Analysis of Acid Mine Drainage Effects to the Domestic Water Resources Using GIS-Based Technique

DELIA SENORO, KEVIN LAWRENCE DE JESUS & CRIS EDWARD MONJARDIN

Abstract Acid mine drainage (AMD) is a serious problem to the environment, water resources and people. Calculating areas affected by AMD is helpful to create strategic programs for the protection of water resources, its remediation needs, reduction of adverse health effects, and enhancement of policy or guideline values. Accounting the extent of area contaminated by metals and metalloids (MMs), the research team collected 26 groundwater (GW), 49 tap water (TW), and 25 water samples from refilling stations (RS) in the island province that was exposed to mining disaster. The analyzed water samples coupled with geographic information system (GIS) created the spatial MMs concentration maps that were then used as environmental accounting tool to determine specific areas contaminated by As, Ni, and Pb. Records showed that 80 – 100% of the total area of the island province have water resources containing MMs concentration beyond the Philippines NSDW and WHO permissible limit.

Keywords: • AMD • environmental accounting • GIS • spatial analysis • water resources

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1 Introduction

Abandoned mines pits are major sources of acid mine drainage (AMD) that have detrimental effects to the environment, the wildlife that thrives in the surrounding area, and the people. Mining pits with low pH and elevated concentrations of metals and metalloids (MMs) alter the ecosystems and have an adverse impacts on human and natural environments (Rezaie and Anderson, 2020; Menzel et al., 2021). More than 630,000 mining sites worldwide were abandoned and have little to no rehabilitation (Tabelin et al., 2022) had been carried out. Also, there were about 50,000 of these mines were projected to release contaminated water, that could severely damaged about 6400 km of rivers, 8000–16,000 km of streams, and 72,000 hectares of lakes and reservoirs (Kiiskila et al., 2019). In the Philippines alone, there are more than 20 abandoned mining sites (Samaniego et al., 2020). Accounting of these contaminations have not been given attention. Hence, this study focused in the accounting of the extent of contamination in water resources in the island province. Accounting the areas and the extent of contamination is helpful in creating strategies and programs for the protection of water resources, determining the appropriate remediation needs, reduction of adverse human health effects, and enhancement of relevant policies and/or guidance values intended for specific area. Therefore, the outputs of the present study aimed to provide information on the extent of the effect/s of these MMs in domestic water resources by establishing the area coverages where water quality contains MMs concentrations beyond the threshold limits of the PNSDW 2017.

2 Literature Review

According to the Philippines Mines and Geosciences Bureau, about 9 million hectares, or 30% of the Philippines' total land area, have strong mineral deposits potential. Various mining activities, consisting of 55 metallic mines and 60 non-metallic mines, covered 2.54% of the nation's total land area as of June 2022. Copper, nickel, and gold are the primary mineral products of the country (Mines and Geosciences Bureau, 2022). The Philippines have several abandoned mine tailing areas as reported in the study of Aggangan et al. in 2019 and Samaniego et al., 2020. This includes the abandoned mine pits in the island province of Marinduque. This island provnce is situated at the southwestern tagalog region in the Philippines. The island province of Marinduque, known for its mineral deposits, has its mining operations commenced since 1969. Marinduque province experienced two major mine tailing disasters in the 1990s resulted to devastating environmental effects. The Mogpog town was inundated by the collapse of the Maguilaguila Tailings Storage Facility embankment in December 1993. Twenty-one barangays in Mogpog were submerged in contaminated floodwater and tailings as a result of this disaster. Another disaster event was in 1996. The concrete drainage tunnel cap of another mining spot, i.e., the Tapian pit, ruptured on March 24, 1996, causing over millions of cubic meter of hazardous mine tailings to spill into the Boac River.The Boac River is the longest river and important river system in Marinduque This was the second disaster and one of the most catastrophic mining and environmental disasters to ever occur in the Philippines (Monjardin et al., 2022). Prior to the mining disasters in 1993 and 1996 that severely damaged the communities and environment, mining industry contributed signifcantly to the Marinduque's economy (Salvacion, 2021). Nearly three decades after the disaster, several studies reported elevated levels of MMs such as arsenic (As), chromium (Cr), manganese (Mn), iron (Fe), lead (Pb), cadmium (Cd), zinc (Zn), nickel (Ni), and copper (Cu) in groundwater (GW) (De Jesus et al., 2021), domestic water (DW) (Senoro et al., 2022), sediments (Senoro et al., 2019), soils (Monjardin et al., 2022), crops and agricultural yields (Senoro et al., 2020).

In the study of Nelson et al. conducted in Marinduque reported more than a third of the household respondents obtained their drinking water from public sources including pumps, shallow wells, and municipal waterworks in addition to natural sources like springs, rivers, or streams. Some of this public water source contain elevated MMs. The consumption of contaminated water resulted in adverse health consequences in the people residing in the nearby communities. Igual et al. cited that there were villagers that were incapacitated due to direct and indirect exposures to MMs. Morover, the research of Fatalla in 2019 mentioned that MMs poisoning in the villagers resulted to chemical intoxication, gastrointestinal problems, and a suspected death of children in the area. Increasing mental health cases, and anemia in children below 5 years were reported, too. The adverse environmental impact of some mining activities is a global concern and has become prevalent in recent years.

