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Groundwater Heavy Metal Contamination and Pollution Index in Marinduque Island, Philippines using Empirical Bayesian Kriging Method

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ABSTRACT

This research exhibits the current state of the groundwater resources of the Province of Marinduque more than 20 years after the mining disaster. The sampling locations included thirty – five (35) sites that were extending all six municipalities of the province. The concentration of chromium, iron,

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manganese, lead, and zinc exceeded the maximum admissible limit (MAL) based on the Philippine National Standards for Drinking Water (PNSDW) 2017. Thirteen of the sampling sites were classified as severe pollution based on its pollution index. The highest pollution indices were found to be at Brgy. Sumangga, a riverside barangay in the Municipality of Mogpog. These indices were utilized to produce a spatial metal concentration map of the Province of Marinduque using the Empirical Bayesian Kriging (EBK) method. Based on the map, the groundwater of the municipality of Torrijos needs prompt attention for remediation. The findings revealed that the province of Marinduque's groundwater quality is in danger of deteriorating. It is possible to infer that EBK is an effective method for monitoring groundwater quality based on the data and correlation provided. The results of this study could assist in planning rapid response and strategies that are beneficial in the execution of programs that will enhance the adaptive capacity of the province.

Keywords: *Groundwater; Heavy Metal; Pollution Index; Spatial Analysis; Empirical Bayesian Kriging*

Introduction

Groundwater (GW) is essential in the daily activities of people worldwide. These activities are the per capita consumption, irrigation, and industries. The GW resources were subjected to the intensified threat of irreversible pollution and degradation [1] caused by anthropogenic activities such as mining and other manufacturing processes that used hazardous chemicals and processes that were not properly managed. This happened to the island province of Marinduque situated in the Southwestern Tagalog Region that has been recognized to have one of the Philippines' major copper reserves. The mining activities extracted copper started in 1969 until 1997. Marinduque experienced mining disasters in 1993 and 1996 and was considered among the world's disastrous mining events [2]. These two mining disasters resulted in marine environment, surface water, and soil pollution. The island province sits on sedimentary, igneous, and volcanic rocks, and was believed that its groundwater has been contaminated by these two disasters. Most of the communities in Marinduque rely on GW as a source of domestic water supply. Hence, periodic monitoring of the heavy metal concentration in groundwater is essential to prevent any detrimental, further degradation, water quality induced illnesses, and water-born–related diseases [3]. It was observed that several studies employed Nemerow's Pollution Index (NPI) in areas where there are related environmental issues. The results aided in the convenience of the studies and helped evaluate contaminated groundwater samples [4,5,6]. The NPI presents the ratio of the individual heavy metals to the standard

/permissible values. This explains the pollution contributed by individual heavy metal elements in the sampling points analysed [7]. Another technique is spatial analysis that is critical in the characterization of physicochemical factors and determination of contaminants in groundwater. These techniques give the assessment and spatial structure of the parameter/s being considered.

In addition to NPI, the Empirical Bayesian Kriging (EBK) is a geo-statistical interpolation technique that calculates the constraints or target parameter using sub-setting and iteration processes. EBK only requires minimal interactive modelling by which its standard errors of prediction were more exact compared to other types of Kriging methods for small datasets [8].

Several recent studies applied EBK in groundwater assessment including hazard modelling of the distribution of trace elements such as Zn, Cd, Pb, Cu, Ni and Fe [9], groundwater fluoride distribution and water quality index modelling [10], nitrate in groundwater modelling [11], groundwater vulnerability modelling for saltwater intrusion [12] and groundwater table modelling [13]. Therefore, this approach when developing into an environmental tool would provide convenience in monitoring groundwater quality. Hence, the purpose of the research is to exhibit the metal intensities in groundwater considering EBK with sampling points across Marinduque, Philippines. This will aid in the development of an environmental monitoring tool that would determine the spatial metal concentration in the study area and in areas of a similar geospatial profile, where access is a challenge.

Methodology and Research Framework

This study exhibited the data characteristic of both descriptive quantitative and applied qualitative. Employed in this study is an EBK method adopted from the work of Zou et al [14] by which this study followed the processes shown in Figure 1.

