves and their Associates in Metal-Rich Soils in Candelaria, Zambales Province, Philippines

ABSTRACT

The Philippines, an archipelagic nation in Southeast Asia, has a coastline of over 18,000 km. and hosts at least 50 % of the world's 65 mangrove species. Mangrove ecosystems are vital in mitigating heavy metal pollution; however, their resilience is compromised in environments with excessive heavy metal contamination. The diversity of true mangrove species and their associates in San Vicente River, Candelaria, Zambales, Philippines was determined. With respect to the physico-chemical composition of the water and sediments. Twenty species of true mangroves were recorded belonging to 11 different families indicating moderate diversity, and 11 mangrove-associated species observed from 10 families. Acanthus ebracteatus was the most abundant species, while Osbornia octodonta was the rarest, found only in Station 1 with only 2 individuals. Sediment samples showed heavy metal concentrations exceeding limits for chromium, iron, nickel and copper. The study highlights the impact of heavy metal contamination on mangrove diversity and soil health, disseminating conservation and remediation efforts for mangrove ecosystem in polluted environments.

Keywords: *species diversity, mangrove forest, mangrove associates, heavy metals, metal-rich soils*

Kathrina Mapanao-Villar[1*]
Gella Patria L. Abella[1]
Daryl A. Juganas[1]
Marietta Pakaigue-Valera[1]
John Wayne A. Villen[1]
Carl Dionelle B. Ponce[1]

[1] Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines 3120

*corresponding author: kathrinamapanao@clsu.edu.ph

INTRODUCTION

Mangroves are salt-tolerant flowering plants of tropical and subtropical sheltered coastlines. They have been variously described as coastal woodland, tidal forest, and mangrove forest (*Marine Ecology Fiji 2020*). Mangrove forests typically thrive where mud deposits accumulate in reverine and coastal areas (*Santini et al. 2015*). Mangrove forests are among the world's most most productive and biologically important ecosystems because they provide essential and unique ecosystem goods and services to human society and coastal and marine systems (*Carugati et al. 2018*). They are considered the best form of coastal bio-shield since they help reduce the devastating impact of cyclonic storms, hurricanes and tsunamis on human lives and properties (*Kumar et al. 2014*). Mangrove reduce coastal erosion and provide important ecosystem goods and services such as stabilizing the coastline and reducing erosion from storm surges, currents, waves, and tides. The intricate root system makes mangrove forests attractive to fish and other organisms provides crucial habitat for diverse wildlife, serves as safe nurseries for young fish. Supports healthy ecosystems and sustains fishing industries, benefiting both nature and communities (*National Oceanic and Atmospheric Administration 2019*).

Mangrove forests are severely threatened by heavy metals (HMs). Mangroves are contaminated in different ways such as surface runoff, human-induced actions, and industrial activities (*Nguyen et al. 2020*). Mostly, HMs are discharged into coastal waters and estuaries at several sites due to mining practices. Heavy metals in sediments transported into mangrove ecosystems (*Mohammed et al. 2024*) pose threats to human health (*Hossain et al. 2022*) and ecological risks (*Zhenglei et al. 2022*) as these are toxic and do not degrade in the environment. Several studies on the ability of mangroves to absorb HMs (*Paz-Alberto et al. 2014*) as well as their great resistance to heavy metal stress (*Lee et al. 2014*) have been conducted.

In Candelaria, Zambales, Philippines, the people rely heavily on mangroves for their everyday lives. These special coastal forests help protect the town from severe tropical storm, typhoon, and coastal erosion. and coastal erosion. Many coastal families depend on mangroves for their fishing and aquaculture activities. Mangroves are also important for the local environment, as they serve as habitats for for many fish and marine species. This relationship shows the importance of mangrove conservation, as the people depends on the health of these forests. Candelaria, Zambales, faces several environmental challenges threatening its coastal its coastal ecosystem, particularly the vital mangrove forests. Increased pollution, coastal development, and climate change have led to deteriorating water and sediment quality in these areas. These issues compromise the health of the mangroves and, the well-being of the community that depends on them. To address these concerns and formulate effective conservation strategies, assessing the physico-chemical composition of the mangrove water and sediments is crucial.

The study aims to identify mangroves that thrive in metal-rich soils and to provide environmental parameters that highlight the extent of pollution affecting them.

MATERIALS AND METHODS

Study area

The San Vicente River (downstream) and Lake Alindayat (upstream) are the areas surveyed for the mangrove diversity. The lake and river are situated on the western side of Luzon along the West Philippine Sea. Lake Alindayat is one of the ecologically and economically important lakes in the Municipality of Candelaria, Zambales, Philippines. It is situated in Barangays Catol, Babancal, Pamibian, Poblacion, Malabon and Panayunan with GPS coordinates of N:15.621233° and E:119.940489°. Four sampling stations were established in the mangrove ecosystem (**Figure 1**). The location of the sampling sites was determined using a GPS (Global Positioning System) device (**Table 1**).

The true mangrove and mangrove-associate species were recorded. The sediment and water samples were collected per site and analyzed accordingly. The sampling habitat is riverine (rivermouth to upstream); with variable inundation and influence of brackish/freshwater.