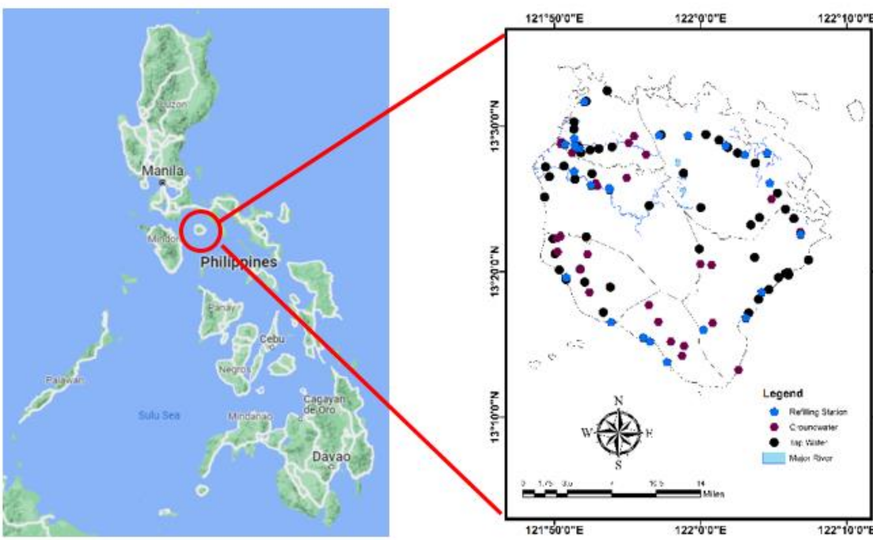
On water pollution accounting, water stress assessment and its analysis, a related study conducted at the Licum River water at Qingdao, China, showed that the industrial discharge was not the main source of pollution in the river but it was the contribution of TP and NH_3-N concentration from non-point source (Zhang et al., 2022). In the work of Wang, et al. (2021), it was elaborated on how to measure the physical water stresses to account for the water footprints which is useful in conducting the water stress assessment. Also, Robielos et al., (2020) demonstrated on how to account the disaster risks reduction indicators in order to assess the vulnerabilty of three geo-politcal levels. Further, the work of Prasetyo et. al. (2020), elaborated on how to account and analyze the interrelationship among the three dimensions of vulnerability risks utlizing the 'confirmatory factor analysis« technique. These techniques and methodologies on environmental polllution accounting, vulnerability reduction, disaster risks reduction, and among other related studies aided in making decision/s to determine the appropriate treatment strategy and program/s for the improvement of river water, environmental quality, and reduce health risks.

3 Materials and Methods

Description of the Study Area

The island province of Marinduque (Figure 1) located at 13⁰24' N latitude and 121⁰58' E longitude is in the Luzon island group in thhe Philippines. Marinduque has an estimated land area of 952 km^2 with a population density of 251 inhabitants per km^2. It has 218 barangays (smallest local government unit) in 6 municipalities, i.e., Boac (the capital municpality), Buenavista, Gasan, Mogpog, Santa Cruz, and Torrijos (PhilAltas, 2022). Rice, root crops and coconuts are among the agricultural products grown in Marinduque. The precipitation in the province varies from 10mm (during March) to 331mm (during October) while its temperature is ranging from 22.3^0C to 28.8^0C, during January and May, respectively (Salvacion, 2017).

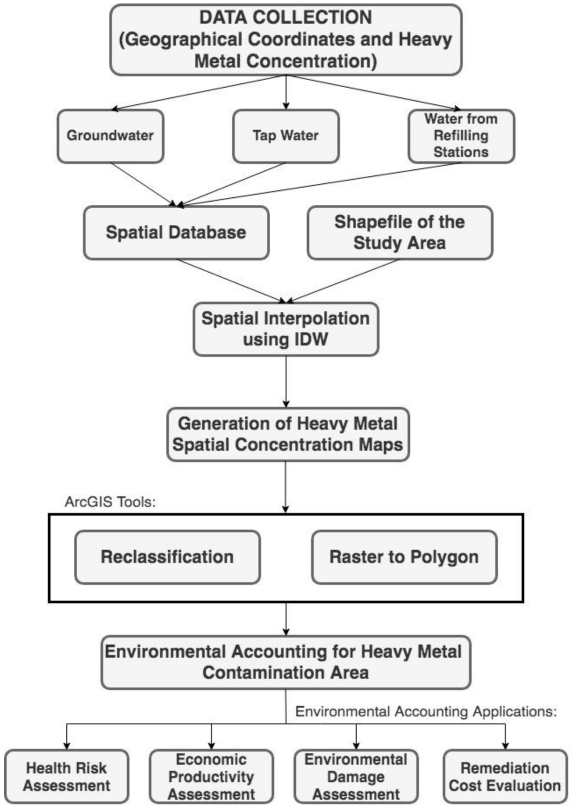
Figure 1: Sampling Locations of the Study



4 Theoretical Framework

Figure 2 demonstrates the theoretical framewotk of AMD for environnmental assessment to account on the effects, impacts to the ecosystem by metals and metalloids using the GIS technique. Several studies utilized Geographic Information System (GIS) in the monitoring and assessment of water resources impacted by MMs in different asian countries including Bangladesh (Towfiqul Islam et al., 2017), China (Fei et al., 2017), Cambodia (Bun et al., 2021), India (Raja et al., 2021), Indonesia (Wulan et al., 2020), Iran (Eslami et al., 2022), Iraq (Amin Al Manmi et al., 2019), Malaysia (Zainol et al., 2021), Pakistan (Bux et al., 2022), Philippines (Nelson et al., 2020; Senoro et al., 2021), Taiwan (Liang et al., 2017), and Thailand (Nilkarnjanakul et al., 2022). In an AMD-affected site, the GIS in conjunction with the Inverse Distance Weighting (IDW) method is a crucial tool for guaranteeing frequent and ongoing assessments and tracking of GW (Hamzaoui-Azaza et al., 2020) quality. When it comes to deploying and assessing geographical knowledge about water resources for spatial analysis, GIS is a potent tool to observe patterns and relationships of pollutants, a less time-consuming and cost-effective technique converts data sets into spatial representations. For human consumption, agricultural use, and the protection to serious environmental health problems, a map of the quality of the water is vital (Panneerselvam et al., 2020).