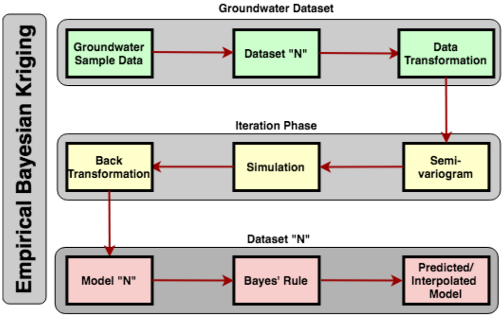

Figure 1: Interpolation Procedure using Empirical Bayesian Kriging.

Area of study and sampling locations

The focus of the study was the six (6) municipalities of the Province of Marinduque (13.47670 N, 121.90320 E) shown as Figure 2. Marinduque Province has overall area of 952.58 square kilometers [15]. A total of thirty-five (35) sites (Figure 2) were identified. The municipality of Boac has seven (7) sampling locations in different barangays/villages: Tagwak, Maligaya, Puting Buhangin, Balaring, Bantay, Hinapulan and Balimbing. The municipality of Buenavista has five (5) sampling points: Poblacion III, Daykitin, Poblacion I, Malbog and Tungib – Lipata. The municipality of Gasan has six (6) sampling sites: Banuyo, Masiga, Libtangin, Mahunig, Dawis and Tiguion. The municipality of Mogpog has six (6) sampling sites: Sumangga, Nangka II, Nangka III, Anapog – Sibucao, Butansapa and Puting Buhangin. The municipality of Santa Cruz has five (5) sampling locations: San Antonio, Dolores, Napo and Matalaba. Lastly, the municipality of Torrijos has six (6) sampling locations, i.e., Marlangga, Poctoy, Dampulan, Sibuyao and Suha.

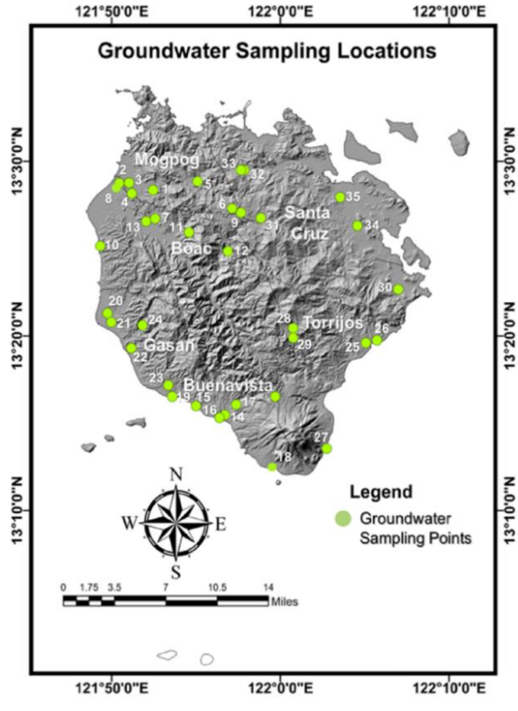

Figure 2: Sampling locations of the groundwater in Marinduque Province.

Groundwater sampling, storage, and testing

Ocular inspection was conducted to determine the location of the wells considered as sampling points in the study. The collection of GW samples were carried out thereafter. Hanna HI 9811-5 handheld Multi-parameter instrument was used for in–situ detection of physicochemical parameters of the GW samples. These parameters were temperature (T in ^{o}C), pH, total dissolved solids (TDS in mg/L), and electrical conductivity (EC in µS/cm). The measured EC and TDS were interpreted and classified using the values indicated in Table 1. One liter Polyethylene (PE) bottles were used to store the treated GW samples for ICP-OES analysis.