Diversity Index

In this study, two different diversity indices were used: the Shannon-Weiner diversity Index (H') and the Gini-Simpson Index (1-D), to explain and compare the diversity of selected mangrove ecosystems. Additionally, species richness (S), and species evenness (E) were computed. The Simpson's Index (*Simpson 1949*), typically expressed as its inverse (1/D) or its complement (1-D), is also known as the Gini-Simpson Index developed by *Gini* (*1912*). The interpretation of these indices is inverse: a lower value of the Simpson's Index (range 0-1) indicates higher diversity, while a lower value of the Gini-Simpson Index (range 0-1) indicates lower diversity. In this study, the Gini-Simpson Index was used

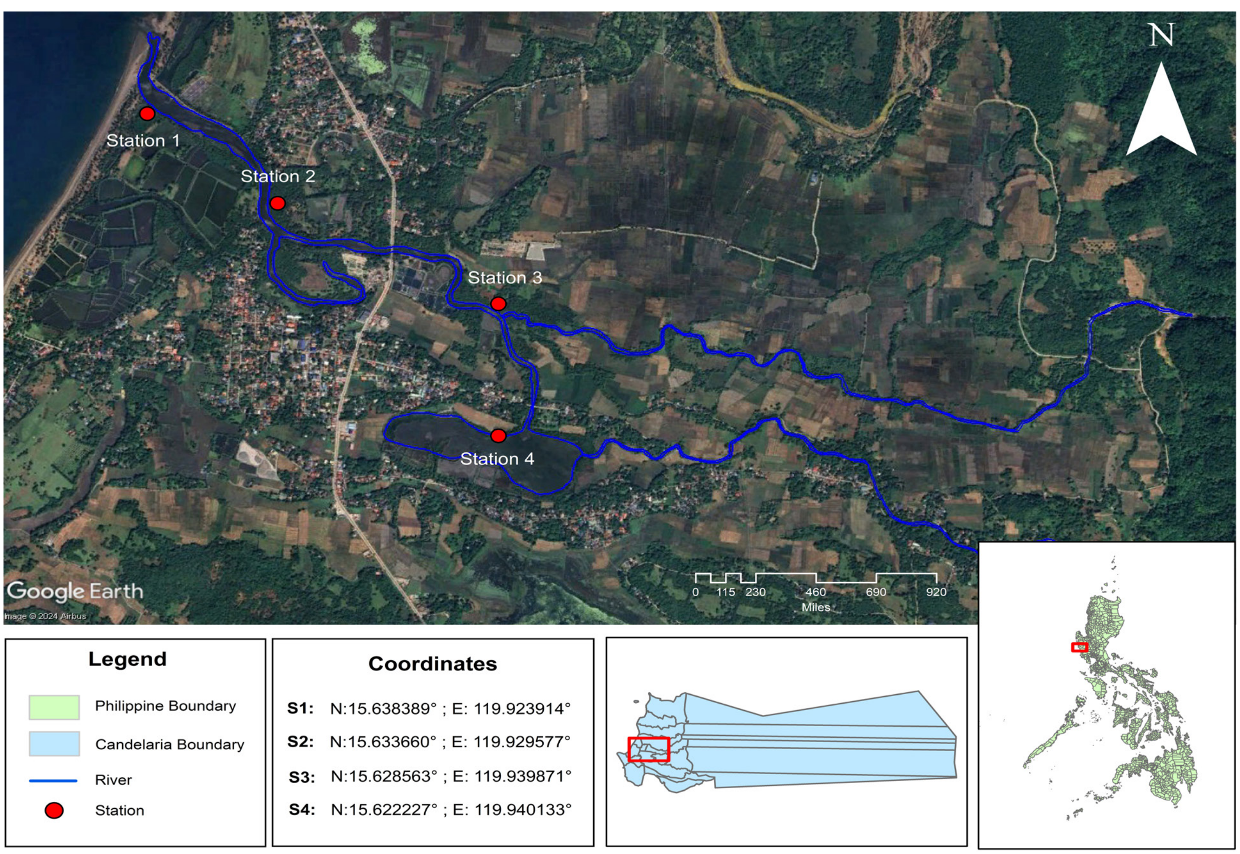

Figure 1. The map of the Municipality of Candelaria, Zambales Philippines showing the study areas.

Table 1. Habitat descriptions and locations of sampling sites in San Vicente River and Lake Alindayat (Maalat), Candelaria, Zambales, Philippines.

Site/ Location	Coordinates		Substrate	Description
	North	East		
Station 1	15.638389°	119.923914°	Sandy substrate	River mouth
Station 2	15.633660°	119.929577°	Muddy and Sandy Substrate	Merging point of coastal water and San Vicente River
Station 3	15.628563°	119.939871°	Muddy Substrate near seaward area	Along the channel downstream; Sandy on the north side of the river Near Lake Alindayat
Station 4	15.622227°	119.940133°	Muddy and Sandy Substrate	Near the mouth of Lake Alindayat (maalat/salty)

alongside the Shannon-Weiner Index to assess diversity:

$$\text{SDI: } H' = \sum_{i=1}^{s} pi \ln pi \qquad D = 1 - \sum (n/N)^2$$

All the mangrove species inside each quadrat along the transect line were identified and counted. The mangrove vegetation survey followed the standard protocol described by *English et al. (1997).*

A series of 10 x 10 m quadratic transect perpendicular lines until the transect line meets the end of the mangrove area. Data was collected at four designated mangrove stations (**Figure 1** and **Table 1**). The number of individual mangroves per species and associated species were identified and recorded.

Water Sampling

Water samples were collected using the grab method. Consistent with the Ambient Water Quality Monitoring Manual of EMB-DENR, in shallow rivers and streams (<2.5 m), composite samples were collected (top, middle, and bottom) from each sampling stationwith three replicates. Water samples were collected on May 17, 2013, between 3:00 to 4:00 PM. The collected samples were placed in plastic bottles (2 L capacity) and stored in a thermo-cooler box with half-filled ice to maintain the quality until it reached to CRL Environmental Corporation Laboratory on May 18, 2023 for analysis.