Figure 2: Theoretical Framework of the AMD Assessments for Environmental Accounting



Water Sampling and Analysis

Sampling points (Figure 1) were selected randomly to cover major river system, watersheds, and those water refilling stations (RSs) in populated areas. The GW samples were obtained from 26 different private and public hand pump wells, and placed in polyethylene bottles. Additionally, 49 tap water (TW) samples were collected from faucets throughout the province while 25 samples obtained were water from RSs. The coordinates of the sampling locations were recorded utilizng the Garmin Montana 680 global positioning system. The HM concenration such as As, Ba, Cu, Fe, Pb, Mn, Ni, and Zn were detected in the sample analysis using the Olympus Vanta portable handheld X-ray Fluoresnce Spectrometer and Accusensing metals analysis system (MAS). The Accusensing MAS was utilized for HMs concentration detection when pXRF recorded 'limits of detection (LOD)'.

Statistical Analysis

A descrtiptive statistical analysis of the water samples were obtained from Table 1 to have an overall view of the range of each water quality parameter. The analysis was performed using the IBM SPSS software which includes the maximum, minimum, range, standard deviation, skewness, and kurtosis of the datasets for GW, TW, and water from RS. The descriptive statistics of the GW, TW, and water from RSs datasets are enumerated in Table 1. Additionally, the results was assessed and compared to the threshold values set by the WHO (2004) and PNSDW 2017.

Table 15: Descriptive statistics of the datasets (Senoro et al., 2022)

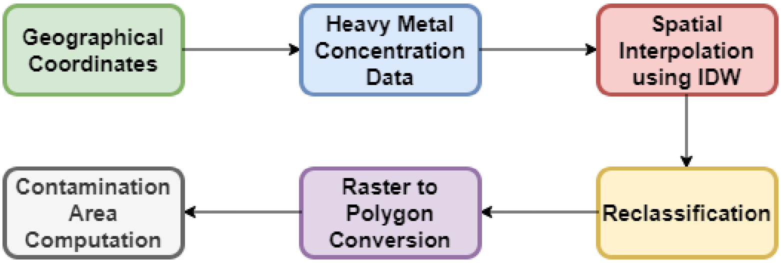
	Metal	**Max**	**Min**	**Range**	**SD**	**Skewness**	**Kurtosis**	**WHO**	**PNSDW 2017**
Ground-water (n = 26)	As	0.760	0.020	0.740	0.195	2.640	6.358	0.01	0.01
	Ba	0.049	0.000	0.049	0.015	-0.773	-0.607	0.70	0.70
	Cu	0.310	0.000	0.310	0.062	4.206	18.889	2.00	1.00
	Fe	15.026	0.000	15.026	2.929	4.846	24.113	0.30	1.00
	Pb	13.430	0.160	13.270	3.027	3.400	11.702	0.01	0.01
	Mn	0.028	0.000	0.028	0.006	1.279	1.935	0.40	0.40
	Ni	0.250	0.000	0.250	0.043	2.347	11.214	0.07	0.07
	Zn	0.149	0.000	0.149	0.033	1.995	4.895	3.00	5.00
Tap Water (n = 49)	As	19.030	0.020	19.010	3.845	3.919	14.454	0.01	0.01
	Ba	0.051	0.000	0.051	0.019	-0.261	-1.587	0.70	0.70
	Cu	0.540	0.000	0.540	0.088	5.126	27.248	2.00	1.00
	Fe	2.129	0.000	2.129	0.310	5.732	37.043	0.30	1.00
	Pb	4.750	0.160	4.590	0.796	4.096	18.889	0.01	0.01
	Mn	0.021	0.002	0.019	0.005	0.438	-0.617	0.40	0.40
	Ni	3.410	0.000	3.410	0.576	4.626	22.435	0.07	0.07
	Zn	0.074	0.000	0.074	0.015	0.901	1.619	3.00	5.00
Water from Refilling Stations (n = 25)	As	9.310	0.020	9.290	1.862	4.761	23.238	0.01	0.01
	Ba	0.059	0.000	0.059	0.019	-0.363	-0.963	0.70	0.70
	Cu	0.330	0.000	0.330	0.085	3.017	8.386	2.00	1.00
	Fe	1.503	0.000	1.503	0.308	3.587	15.131	0.30	1.00
	Pb	2.750	0.160	2.590	0.587	3.464	12.251	0.01	0.01
	Mn	0.017	0.002	0.016	0.004	0.067	-0.328	0.40	0.40
	Ni	0.180	0.010	0.170	0.025	1.649	12.907	0.07	0.07
	Zn	0.050	0.000	0.050	0.014	0.090	0.362	3.00	5.00

Spatial Analysis

The ArcGIS Desktop 10.8.1 was employed to generate the geographic variation pattern for each water quality indicator. Its feature called 'inverse distance weigthing (IDW)' was used for spatial interpolation of GW quality. The weights were allocated to each site (Borrego-Alonso et al., 2022) to establish distances, numbers (calculations) were obtained based on the areas that were known to be nearest. The geographical map's delineation of the concentration of each water evaluation metric makes it simple to view by the general public and decision-makers working in the water resources sector (Pal et al., 2022). It produces geographical decision support data sets by which decision-makers may simply understand to address GW quality management and environmental issues (Kada et al., 2022).