Table 1: Groundwater classification based on EC and TDS [16,17]

Parameter	Range	Classification
EC (µS/cm)	< 250	Excellent
	250 – 750	Good
	750 – 2,000	Permissible
	2,000 – 3,000	Doubtful
	> 3,000	Unsuitable
TDS (mg/L)	< 500	Desirable for Drinking
	500 – 1,000	Permissible for Drinking
	1,000 – 3,000	Useful for Irrigation
	> 3,000	Unfit for Drinking and Irrigation

Preservation protocol was in accordance with the EPA No. SESDPROC-301-R3 i.e., the operating procedure for groundwater sampling. The digestion followed the Method 3005A. This is for the total recoverable metals from water for ICP-OES analysis. Table 2 presents the instrument settings employed in the examination of GW samples [18,19]. The evaluation of the state of GW resources from Boac, Marinduque, Philippines was determined using Nemerow's Pollution Index (NPI) described below.

Correlation and statistical methods

The relationship concerning the physicochemical factors and the metal concentrations detected in groundwater samples were determined using a correlation matrix thru MATLAB 2019a. The correlation matrix established the occurrence and heavy metal association potential source of contaminant in study [20]. The descriptive statistics of the physicochemical factors and metal concentrations were analysed using IBM SPSS Statistics 25.

Table 2: Instrument settings of Optima 8000 (Perkin – Elmer) DV ICP – OES employed in the examination of groundwater samples

Instrument Condition	Classification
RFP[a]	1500
PGF[b]	8
AGF[c]	0.2
NGF[d]	0.7
PPS[e]	1.0
SC[f]	Cyclonic
TCP[g]	-3
P[h]	Low Purge (1 L/min)
RD[i]	45 seconds
WT[j]	Standards: 40 seconds Samples: 70 seconds
RT[k]	Auto: 1 – 5 seconds
NR[l]	2 replicates
SUR[m]	1 mL/min

[a]RFP – Radio Frequency Power (in Watts), [b]PGF – Plasma Gas Flow (in L/min), [c]AGF – Auxiliary Gas Flow (in Liters/minute), [d]NGF – Nebulizer Gas Flow (in Liters/minute), [e]PPS – Peristaltic Pump Speed (in Milliliters/minute), [f]SC – Spray Chamber, [g]TCP – Torch Cassette Position, [h]P – Purge, [i]RD – Read Delay (in seconds), [j]WT – Wash time (in seconds), [k]RT – Read Time (in seconds), [l]NR – Number of Replicates, [m]SUR – Sample Uptake Rate (in Milliliters/minute)

Risk assessment of groundwater samples

The detected elements in the GW samples were assessed and compared to the baseline values based on the Philippine National Standards for Drinking Water (PNSDW) 2017. The PNSDW 2017 consists of approved methods of analysis for the microbiological quality of drinking water. The PNSDW was used as basis of reference because most of the communities rely on GW source without treatment for domestic water supply. Hence, risk assessment [21] was carried out to assess the metal concentration in groundwater.

Single factor pollution index

The Single Factor Pollution Index (SFPI) approach was employed to determine the effect/s of each metal in the GW at a specific sampling location in terms of pollution index. The SFPI was computed using the Equation (1) presented below. Table 3 describes the classes or category of GW pollution based on NPI values.

$$SFPI = \frac{C_i}{S_i} \quad (1)$$

where C_i denotes the recorded concentration (mg/L) of metal *i* in the GW and S_i is the evaluation standard based on PNSDW 2017 shown in Table 8 of the metal contaminant *i* in the GW. A SFPI value greater than 1 signifies that the heavy metal pollutant exceeded the standard [4].

Table 3: Interpretation of Nemerow's pollution index values [4]

Pollution Class No.	Nemerow's Pollution Index	Interpretation
A	≤ 0.5	No Pollution
B	0.5 – 0.7	Clean
C	0.7 – 1.0	Warm
D	1.0 – 2.0	Polluted
E	2.0 – 3.0	Medium Pollution
F	> 3.0	Severe Pollution

Nemerow's pollution index

The Nemerow's Pollution Index (NPI) was employed to calculate and interpret the influence of a several heavy metals as it pollutes the GW at a particular sampling location. The NPI was calculated using the Equation 2.

$$NPI = \sqrt{\frac{(SFPI_{\max})^2 + (SFPI_{ave})^2}{2}} \tag{2}$$

where $SFPI_{max}$ indicates the highest SFPI of a pollutant; and $SFPI_{ave}$ denotes the mean SFPI of the pollutants considered [22].