Soil Sampling

Sediment samples were collected from each sampling station using the dipper method. A stainless-steel dipper was used to collect the sample by pushing it firmly downward into the sediment. Composite samples were collected from each sampling station with approximately one kilogram of sediment per sampling site.

Physical and Chemical Characteristics of the Mangrove Ecosystems

Mangrove species were identified and counted inevery station. The classification and identification of true mangroves and associated species were based on specifics of *Primavera* (*2009*).

The water samples collected from the study sites were analyzed to determine the ambient sediment and water quality conditions. In-situ analysis of physical parameters such as Dissolved Oxygen (DO), temperature, and pH were determined onsite using portable DO meter, thermometer and digital pen-type pH meter respectively. The average of three readings per station was recorded. These parameters are important to determine basic water quality conditions at the time of sampling. Water samples were collected on May 17, 2023, between 3:00 to 4:00 PM and transported to CRL Laboratory on May 18, 2023 for analysis. The samples were tested for salinity, conductivity, total suspended solids (TSS), chemicals such as nitrite, phosphate, and sulfate and HMs including Ni, Fe, Cr, and Cu. Heavy metals in water were analyzed using the Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES).

Sampling was carried out at low tide, when when walking inside the mangrove forest was possible.. The sediment samples were gathered in all the sampling stations, established in the mangrove forest using composite sampling method. The dipper method from the CRL protocol was used to collect sediment samples. One scoop of sediment was dug in every location within the quadrat. Samples from each location were transferred in a stainless-steel bowl and homogenized using a stainless spoon before transferring them into a clean container and labeled properly. The collected samples were sent to CRL Environment Corporation at Clark City, Pampanga for heavy metal analysis such as Fe, Cr, Ni, and Cu.

RESULTS AND DISCUSSION

Mangrove Profiling

The identification and classification of true mangroves and associated species were based on protocols of *Primavera* (*2009*). A total of 20 true mangrove species belonging to 11 different families and 11 mangrove associated species belonging to 10 families were documented in all sampling stations, established at San Vicente River and Lake Alindayat (Maalat), Candelaria, Zambales. *Acanthus ebracteatus* was the most abundant species (11 individuals) followed by *Nipa fruticans* (eight individuals) and *Avicennia marina* (six individuals), *Heritiera littoralis* (six individuals), and *Rhizophora apiculata* (six individuals). The rarest species is *Osbornia octodonta*, which was recorded only in Station 1 with only two individuals (**Table 2**). According to *Putra and Dewi* (*2019*), *Osbornia octodonta* species is quite rare in areas frequently inundated, as this is contrary to its preferred living conditions.

For conservation status, 18 species were recorded to be of Least Concern while two species were considered vulnerable, based on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species 2023-1. Eighteen out of twenty species assessed are experiencing declining population trends, while *Acrostichum speciosum* is considered stable, and the status of *Nypa fruticans* remains unknown according to the IUCN categorization.

River banks of the San Vicente River are generally occupied by the *Avicennia-Sonneratia-Rhizophora* species, followed by the *Bruguiera-Lumnitzera-Ceriops* in the middle zone from the river bank to the landward side and the *Excoecaria-Acrostichum-Heritiera-Nypa* species on the landward side of the river. According to the study conducted by *Ludwig et al.* (*2021*), zones of dominant mangrove species run parallel to the shoreline or to the banks of tidal creek systems. *Avicennia* species are most suited to early colonization and a variety of soil conditions are likely to dominate the seaward side of the community. *Sonneratia* often grows in this zone as well. While *Rhizophora* is typically located behind this area where it is inundated at medium high tides. Its long prop roots provide it a sturdy footing against wind and waves (*Mariano et al. 2019*). Further, inland area was dominated by *Nypa fruticans*. Due to their dispersal mechanism, the tide can deposit the floating nuts (*Widodo et al. 2020*) and is best adapted to grow with only moderate salt loads (*Hossain and Islam 2015*).

For the conservation status of the recorded mangrove associates, eight species were recorded at Least Concern while three species were not yet assessed by the IUCN

Table 2. List of mangrove species identified from the study sites in San Vicente River and Lake Alindayat (Maalat), Candelaria, Zambales, Philippines with their conservation statuses and population trends.