Contamination Area Calculation
Using the raster created for each water quality using the IDW method, the area of contamination was calculated and evaluated with respect to the domestic water resource quality threshold limits set by the PNSDW 2017. Figure 2 exhibits the schematic diagram of the flow of the procedure in the contamination area calculation for each HM detected in GW, TW, and water from RSs.

Figure 2: The HM contamination area calculation procedure



5 Results and Discussion

Spatial Analysis
The spatial HM concentration maps of the GW samples are illustrated as Figure 3. It was observed that the 'hotspot' area for As, Ba and Mn is in Brgy. Bagacay, in the municipality of Buenavista with concentration of 0.76, 0.05 and 0.03 mg/L, respectively. The highest concentration for Fe (15.03 mg/L) and Zn (0.15 mg/L) were observed in Brgy. Bachao Ilaya in the municipality of Gasan (13.30977^0 N, 121.8732^0 E). The highest concentration of Cu was 0.31 mg/L and was recorded in Brgy. Bocboc, municipality of Mogpog (13.46756^0 N, 121.9377^0 E). The elevated concentration of Pb (13.43 mg/L) was detected in Brgy. Bicas Bicas, municipality of Buenavista (13.2369^0 N, 121.97878^0 E). Moreover, the highest Ni (0.25 mg/L) concentration was observed in Brgy. Sibuyao, municipality of Torrijos (13.34089^0 N, 121.01254^0 E).

Figure 3: The GW spatial concentration map of Marinduque (a) As, (b) Ba, (c) Cu, (d) Fe, (e) Mn, (f) Ni, (g) Pb, (h) Zn.

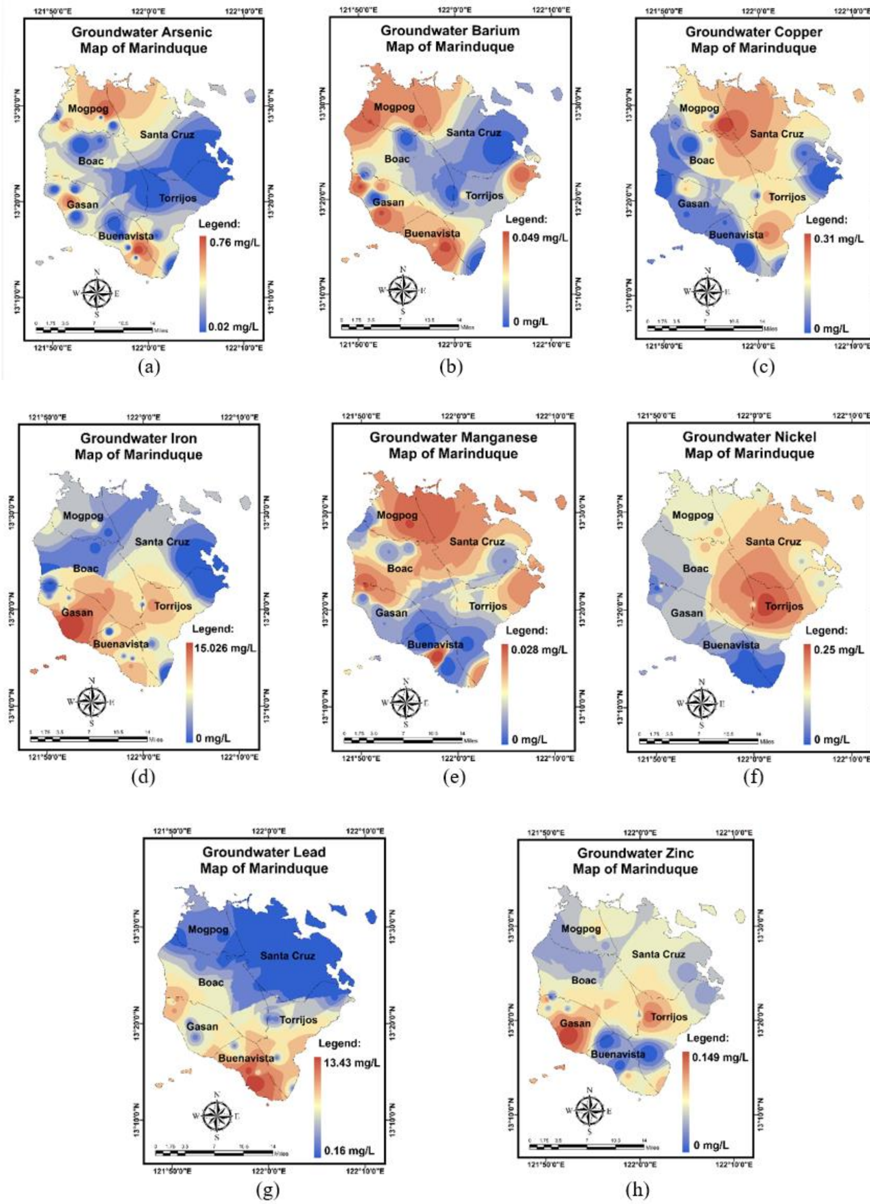
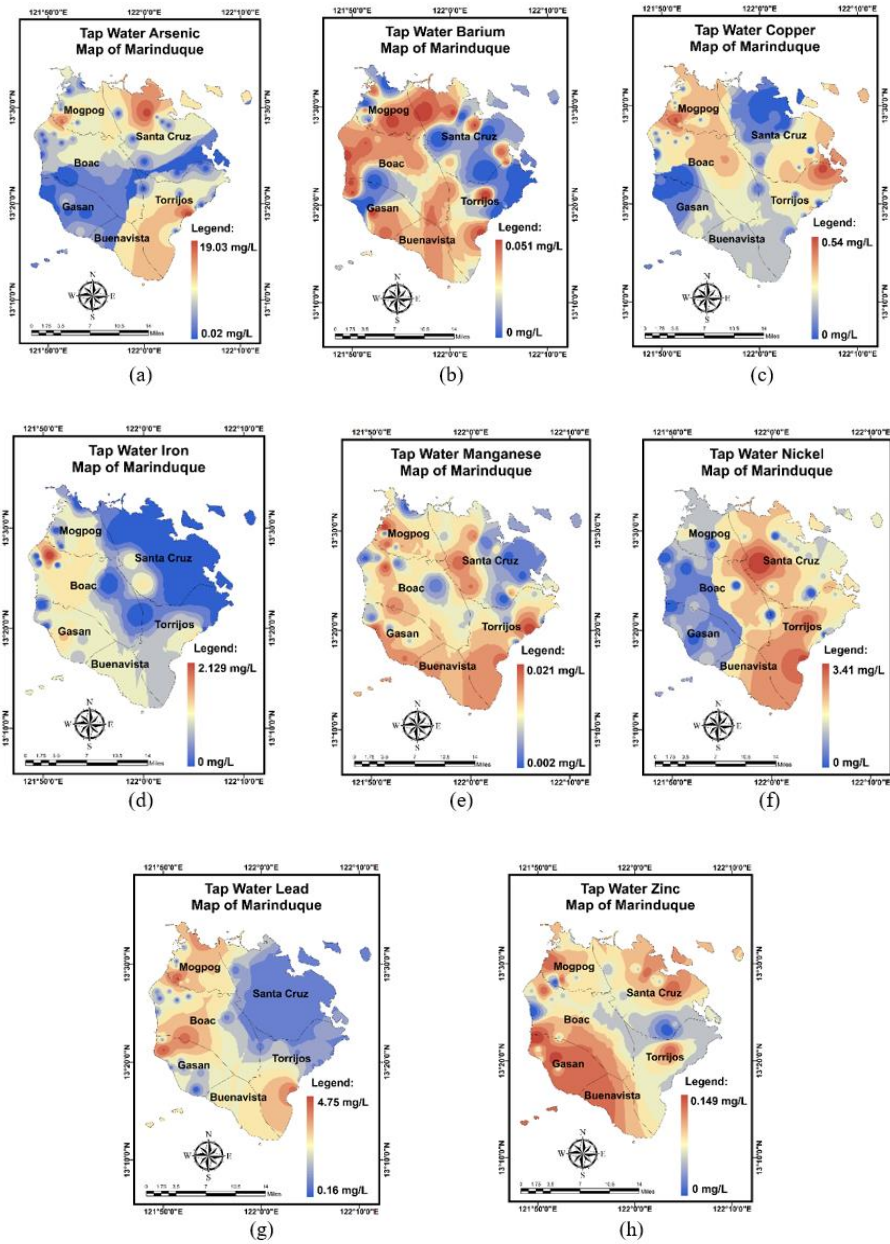