Spatial interpolation using Empirical Bayesian Kriging (EBK)

The measured physicochemical parameter and detected heavy metal concentrations were mapped utilizing ArcGIS platform. The specific positions of the sampling sites were recorded using GARMIN Montana 650 GPS (Global Positioning System). The position of the sampling sites was plotted in the Geographical Information System (GIS) platform. Likewise, the calculated pollution indices were applied to create maps operating the Geostatistical Analyst Tool in the ArcGIS 10.5 software. This software contains EBK that automatically optimizes the parameters through a simulation process that employs estimation of various semi – variogram models instead of individual semi – variogram. It utilized interpolation to simulate the most challenging parts in creating a reliable kriging model. In addition, it utilizes intrinsic random function unlike the other kriging techniques that use calculations of semi – variogram considering the known data locations that can result to the estimation below the standard error of the prediction [23].

Results and Discussion

The subsection below elaborates the results of the study.

Physicochemical properties of groundwater

The physicochemical parameters of groundwater measured by Hanna Multi – parameter HI 9811-5 handheld meter were summarized in Table 4 and illustrated in Figure 3. The temperature showed positive skew which translated to a greater number of groundwater sampling points to have temperature more than 30.41 ^{o}C. Also, a similar positive skew was observed for EC and TDS. The average EC and TDS data were EC and TDS with 832.8571 µS/cm and 428.0286 mg/L. These values were classified as “permissible and desirable” based on the EC and TDS classification in Table 1, respectively. However, a slightly negative skew was recorded for pH. The average pH was 7.03 and based on the skewness recorded, more sampling points recorded a pH value lower than 7.03.

The correlation values obtained from the evaluation were summarized in Table 5. As presented in Table 5, only the association of TDS to EC presents a substantial positive correlation result with Pearson Correlation “R” of 0.87. This result agrees with the findings in the study of Srivastava and Ramanathan in 2008, which shows that the EC and TDS have a very high correlation ($R = 0.99$) because the EC increases as the concentration of all dissolved ions increases [24]. On the contrary, EC and pH have negative correlation results which are in line with the findings in the study of Kouras et al. in 2007 [25]. These groundwater physicochemical characteristics were likewise observed to have a link to the total hardness of the water. The EC [26] and TDS [27] were found to have a substantial positive correlation with total hardness, while the groundwater pH was described as having a significant negative correlation with total hardness [28].

Table 4: Physicochemical parameters of the groundwater samples in Marinduque, n = 35

Parameter	Temp (^{0}C)	Interpretation
Δ	23.30	-
Minimum	26.30	-
Maximum	49.60	-
Average	30.41	-
Standard Deviation	3.92	-
Variance	15.34	-
Skewness	3.45	-
Kurtosis	13.64	-
Parameter	pH	Interpretation[a b]
Δ	1.80	-
Minimum	6.10	SA
Maximum	7.90	SB
Average	7.03	SB
Standard Deviation	0.43	-
Variance	0.18	-
Skewness	-0.36	-
Kurtosis	0.66	-
Parameter	EC (μS/cm)	Interpretation[c d e]
Δ	2,270.00	-
Minimum	80.00	E
Maximum	2,350.00	D
Average	832.86	P
Standard Deviation	499.66	-
Variance	249,656.3	-
Skewness	1.22	-
Kurtosis	2.40	-
Parameter	TDS (mg/L)	Interpretation[f g]
Δ	1,120.00	-
Minimum	30.00	DD
Maximum	1,150.00	UI
Average	428.03	DD
Standard Deviation	267.66	-
Variance	71,639.56	-
Skewness	1.2146	-
Kurtosis	2.4421	-

[a]SA- Slightly Acidic, [b]SB- Slightly Basic, [c]E – Excellent, [d]D – Desirable, [e]P – Permissible, [f]DD – Desirable for Drinking, [g]UI – Useful for Irrigation