Family Name	Species Name	Local Name	Station				Conservation Status*	Population Trend*
			1	2	3	4		
Acanthaceae	*Acanthus ebracteatus*	Lagiwliw		9	11	2	Least Concern	Decreasing
Acanthaceae	*Acanthus volubilis*	Lagiwliw		2			Least Concern	Decreasing
Pteridaceae	*Acrostichum speciosum*	Lagolo/Palaypay		2		4	Least Concern	Stable
Avicenniaceae	*Avicennia marina*	Kalapini/Bungalon	6				Least Concern	Decreasing
Avicenniaceae	*Avicennia officinalis*	Kalapini	2		2	1	Least Concern	Decreasing
Avicenniaceae	*Avicennia rumphiana*	Kalapini/Bungalon		4	1	3	Vulnerable	Decreasing
Rhizophoraceae	*Bruguiera cylindrica*	Pototan lalake		2	4		Vulnerable	Decreasing
Rhizophoraceae	*Bruguiera sexangula*	Pototan	2	2		2	Least Concern	Decreasing
Rhizophoraceae	*Ceriops decandra*	Malatangal	3				Least Concern	Decreasing
Rhizophoraceae	*Ceriops tagal*	Tangal	4	1	3	3	Least Concern	Decreasing
Euphorbiaceae	*Excoecaria agallocha*	Buta-buta	1	1	2		Least Concern	Decreasing
Sterculiaceae	*Heritiera littoralis*	Dungon		4	6	2	Least Concern	Decreasing
Combretaceae	*Lumnitzera racemosa*	Kulasi		2		1	Least Concern	Decreasing
Arecaceae	*Nypa fruticans*	Nipa		5	8	4	Least Concern	Unknown
Myrtaceae	*Osbornia octodonta*	Taualis	2				Least Concern	Decreasing
Rhizophoraceae	*Rhizophora apiculata*	Bakhaw lalaki	5			6	Least Concern	Decreasing
Rhizophoraceae	*Rhizophora mucronata*	Bakhaw babae		3			Least Concern	Decreasing
Lythraceae	*Sonneratia alba*	Pagatpat	1	3		1	Least Concern	Decreasing
Lythraceae	*Sonneratia caseolaris*	Pagatpat/Pedada		2		2	Least Concern	Decreasing
Rubiaceae	*Scyphiphora hydrophyllacea*	Nilad	5				Least Concern	Decreasing
		TOTAL	31	42	37	31		

Note: *www.iucnredlist.org

Red List of Threatened Species 2023-1 (**Table 3**).

Mangrove Diversity Indices

Diversity indices are used to measure the richnessand evenness of species diversity (*Maguran 2021*). The sampling site has species richness of 20. The species with the highest number of individuals was obtained by *A. ebracteatus* with 22 individuals. This was followed by *N. fruticans* with 17 individuals recorded while *A. volubilis* and *O. octodonta* obtained the lowest with only two. The species evenness was found very high (0.9181), showing that the species the area are evenly distributed across the site (**Table 4**). Shannon diversity index of 2.7505 revealed that the area is moderately diverse based on the classification given by *Fernando* (*1998*). The calculated mangrove of the Gini-Simpson's index is 0.9290 showing that the area is characterized by a high level of dominance, with a single species potentially having a significant influence on the overall composition of the community.

Water Quality Analysis of the Mangrove Forest

The physico-chemical properties such as temperature, pH, conductivity, dissolved oxygen (DO), salinity, total suspended solids, nitrite, phosphate and sulfate of all sampling sites were obtained. Based on the data, all parameters fall within normal ranges specified for class C (freshwater) and class SC (marine waters). The pH levels ranged from 7.51 to 7.86, TSS from 18 to 39, nitrate from 0.017 to 0.07, and phosphate from 0.00064 to 0.5. the temperatures in sites 2-4 and sulfate exceeded the standard value (**Table 5**).

Conductivity increases generally from upstream to downstream. However, Station 3 had a lower conductivity than Station 3 which is the lake (**Table 5**). This is likely due to the dilution of nutrient-enriched water from other nearby tributaries and the influence of agricultural runoff (*Harwell et al. 2008*). The proximity to agricultural land can introduce various dissolved ions and pollutants into the rivers (**Figure 1**). Changes in conductivity of a river near coastal areas can be influenced by several factors, such as the interaction between freshwater and saltwater and human activities (*US EPA 2024*). In the study conducted by *Minali and Chang* (*2021*) agricultural activities or sand cover and high population density are some factors which contributes in the reduction of conductivity concentration of the riverine water.

Table 3. Mangrove associates and their conservation status found in San Vicente River and Lake Alindayat (Maalat), Candelaria, Zambales, Philippines.

Family Name	Species Name	Local Name	Station				Conservation Status (IUCN Red List of Threatened Species 2023-1)
			1	2	3	4	
Apocynaceae	*Cerbera manghas*	Batano	-	-	+	-	Least Concern
Bignoniaceae	*Dolichandrone spathacea*	Tui	-	-	+	+	Least Concern
Malvaceae	*Hibiscus tiliaceus*	Malubago	-	+	-	-	Least Concern
Ribiaceae	*Morinda citrifolia*	Bangkoro	-	+	-	+	Not yet assessed
Pandanaceae	*Pandanus tectorius*	Pandan-dagat	-	+	+	-	Least Concern
Fabaceae	*Pongamia pinnata*	Bani	-	+	+	+	Least Concern
Verbenaceae	*Premna serratifolia*	Alagaw	+	-	-	-	Least Concern
Goodeniaceae	*Scaevola taccada*		+	-	-	-	Not yet assessed
Combretaceae	*Terminalia catappa*	Talisay	-	-	-	+	Least Concern
Malvaceae	*Thespesia populnea*	Banalo	-	-	-	+	Least Concern
Lamiaceae	*Volkameria inermis*		+	-	-		Not yet assessed

Note: + Present - Absent

Table 4. Species richness (n=20), and the computed species evenness (0-1), Shannon-Weiner (0-3.5) diversity and Simpson's diversity indices (0-1) of mangrove species in Candelaria, Zambales , Philippines.

Diversity Index	Value
Species Richness	20
Species Evenness	0.9181
Shannon Diversity index	2.7505
Gini-Simpson's index	0.929

Sulfate concentrations exceeded the allowable level (275 ppm) in all study sites, often due to natural leaf breakdown streams (*Leustek 2002*). High sulfate levels are major water contaminants, commonly introduced by industrial wastewater. Industries like mining contribute significantly, using sulfuric acid in ore processing (*Bhattacharya et al. 2022; Trisnaning et al. 2022*). This pollution worsens with droughts or heavy rain, especially in areas affected by acidic mine discharge (*Moreno-Casas 2009*).