Figure 4 displayed a map of the tap water samples' HM spatial concentrations. The hotspot for Cu (0.54 mg/L) and Pb (4.75 mg/L) concentrations was found in Brgy. Market Site, located in the Mogpog Municipality. The highest concentration value of As (19.03 mg/L) was found in Brgy. Buangan in the Torrijos municipality (13.31286^{0} N, 121.07771^{0} E). The Brgy. Malusak in the municipality of Mogpog (13.47623^{0} N, 121.89895^{0} E) had the highest Ba (0.05 mg/L) concentration. While, highest concentration of Fe (2.13 mg/L) was found in Brgy. Tanza, municipality of Boac (13.45433^{0} N, 121.8441^{0} E).

Highest Mn concentrations of 0.02 mg/L were detected in multiple locations including Brgy. Ino (13.50491^{0} N, 121.85581^{0} E), municipality of Mogpog and Brgy. Poctoy, municipality of Torrijos (13.32956^{0} N, 121.10024^{0} E). Highest Ni concentration was observed in Brgy. San Antonio, municipality of Santa Cruz (13.44613^{0} N, 121.98041^{0} E) with 3.41 mg/L concentration. Furthermore, highest Zn concentration which is 0.07 mg/L were detected in municipality of Gasan including Brgy. Bahi (13.371^{0} N, 121.83178^{0} E), and Brgy. Tiguion (13.3361^{0} N, 121.86275^{0} E).