Table 5: Correlation analysis between physicochemical factors of the groundwater samples

Parameter	Temp	pH	Electrical Conduc-tivity	Total Dissolved Solids
Temperature	1.000	-	-	-
pH	0.310	1.000	-	-
Electrical Conductivity	0.170	-0.050	1.000	-
Total Dissolved Solids	0.060	-0.010	0.870	1.000

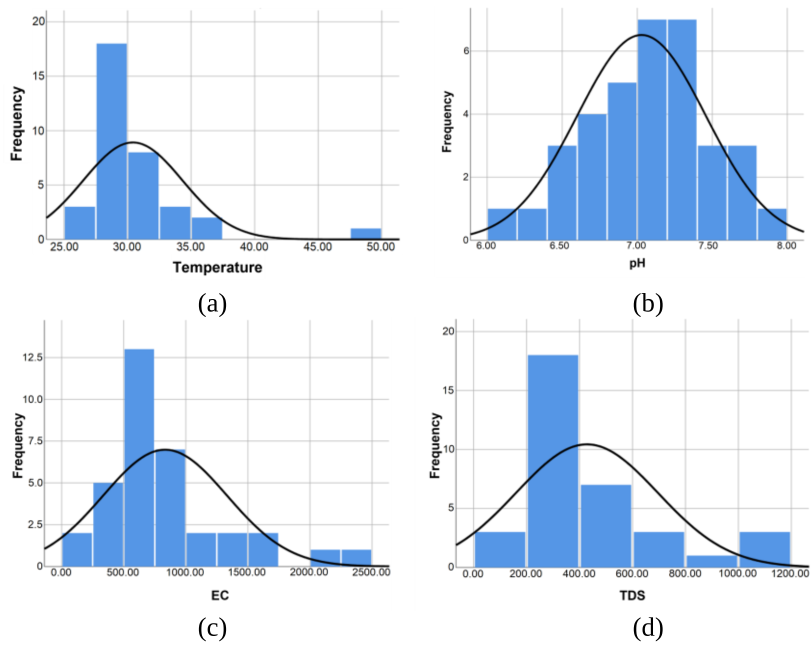

Figure 3: Distribution of the Physicochemical Parameters of the Groundwater Samples: (a) Temperature, (b) pH, (c) Electrical Conductivity, and (d) Total Dissolved Solids.

Heavy metal concentration in groundwater

Results of the ICP-OES analysis of GW samples for heavy metal intensity readings and evaluation are presented in Table 6. The descriptive statistics of the documented metals with significant concentrations were also exhibited in Table 6. The minimum and maximum concentration (in mg/L) of Cd, Cu, Cr, Fe, Pb, Mn, Ni and Zn were 0.0006 – 0.1039, 0.0009 – 0.2605, 0.0001 - 0.1718, 0.0004 – 54.6857, 0.0004 – 0.1218, 0.0001 – 8.7186, 0.0001 – 0.1253 and 0.0010 – 56.9613, respectively. The correlations obtained in the evaluation were presented in Table 7. Based on these results, Pb has high correlation with Cr, Cd, and Ni, while Zn with Fe, and Cr with Ni. This correlation suggested that potential source was from anthropogenic activities. This result is similar to the work of Hatar et al. in Malaysia [29].

Table 6: Metal concentrations (mg/L) of the GW samples in Marinduque, n=35

Element	Range	Minimum	Maximum	Mean
Cadmium	0.1033	0.0006	0.1039	0.0286
Copper	0.2596	0.0009	0.2605	0.0767
Chromium	0.1717	0.0001	0.1718	0.0504
Iron	54.6853	0.0004	54.6857	2.8169
Lead	0.1214	0.0004	0.1218	0.0404
Manganese	8.7185	0.0001	8.7186	0.6192
Nickel	0.1252	0.0001	0.1253	0.0342
Zinc	56.9603	0.0010	56.9613	3.2103
Element	**SD**	**Variance**	**Skewness**	**Kurtosis**
Cadmium	0.0451	0.002	0.1048	-2.2068
Copper	0.0583	0.003	0.1524	1.4249
Chromium	0.0408	0.002	0.4775	-0.9829
Iron	9.3748	87.886	4.1378	18.1243
Lead	0.0507	0.003	0.1072	-2.2022
Manganese	8.7185	2.348	3.1738	10.9372
Nickel	0.0534	0.003	0.1067	-2.2031
Zinc	10.4283	108.749	3.8485	15.7609