Table 5. Physio-chemical properties of water in each sampling station at San Vicente River and Lake Alindayat (Maalat), Candelaria, Zambales, Philippines 2023.

Parameters	Station				Reporting Limit DAO (2016-08)	
	1	2	3	4	CLASS C (ppm)	CLASS SC (ppm)
Temperature (^{o}C)	31.0	32.8	32.7	32.5	25-31	25-31
pH	7.51	6.82	7.55	7.86	6.5-9.0	6.5-8.5
Conductivity (1 x 10^{-4} S/m)	52,100	50,100	48,200	49,800	0-800*	
DO (ppm)				3.5	5.0	5.0
TSS (ppm)	18	25	39	34	80	80
Salinity (ppm)	30,200	33,900	31,900	33,000		
Nitrate (ppm)	0.017	0.02	0.05	0.07	7.0	10
Phosphate (ppm)	0.00064	0.007	0.02	0.03	0.5	0.5
Sulfate (ppm)	2,060	2,040	1,810	1,980	275	275

Note: DAO 2016-08.-DENR Administrative Order 2016-08: Water Quality Guidelines and General Effluent Standards
CLASS C (Freshwater) - I. 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://mrcc.org.au/wp-content/uploads/2013/10/Water-Quality-Salinity-Standards.pdf)

Heavy Metal Analysis in Mangrove Forest

Heavy metals in water were analyzed using the Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) for the detection of copper (Cu), chromium (Cr), nickel (Ni) and iron (Fe) in the surface water (**Table 6**).

Based on the results, water in the mangrove forest is within the acceptable amounts of HM in freshwater. But HMs are toxic even at very low concentrations (*Masindi and Muedi 2017*). It was also suspected that HMs settle on the sediments of the mangrove forest due to the low presence of total suspended particles (TSS) in water (**Table 5**). According to *Tchounwou et al.* (*2014*), heavy metals are naturally occurring elements with a high atomic weight and density at least five times greater than water. However, soil is the ultimate sink for HMs and becomes a medium to spread into water bodies (*Ahmad et al. 2021*). The present study by *Sazon and Migo* (*2020*) confirmed sediments from the Alinsaog River in Sta. Cruz, Zambales, where mining activities are ongoing, contains a high concentration of toxic heavy metals, such as iron (Fe), chromium (Cr), nickel (Ni) and manganese (Mn) which exceeded the maximum allowable level for inorganics in sediments. Furthermore, the accumulation of heavy metals in mollusks from Uacon Lake in Candelaria indicates a significant level of soil contamination by HM (*Marbella 2020*).

Laboratory analysis on the presence of HMs in the soil/sediment of the mangrove forest at San Vicente River up to Lake Alindayat (Maalat) was based on USEPA and PEC (**Table 7**). The study adapted the standard developed by *Macdonald et al.* (*2000*) as there is no current sediment standard in the Philippines.

All the collected soil samples from the sites exceeded the reporting limit set by the United States Environmental Protection Agency (USEPA) and *Macdonald et al.* (*2000*) for all the HMs tested. Among the four stations, Station 3 has the highest Ni, Cr, and Fe concentration while Station 1 has the highest concentration for HM Cu. The high concentration of these HMs can be attributed to anthropogenic activities such as unregulated mining practices, and road and dike construction in metals-

Table 6. Heavy metal content of mangrove water in Candelaria, Zambales, Philippines, 2023.

Heavy Metals (ppm)	Station				Reporting Limit DAO (2016-08)	
	1	2	3	4	CLASS C (ppm)	CLASS SC (ppm)
Nickel	0.003	0.003	0.01	0.01	0.20	0.20
Chromium	0.005	0.005	0.005	0.005	0.01	0.01
Copper	0.003	0.003	0.007	0.003	0.02	0.02
Iron	0.09	0.1	0.3	0.3	1.5	1.5

DAO 2016-08.-DENR Administrative Order 2016-08: Water Quality Guidelines and General Effluent Standards
CLASS C (Freshwater) - I. 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.

Table 7. Heavy metal content of mangrove sediment, Candelaria, Zambales, Philippines 2023.

Heavy Metals (mg kg^{-1})	Station				Reporting Limit DAO (2016-08)	
	1	2	3	4	USEPA (mg kg^{-1})	PEC Consensus-Based
Nickel	876	1,150	1,320	363	1.50	49
Chromium	151	285	457	132	2.50	111
Copper	21	20	15	16	0.20	149
Iron	28,400	37,600	39,100	17,500	250	40,000*

MacDonald et al. 2000a. Development and Evaluation of Consensus-based Sediment Quality Guidelines for Freshwater Ecosystems. Arch. Environ. Contam. Toxicol. 39. 20-31.
**Persaud et al. 1993*. Guidelines for the Protection and Management of Aquatic Sediments in Ontario. Standards Development Branch. Ontario Ministry of Environment and Energy. Toronto, Canda.
USEPA - United States Environmental Protection Agency

enriched areas that can increase erosion and can mobilize metals into streams.