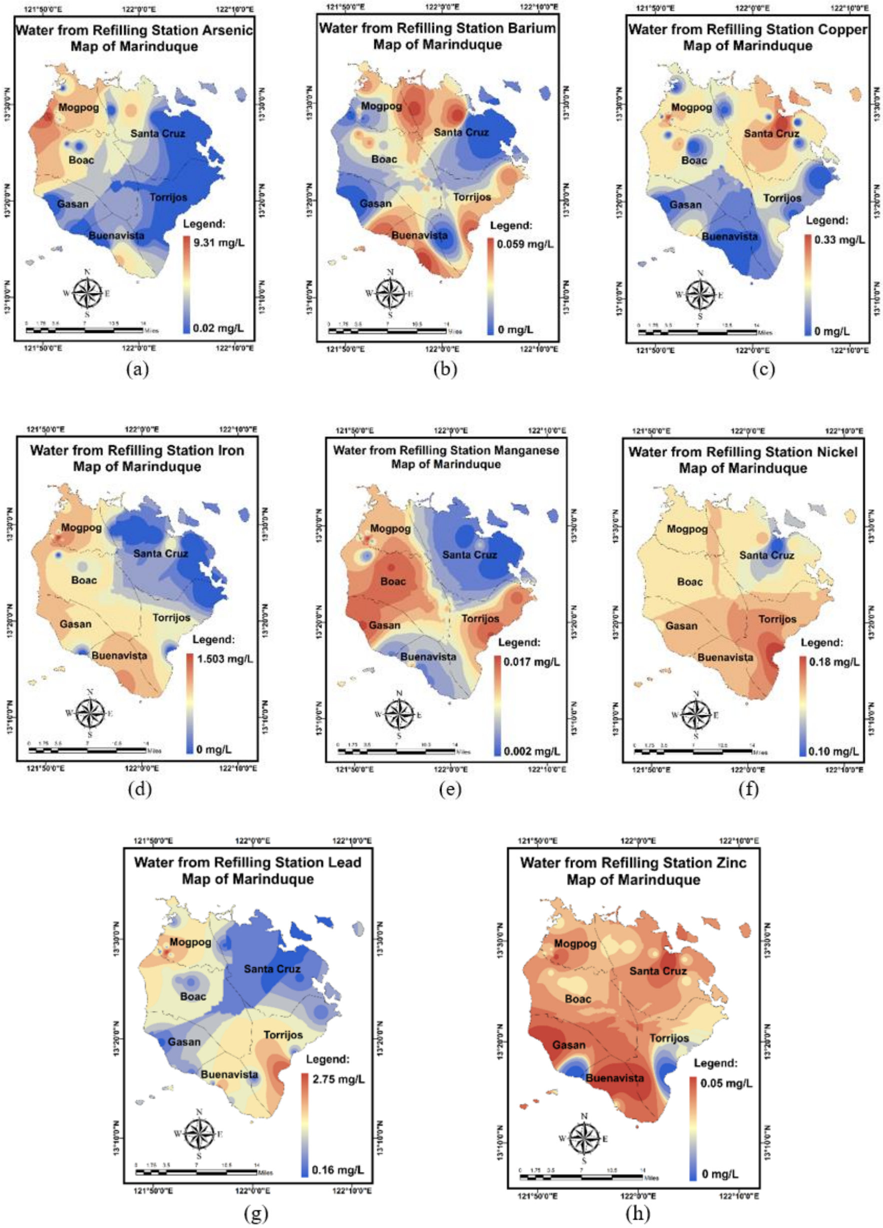
Figure 4: Tap water Spatial concentration map of Marinduque (a) As, (b) Ba, (c) Cu, (d) Fe, (e) Mn, (f) Ni, (g) Pb, (h) Zn



The HM spatial concentration levels water from RS were shown in Figure 5. Brgy. Janagdong in the municipality of Mogpog (13.47932^0 N, 121.84538^0 E) recorded the highest concentration of As (9.31 mg/L). Brgy. Libas in the municipality of Buenavista (13.22996^0 N, 121.96165^0 E) recorded the highest Ba concentration of 0.06 mg/L while Brgy. Buyabod in the municipality of Santa Cruz (13.46743^0 N, 122.05034^0 E) has the highest Cu and Zn concentration of 0.33 mg/L and 0.0495 mg/L, respectively. Highest Ni cocnentration was recorded in Brgy. Cabuyo, municipality of Torrijos (13.28071^0 N, 122.05138^0 E) with 0.18 mg/L. Highest concentration of Fe (1.50 mg/L), Pb (2.75 mg/L), and Mn (0.02 mg/L) was observed in Brgy. Nangka I, in the municipality of Mogpog (13.4779^0 N, 121.85673^0 E). Moreover, highest Zn (0.05 mg/L) concentration was reported in multiple sites including Barangay II (13.25355^0 N, 121.94233^0 E) and Brgy. Kaigangan (13.25821^0 N, 121.9345^0 E), in the municipality of Buenavista, Barangay I in municipality of Gasan (13.32708^0 N, 121.8467^0 E), Brgy. Gitnang Bayan in the municipality of Mogpog (13.4746^0 N, 121.8621^0 E), and Brgy. Malibago in municipality of Torrijos (13.26705^0 N, 122.00304^0 E).

Overall HM concentrations scenario, amd considering the As and Pb concentrations in GW, TP and water from RS, it was observed that these two HMs (As and Pb) exceeded the threshold of 0.01 mg/L set by the PNSDW 2017. Moreover, the Fe and Ni maximum concentrations detected in all water types samples were more than the permissible limits of 1.00 mg/L and 0.07 mg/L, respectively.