Table 7: Correlation analysis concerning the heavy metals studied

Heavy Metal	Cd	Cu	Cr	Fe	Pb	Mn	Ni	Zn
Cr	1.00	-	-	-	-	-	-	-
Mn	0.12	1.00	-	-	-	-	-	-
Fe	0.10	0.07	1.00	-	-	-	-	-
Pb	0.93	0.06	0.18	1.00	-	-	-	-
Cd	0.91	0.02	-0.06	0.96	1.00	-	-	-
Zn	0.05	-0.07	0.86	0.21	-0.01	1.00	-	-
Ni	0.92	0.03	-0.06	0.96	1.00	-0.01	1.00	-
Cu	0.41	-0.01	0.26	0.45	0.41	0.31	0.41	1.00

Risk assessment of groundwater samples

The detected elements in the GW samples were checked in comparison with the PNSDW 2017. Table 8 presents the limit reference guidelines from the World Health Organization (WHO) and Philippine National Standards for Drinking Water (PNSDW). Based on the results, Cd, Cr, Fe, Pb and Mn exceeded the maximum admissible level set by the PNSDW 2017. The Single Factor Pollution Index (SFPI) for each element was calculated and shown in Table 9. Iron has the highest SFPI of 54.686 while Cu has the least SFPI of 0.260. Furthermore, Cr, Mn, Fe, Pb and Cd exceeded an average SFPI value of 1.0 which indicated that the abovementioned elements exceeded the maximum admissible levels. This record is similar to the work of Haque et al. [30].

The Nemerow's Pollution Index was computed using the SFPI obtained from each element which is presented in Table 10. Thirteen (13) sampling locations exceeded NPI value of 3.0 which indicated severe contamination. As observed, the highest NPI was calculated from a sampling point in the municipality of Mogpog with NPI of 39.249. All sampling locations in the municipality of Torrijos and 4 out of 5 sites tested in the municipality of Santa Cruz exceeded the criteria for having severe pollution and high heavy metal concentration. The elevated metals concentration in groundwater was attributed to the releases of metals from sediments [33] similar to the work of Zhong et al [31].

Table 8: Concentration evaluation of heavy metals indentified in the groundwater with maximum admissible levels [31,32]

Heavy Metal	Limits of Concentration, ppm		
	Maximum Admissible Level (MAL) PNSDW 2017	Guideline Value WHO	Average Detected Concentration (ppm)
Cadmium	0.003	0.003	0.0286
Copper	1.000	2.000	0.0767
Chromium	0.050	0.050	0.0504
Iron	1.000	3.000	2.8169
Lead	0.010	0.010	0.0404
Manganese	0.400	0.050	0.6192
Nickel	0.070	0.070	0.0342
Zinc	5.000	3.000	3.2103

Table 9: Single factor pollution index for each HM concentration (in ppm) detected in groundwater

Heavy Metal	Min	Max	Mean	Range	SD	SFPI Description[a b c]
Cr	0.003	3.436	1.008	3.434	0.816	ESL
Mn	0.000	21.796	1.548	21.796	3.831	ESL
Fe	0.000	54.686	2.817	54.685	9.375	ESL
Pb	0.039	12.178	4.045	12.139	5.068	ESL
Cd	0.185	34.631	9.548	34.447	15.025	ESL
Zn	0.000	11.392	0.642	11.392	2.086	BSL
Ni	0.002	1.790	0.488	1.789	0.763	BSL
Cu	0.001	0.260	0.077	0.260	0.058	BSL

[a]Based on the Mean Values, [b]ESL - Exceeded the Standard Level, [c]BSL - Below the Standard Level