The analysis of soil from various sites in mangrove ecosystem in Candelaria, Zambales, reveals alarming levels of heavy metals, confirming the findings of previous studies. Candelaria, Zambales has experienced significant land use changes over recent years (*Paz-Alberto et al. 2021*), primarily driven by mining, agricultural, and industrial activities, which had intense environmental impacts, including high levels of heavy metals in soil and water. Mining has been a dominant economic activity in Candelaria, particularly for nickel and chromite. According to (*Dulfo 2020*) soil samples collected from agricultural fields of the Municipalities of Masinloc, Candelaria, and Sta. Cruz, Zambales exhibited significant contamination levels by heavy metals such as nickel, with levels 14 to 57 times higher and chromium levels 2 to 9 times higher than the maximum allowable concentrations for agricultural soils.

The findings also reveal that Ni, Cu and Cr are the primary heavy metal pollutants in mangrove sediments of the river and lake, typically linked to human activities. Among them, Cr does not occur naturally which comes from a various range of natural and man-made sources and enters the air, water, and soil matrices (*Tchounwou et al. 2014*). Arsenic, cadmium, chromium, and nickel are carcinogenic metals linked to DNA damage (*Kim et al. 2015*). Moreover, the highest concentrations of these HMs were found in mangrove sediments at stations 2 and 3. The high concentration levels are likely influenced by the proximity to memorial parks (**Figure 1**), which may be influenced by the rapid spread of these heavy metals into the environment (*Kaczmarek 2018*). Additionally, the-level concentrations of Ni and Cr can be attributed to the increased input of contaminated sediments. Station 3, in particular, is linked by the sewage outlet of the Lalol River. Furthermore, previous small-scale mining operations, located 3 km from the Lalol River may have contribute to the heavy metal contamination. Station 2, on the other hand, is surrounded by a dense residential area where traffic activities significantly influence the accumulation of heavy metals.

Although mangroves can help reduce HM pollution if the environment is overly contaminated, it will negatively impact the quality and health of this ecosystem (*Dudani et al. 2017*). Notably, the high concentration of HMs in the sediments of San Vicente and Alindayat Lake in Zambales may negatively impact the diversity of mangrove species. Heavy metals can alter the health of the soil and reduce its fertility, and harm microorganisms leading to a decline in mangrove species diversity (*Sandilyan and Kathiresan 2014*). Moreover, several studies have shown that high concentrations of heavy metals in sediments can severely impact the health and growth of mangrove ecosystems. *Sandilyan and Kathiresan* (*2014*) highlighted that heavy metals, such as mercury (Hg), cadmium (Cd), nickel (Ni), lead (Pb), copper (Cu) and zinc (Zn), cause significant physiological stress in mangrove species, leading to a decline in their numbers. In addition, *Nguyen et al.* (*2020*) demonstrated that heavy metals like Ni, Cr and Cu, accumulate in the roots of mangrove plants, adversely affect their growth at high concentration levels.

Additionally, the presence of HM in mangrove sediments is a matter of concern because the mangrove ecosystem is a home to several animal species consumed by humans (*Bomfim et al. 2018*). The findings of this study provide the current heavy metalpollution levels in the mangrove sediments of the lake and river in Candelaria, Zambales, Philippines.

CONCLUSION AND RECOMMENDATIONS

The mangrove areas of San Vicente River and Alindayat Lake in Zambales fall under moderate diversity. This is commonly observed in most mangrove studies in the Philippines. The moderate diversity highlights the balance, rather than exceptionally high variety of species, which is consistent with the general patterns seen in similar environments throughout the region. The area has a total number of 20 mangrove species which belong to 11 different families and 11 mangrove-associated species belonging to 10 families. River banks of San Vicente River are generally occupied by the *Avicennia-Sonneratia-Rhizophora* species, followed by the *Bruguiera-Lumnitzera-Ceriops* on the middle zone from the river bank to the landward side and the *Excoecaria-Acrostichum-Heritiera-Nypa* on the landward side of the river. In addition, traces of HMs in the water samples are normal and in acceptable amounts. However, the heavy metals (Ni, Cr, Cu and Fe) in the mangrove sediment exceeded the reporting limit set by the United States Environmental Protection Agency (USEPA) and *Macdonald et al.* (*2000*). The result showed the diversity of mangroves and the baseline physic-chemical conditions of the environment. Still, it did not particularly give us the process on how mangroves maintain ecological balance. Conservation effort must be considered knowing that the area was contaminated by HMs which will negatively impact the quality and health of the ecosystem. For future studies, it is highly recommended to conduct an assessment and heavy metal analysis of the aquatic fauna along the mangrove area of San Vicente River and Alindayat Lake, Zambales.

REFERENCES

Ahmad, W., Alharthy, R.D., Zubair, M., Ahmed, M., Hameed, A., and Rafique S. 2021. 'Toxic and Heavy Metals Contamination Assessment in Soil and Water to Evaluate Human Health Risk." *Scientific Reports*. 11:17006 https://doi.org/10.1038/s41598-021-94616-4

Bhattacharya, J., Da, B., and Dev, S. 2022. Subchapter 3.5 - Geogenic sulfate-rich wastewater: Sources, characteristics, effects and treatment technologies. Innovative Exploration Methods for Minerals, Oil, Gas, and Groundwater for Sustainable Development https://doi.org/10.1016/B978-0-12-823998-8.00095-8

Bomfim, M.R., Santos, J.G., Costa, O.V., Conceiçao, J.N., Silva, A.A., Souza, C. and Almeida, M.C. 2018. Morphology, Physical and Chemical characteristics of Mangrove Soil under Riverine and Marine Influence: A Case Study on Subae River Basin, Bahia, Brazil. Mangrove Ecosystem Ecology and Function. DOI:10.5772/intechopen.79142