Figure 5: Spatial concentration map of HM in Water from Refilling Station in the Marinduque (a) As, (b) Ba, (c) Cu, (d) Fe, (e) Mn, (f) Ni, (g) Pb, (h) Zn



Through a variety of exposure pathways, the HM contamination in domestic water sources can enhance the risks to human health. Chronic HM exposure through water ingestion has been one of the emerging health concerns around the world. Arsenic exposure can affect skin, liver, and nervous system but the most serious problem it poses is the chronic exposure leading to increased risk for developing cancer (Kumar et al., 2021). Another, exposure to Ba through drinking water can cause gastrointestinal disturbances and muscle weakness (Peana et al., 2021). Ingesting Cu may cause strictures to develop all throughout the digestive track. Direct Cu toxicity can cause tissue necrosis, which can lead to acute liver failure (Royer and Sharman, 2020). Hemorrhagic necrosis and sloughing of the stomach mucosa with extending into the submucosa have been seen in autopsies (WHO, 2004). Exposure to Pb causes gastrointestinal harm, cardiovascular and reproductive issues, renal dysfunction, hematological abnormalities, endocrine diseases, neurological and developmental disabilities. Also, Pb can also cause human cancer (Hossain and Patra, 2020). Manganese is necessary for human health, poisoning may result in "manganism," a motor illness that is somewhat distinct from idiopathic Parkinson's disease but linked with profound neurologic damage (Rehman et al., 2019). Also, lung, nose, larynx, prostate, laryngitis, asthma, chronic bronchitis, respiratory failure, birth abnormalities, allergic responses such skin rashes, and heart conditions can all result from excessive Ni absorption (Hossain and Patra, 2020). Moreover, recurrent dyspnea or airway inflammation following inhalation exposure or gastrointestinal problems with dehydration, and possibly gastrointestinal hemorrhage following ingestion, are the complications caused by Zn toxicity. Additionally, tiredness, anemia, and lightheadedness can occur (Agnew and Slesinger, 2020).

Contamination Area Calculation

Utilizing the IDW maps generated for GW, TW, and water from RSs, the classes were re-classified to determine the areas affected by AMD which were beyond the threshold values set by the PNSDW 2017. In the calculated region where there is contamination of GW samples, there was elevated As and Pb concentrations were in 100% of the area. Additionally, Ni concentrations were found to be above the allowable limit of 0.07 mg/L throughout 89.882% of the entire area, or this is equivalent to 855.7 km^2. In addition, Fe concentrations were found to be over 1 mg/L PNSDW 2017 limit in 17.26% of the province's total area, or around 164.3 km^2. On the contrary, Ba, Mn, Cu, and Zn concentrations were all below the threshold values as set by the PNSDW 2017.

Table 16: Contamination Area Calculation Results for GW

Metal	Threshold Value (mg/L)	% Area Below the Threshold	% Area Above the Threshold
As	0.01	0.000	100.000
Ba	0.70	100.000	0.000
Fe	1.00	82.738	17.262
Pb	0.01	0.000	100.000
Mn	0.40	100.000	0.000
Ni	0.07	10.118	89.882
Cu	1.00	100.000	0.000
Zn	5.00	100.000	0.000

Further, it was recorded that 100% of the area from where the TW samples were collected, was contaminated by As with concentration (19.03 mg/L) above the threshold value. Additionally, 99.956% of the total area or about 951.6 km^2 have Pb concentrations (4.75 mg/L) above the permissible limit of 0.01 mg/L. Moreover, concentration of Ni (3.41 mg/L) was way above the 0.07 mg/L PNSDW 2017 limit in 81.564% of the total area of the province or about 776.5 km^2. On the other hand, concentrations of Fe that recorded above the permissible limit of 1 mg/L was only about 0.283% of the total area or approximately 2.69 km^2. Whereas, all of the total area of the province have concentrations of Ba (0.05 mmg/L), Mn (0.02 m/L), Cu (0.54 mg/L), and Zn (0.07 mg/L) below the threshold values. Table 3 presents the contamination area calculation for TP water.

In the calculated area of contamination for water samples from RSs, As and Pb contamination and concentrations were present in 100% of the area. Additionally, Ni concentrations were found to be above the allowed limit of 0.01 mg/L throughout 95.203% of the entire area, or 906.3 km^2. However, just 0.162 km^2 or 0.017% of the province's total area has Fe concentrations over the acceptable limit of 1 mg/L, whereas the province as a whole has concentrations of Ba, Mn, Cu, and Zn all below the threshold levels. The water from RSs contamination area calculation is shown in Table 4.

Table 17: Contamination Area Calculation Results for Tap water

Metal	Threshold Value (mg/L)	% Area Below the Threshold	% Area Above the Threshold
As	0.01	0.000	100.000
Ba	0.70	100.000	0.000
Fe	1.00	99.717	0.283
Pb	0.01	0.044	99.956
Mn	0.40	100.000	0.000
Ni	0.07	18.436	81.564
Cu	1.00	100.000	0.000
Zn	5.00	100.000	0.000

Accounting of contamination has not given attention, often overlooked, and unaccounted. Every contamination in the environment carries costs. These costs shall be considered by the industries, communities and the prople. The subsequent costs as a result of environmental contamination are as follows (Landrigan, 2012): [1] direct medical expenses of person/s made ill due to exposure to contamination; [2] indirect health-related costs by the concerned person who became ill due to exposure such as time lost from school and/or work, cost of rehabilitation, and/or cost of special education; [3] diminished economic productivity of persons whose organs systems were damaged due to toxic exposures; [4] loss of irreversible damaged to the environmental treasures, and [5] the cost of environmental clean up, remediation. Hence, the outputs of this study such as data and tools are useful in environmental accounting and in determining its subsequent costs. Also, these are useful in making policy and its corresponding guidance values.

Table 18: Contamination Area Calculation Results for Water from RSs.