Carugati L., Gatto B., Rastelli E., Martire M.L., Coral C., Greco S., and Danovaro R. 2018. "Impact of Mangrove Forests Degradation on Biodiversity and Ecosystem Functioning.' *Scientific Reports*. Article number: 13298. https://doi.org/10.1038/s41598-018-31683-0

DENR DAO 2016-008. Water Quality Guidelines (WQG) and General Effluent Standards (GES) of 2016. Accessed 10 July Available at: https://pab.emb.gov.ph/wp-content/uploads/2017/07/DAO-2016-08-WQG-and-GES.pdf

Dudani S.N., Lakhmapurkar J., Gavali D., and Patel T. 2017. 'Heavy Metal Accumulation in the Mangrove Ecosystem of South Gujarat Coast, India.' *Turkish Journal of Fisheries and Aquatic Sciences*. DOI: 10.4194/1303-2712-v17_4_11

Dulfo C. 2020. Speciation of Nickel and Chromium in Paddy Soils of Masinloc, Candelaria and Sta. Cruz, Zambales, Philippines. Archīum.ATENEO. https://archium.ateneo.edu/theses-dissertations/425

Fernando E. S., 1998. Forest formations and flora of the Philippines: Handout in FBS 21. College of Forestry and Natural Resources, University of the Philippines, Los Baños (Unpublished).

Gini, C. 1912. Variabilita e mutabilita. In: Pizetti, E. and Salvemini, T. Eds., Rome: Libereria Eredi Virgilio Veschi, Memorie di metodologica statistica.

Harwell M.C., Surratt D.D., Barone D.M. and Aumen N.G. 2008. "Conductivity as a Tracer of Agricultural and Urban Runoff to Delineate Water Quality Impacts in th Northern Everglades". *Environmental Monitoring and Assessment.* 147: 445-462. https://doi.org/10.1007/s10661-007-0131-3

Hossain B., Masum Z., Rhaman S., Yu J., Noman A., Jolly Y.N., Begum B.A., Paray B.A., and Arai T. 2022. "Heavy Metal Accumulation and Phytoremediation Potentiality of Some Selected Mangrove Species from the Wolrd's Largest Mangrove Forest." *Biology*. doi.org/10.3390/biology11081144

Hossain F. and Islam A. 2015. "Utilization of Mangrove Forest Plant: Nipa Palm (*Nypa fruticans* Wurmb.)." *American Journal of Agriculture and Forestry*. doi: 10.11648/j.ajaf.20150304.16

International Union of Conservation of Nature List of threatened Species. 2023. IUCN. https://www.iucnredlist.org/

Kaczmareck B. 2018. "The Heavy Metal Hazard of Undiscovered World War I and II Graves in Poland." *Global NEST Journal*. 21 (4): pp 461-465. https://doi.org/10.30955/gnj.002680

Kim H., Kim Y.J., and Seo Y.R. 2015. "An Overview of Carcinogenic Heavy Metal: Molecular Toxicity Mechanism and Prevention." *Journal of Cancer Prevention*. 20(4):232-240 DOI: 10.15430/JCP.2015.20.4.232

Kumar, J., Kumar, V.M.E., Bajanna, K. B., Mahesh, V., Kumar, N., Asheesh, A. S., Pandey, K., Manjappa, N., Pal, J.

2014. "Ecological Benefits of Mangroves." *Life Science Leaflets* 48: 85-88

Lee, S.Y., Primavera, J.H., Dahdouh-Guebas, F., McKee, K.; Bosire,J.O.,Cannicci,S.,Diele,K.,Fromard,F.,Koedam,N., Marchand,C. 2014. "Ecological role and services of tropical mangrove ecosystems: A reassessment." *Global Ecology and Biogeography* 23: 726-743 doi.org/10.1111/geb.12155

Leustek, T. 2002. "Sulfate Metabolism". *The Arabidopsis Book.* 1: e0017 doi: 10.1199/ tab.0017

Ludwig, T., Socorro, A.D., Gado ,V.J., Mazo, A.M. and Sierens, T. 2021. "*Avicennia* Genetic Diversity and Fine-Scaled Structure Influenced by Coastal Proximity of Mangrove Fragments." *Frontiers in Marine Science* 8. https://doi.org/10.3389/fmars.2021.643982

Macdonald, D.D., Ingersoll, C.G., Berger, T. 2000. "Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Systems." *Archives of Environmental Contamination and Toxicology*. 39(1):20-31 DOI:10.1007/s002440010075

Maguran, A.E. 2021. "Measuring Biological Diversity." *Current Biology*. 31(19) https://doi.org/10.1016/j.cub.2021.07.049.

Marbella, K. 2020. Heavy Metal Accumulation in Mollusk as Bioindicator of Contamination in Mangrove Sediments in Lake Uacon, Candelaria, Zambales. Archīum.ATENEO. https://archium.ateneo.edu/theses-dissertations/508.

Mariano, H.G., Dagoc, F.L.S., Espr,a A.S. and Amprado, R.F. 2019. Mangrove Diversity, Taxonomic Classification and Morphological Characteristics of Natural and Reforested Mangrove Forests in Selected Municipalities of Zamboanga Del Sur, Mindanao Island, Philippines. *Journal of Biodiversity and Environmental Sciences (JBES)*. http://www.innspub.net

Marine Ecology Fiji 2020. Retrieved from https://www.marineecologyfiji.com/

Masindi, V. and Muedi, K.L. 2017. Environmental Contamination by Heavy Metals. DOI: 10.5772/intechopen.76082

Minali, J. and Chang, H. 2021. "Environmental and Spatial Factors Affecting Surface Water Quality in a Himalayan Watershed, Central Nepal." *Environmental and Sustainability Indicators* 9. https://doi.org/10.1016/j.indic.2020.100096.