Metal	Threshold Value (mg/L)	% Area Below the Threshold	% Area Above the Threshold
As	0.01	0.000	100.000
Ba	0.70	100.000	0.000
Fe	1.00	99.983	0.017
Pb	0.01	0.000	100.000
Mn	0.40	100.000	0.000
Ni	0.07	4.797	95.203
Cu	1.00	100.000	0.000
Zn	5.00	100.000	0.000

Statistical Analysis

The skewness and kurtosis values computed were used to assess and evaluate the HMs' asymmetry and to add understanding of the data. Table 5 elaborates the statistical data analysis interpretation. All HMs, with the exception of Ba showed positive skewness for all water samples; i.e, GW, TP, and water from RSs. The data set of Ba illustrates its normal occurence in all three types of water samples but its existence has been attributed together with other metals. The Ba is a divalent earth metal, produced naturally through weathering of rocks but toxic to human. The negative value is attributed to its normal existence with other metals. The data of Mn and Zn in water showed normal distribution. This means Mn and Zn frequently occurred in all types of water samples that were collected. Another, the As concentrations were seen to occur significantly in the GW. This is attributed to a possible massive extraction of GW in the island province. Also, it has been observed the high affinity of As and Zn. This scenario was als recorded in the study of Otte et al., 1995. Also, other metals were seen in occurrence with other target metals. Further, Cu concentration in water from RSs was recorded to occur moderately.

Table 19: Statistical Date Analysis Interpretation

	Metal	Max	Min	Range	SD	Skewness	Kurtosis	Interpretation
Ground-water (n = 26)	As	0.760	0.020	0.740	0.195	2.640	6.358	Occurrence is significant
	Ba	0.049	0.000	0.049	0.015	-0.773	-0.607	Regular occurrence with other metals
	Cu	0.310	0.000	0.310	0.062	4.206	18.889	With various outliers, occurred with other metals
	Fe	15.026	0.000	15.026	2.929	4.846	24.113	With various outliers, occurred with other metals
	Pb	13.430	0.160	13.270	3.027	3.400	11.702	With various outliers, occurred with other metals
	Mn	0.028	0.000	0.028	0.006	1.279	1.935	Occurrence is substantial
	Ni	0.250	0.000	0.250	0.043	2.347	11.214	With few outliers, occurred with other metals
	Zn	0.149	0.000	0.149	0.033	1.995	4.895	Occurrence is significant
Tap Water (n = 49)	As	19.030	0.020	19.010	3.845	3.919	14.454	With various outliers, occurred with other metals
	Ba	0.051	0.000	0.051	0.019	-0.261	-1.587	Regular occurrence with other metals
	Cu	0.540	0.000	0.540	0.088	5.126	27.248	With various outliers, occurred with other metals
	Fe	2.129	0.000	2.129	0.310	5.732	37.043	With various outliers, occurred with other metals
	Pb	4.750	0.160	4.590	0.796	4.096	18.889	With various outliers, occurred with other metals
	Mn	0.021	0.002	0.019	0.005	0.438	-0.617	Data distribution is fairly symmetrical, regular occurrence
	Ni	3.410	0.000	3.410	0.576	4.626	22.435	With various outliers, occurred with other metals
	Zn	0.074	0.000	0.074	0.015	0.901	1.619	Occurrence is substantial
Water from Refilling Stations (n = 25)	As	9.310	0.020	9.290	1.862	4.761	23.238	With various outliers, occurred with other metals
	Ba	0.059	0.000	0.059	0.019	-0.363	-0.963	Normal occurrence with other metals
	Cu	0.330	0.000	0.330	0.085	3.017	8.386	Occurrence is moderate
	Fe	1.503	0.000	1.503	0.308	3.587	15.131	With various outliers, occurred with other metals
	Pb	2.750	0.160	2.590	0.587	3.464	12.251	With various outliers, occurred with other metals
	Mn	0.017	0.002	0.016	0.004	0.067	-0.328	Normally distributed, regular occurrence in all samples
	Ni	0.180	0.010	0.170	0.025	1.649	12.907	With few outliers, occurred with other metals
	Zn	0.050	0.000	0.050	0.014	0.090	0.362	Normally distributed, regular occurrence in all samples

6 Conclusion

A study on the water source quality for domestic supply was conducted in an island province of the Philippines that experienced two mining disasters a couple of decades ago. This was to account the areas adversely affected by the HMs contamination. The HM concentrations in the domestic water were analyzed, evaluated and compared to the threshold values set by the PNSDW 2017. The findings exhibited elevated concentrations of As, Pb, and Ni in GW, TW, and water from RS. These concentrations in multiple sites were above the permissible limits of the PNSDW 2017. Employing the IDW method of GIS, the spatial concentration maps of the detected HMs including As, Ba, Fe, Pb, Mn, Ni, Cu, and Zn were generated; hence, identifying the pollution hotspot with respect to the HMs. Moreover, utilizing the IDW-based spatial maps, the area of contamination by these HMs were calculated and the findings revealed that 80% - 100% of the total area of the island province have concentrations of As, Pb and Ni greater than the permissible limits set by PNSDW 2017. The Ba concetration was prevalent in all water types samples, and were seen to co-exist with other metals as internsic characteistic of Ba. The As was prevalent in GW samples, and Mn and Zn were observed to occur regularly in all types of water samples. The methodology employed, and the tools created in this study would be beneficial for environmental accounting that would influenced policy makers and research direction. In addition, these environmental accounting tools are useful, for the local government units in conductiong environmental monitoring, create strategic program to reduce health risks, in drafting remediation plan and its corresponding budget. Furthermore, it is recommended to include the As, Pb and Ni in the domestic water quality parameters that are regularly monitored by the local and national government agency.

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