Mohammed, A.H., Khalifa, A.M., Mohamed, H.M., Abd El-Wahid, K., Hanafy, M.H. 2024. "Assessment of Heavy Metals at Mangrove Ecosystem, Applying Multiple Approaches Using in-situ and Remote Sensing Techniques, Red Sea, Egypt." *Environmental Science and Pollution Research.* 31, pp 8118-8133. https://doi.org/10.1007/s11356-023-31625-y

Moreno-Casas, P.A., Aral, H., and Vecchio-Sadus, A. 2009. "Environmental Impact and Toxicology of Sulphate." *In Proceeding of EnviroMine. International Seminar on Environmental Issues in the Mining Industry, Santiago, Chile* 30 September 2 October 2009.

National Oceanic and Atmospheric Administration. 2019. National Ocean Service. What is Mangrove Forest? Retrieved at: https://oceanservice.noaa.gov/facts/mangroves.html.

Nguyen, A., Richter, O., Le, B.V.Q., Phuong, N.T.K, and Dinh, K.C. 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*. doi:10.3390/ijerph17239131

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(01):85-133. DOI:10.4236/ajcc.2021.101005.

Paz-Alberto, A.M., Celestino, A., Sigua, G.C. 2014. "Phytoremediation of PB in the Sediment of a Mangrove Ecosystem." *Journal of Soils and Sediments*. doi:10.1007/s11368-013-0752-9

PENRO Pampanga. 2017. Mangrove Assessment of Sasmuan Bangkung Malapad Critical Habitat and Ecotourism Area (SBMCHEA).

Paz- Alberto, A.M., Vizmonte, J.L.D., and Sigua, G.C. 2015. "Assessing Diversity and Phytoremediation Potential of Mangroves for Copper Contaminated Sediments in subic Bay, Philippines". *International Jounral of Plant, Animal and Environmental Sciences* 5(4):50-59.

Persaud, D.R., R. Jaagumagi, and A. Hayton. 1993. Guidelines for the protection and management of aquatic sediments in Ontario. Standards Development Branch. Ontario Ministry of Environment and Energy. Toronto, Canada. ISBN 0-7778-9248-7

Primavera, J. H. 2009. Field guide to Philippine mangroves. Zoological Society of London-Philippines.

Putra, A.A. and Dewi, C.S.U. 2019. "Analysis of the Ability of Mangrove Sequestration and Carbon Stock in Pejarakan Village, Buleleng Regency, Bali." *Jurnal Ilmu dan Teknologi Kelautan Tropis*. 11(3). DOI: http://

doi.org/10.29244/jikt.v11i3.24049.

Sandilyan, S. and Kathiresan, K. 2014. "Decline of Mangroves – A Threat of Heavy Metal Poisoning in Asia." *Ocean and Coastal Management* 102: 161-168. https://doi.org/10.1016/j.ocecoaman.2014.09.025

Santini, N.S., Rerf R., Lockington, D.A. and Lovelock, C. 2015. "The Use of Fresh and Saline Water Sources by the Mangrove *Avicennia marina*." *Hydrobiologia* DOI: 10.1007/s10750-014-2091-2

Sazon, R., Migo, V. 2020. M"etal Concentrations in Sediments of the Alinsaog River, Santa Cruz, Zambales, Central Luzon, Philippines." *Journal of Health and Pollution.* 10 (27). https://doi.org/10.5696/2156-9614-10.27.200914

Simpson, E.H. 1949. Measurement of diversity. *Nature* 163, 688.

Tchounwou, P.B, Yedjou, C.G., Patlolla, A.K. and Sutton, D. 2014. "Heavy Meta;ls Toxicity and the Environment. National Center for Biotechnology." *National Library of Medicine.* doi: 10.1007/978-3-7643-8340-4_6

Trisnaning, P.T., Zamroni, A., Sugarbo, O., Prasetya, H.N.E., Sagala, S.T. and Hardiansyah M.Y. 2022. "Quality of Surface Water to Sand Mining Activity: A Case study from the Progo River, Daerah Istimewa Yogyakarta Province, Indonesia." *IOP Conference Series: Earth and Environmental Science* 1098: 012031 doi:10.1088/1755-1315/1098/1/012031

Widodo, P, Sukarsa, Herawati, W., Hidayah, H.A, Chasanah, T. and Proklamasiningsih, E. 2020. "Distribution and Characteristics of Nypa Palm (*Nypa fruticans* Wurmb.) in Southern Part of Cilacap Regency." *IOP Conference Series: Earth and Environmental Science 550: 012010* doi:10.1088/1755-1315/550/1/012010.

Zhenglei, X., Gaoru, Z., Min, X., Hua, Z., Wenbin, Y., Yinghui, J., Minxuan, L. and Zaifeng W. 2022. "Risk Assessment of Heavy Metals in a Typical Mangrove Ecosystem – A Case Study of Shankou Mangrove National Natural Reserve, Southern China." *Marine Pollution Bulletin* 178: 113642 https://doi.org/10.1016/j.marpolbul.2022.113642.

ACKNOWLEDGMENT

This study benefited from financial support from a non-government organization (specifiy the NGO). The authors are grateful to Sir Ambeng, Sir Rey, and Sir Gilbert for their assistance and support during fieldwork activities.