Spatial interpolation using Empirical Bayesian Kriging

The spatial concentration array of the target metals and the physicochemical factors in the groundwater specimen in Marinduque Province were presented on the contour plot established on the measured intensities of individual collection site. The spatial distribution map for the physiochemical parameters of groundwater is presented as Figure 4 to Figure 7. The highest temperature measured was 49.6 ^{o}C which was recorded at Brgy. Malbog in the municipality of Buenavista. Whereas the lowest temperature recorded was 26.3 ^{0}C at Brgy. Tagwak in the municipality of Boac. Brgy. Malbog is the location of a large potentially active stratovolcano called Mt. Malindig. The highest pH obtained was 7.9 while the lowest pH is 6.1. This was recorded in Brgy. Malbog, Buenavista and Brgy. Tungib – Lipata, Buenavista, respectively. This pH range is normal for groundwater. The highest electrical conductivity was recorded in Brgy. Maligaya in the Municipality of Boac. It recorded an EC of 2,350 µS/cm that signifies not favourable for domestic consumption. The lowest EC recorded was at Brgy. San Antonio in the municipality of Santa Cruz with EC of 80 µS/cm. Lastly, the highest and lowest TDSs values were 1150 and 30 mg/L.

Table 10: Nemerow's pollution index for each groundwater sampling locations – Part 1

Sampling No.	Sampling Point Label	Latitude	Longitude
1	Mogpog	13.47268	121.87411
2	Mogpog	13.47971	121.85046
3	Mogpog	13.47973	121.85053
4	Mogpog	13.46952	121.85326
5	Mogpog	13.48100	121.91803
6	Mogpog	13.45533	121.95198
7	Boac	13.44551	121.87620
8	Boac	13.47936	121.84087
9	Boac	13.45116	121.96086
10	Boac	13.41933	121.82200
11	Boac	13.43246	121.90953
12	Boac	13.41441	121.94785
13	Boac	13.44291	121.86731
14	Buenavista	13.25813	121.94488
15	Buenavista	13.26675	121.91648
16	Buenavista	13.25553	121.93958
17	Buenavista	13.26806	121.95611
18	Buenavista	13.20521	121.99482
19	Gasan	13.27573	121.89303
20	Gasan	13.35505	121.82911
21	Gasan	13.34646	121.83296
22	Gasan	13.32178	121.85268
23	Gasan	13.28638	121.88908
24	Gasan	13.34365	121.86365
25	Torrijos	13.32683	122.08441
26	Torrijos	13.32943	122.09528
27	Torrijos	13.22590	122.04562
28	Torrijos	13.34091	122.01261
29	Torrijos	13.33164	122.01261
30	Torrijos	13.37776	122.11611
31	Santa Cruz	13.44611	121.98055
32	Santa Cruz	13.49176	121.96383
33	Santa Cruz	13.49183	121.96086
34	Santa Cruz	13.43878	122.07606
35	Santa Cruz	13.46595	122.05896

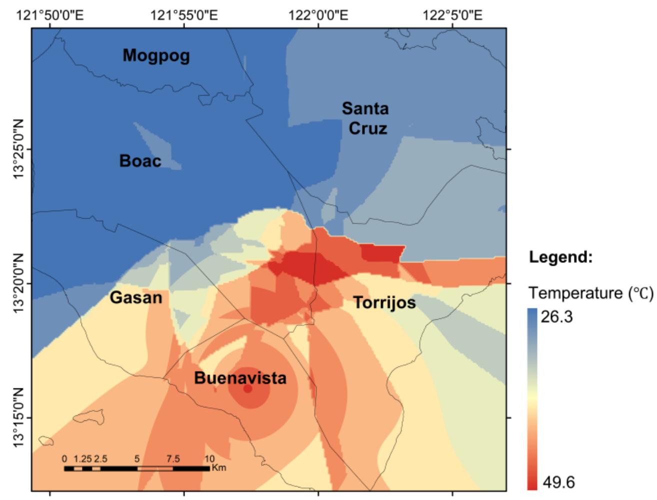

Figure 4: Spatial Concentration Map of GW Temperature in Marinduque Province.

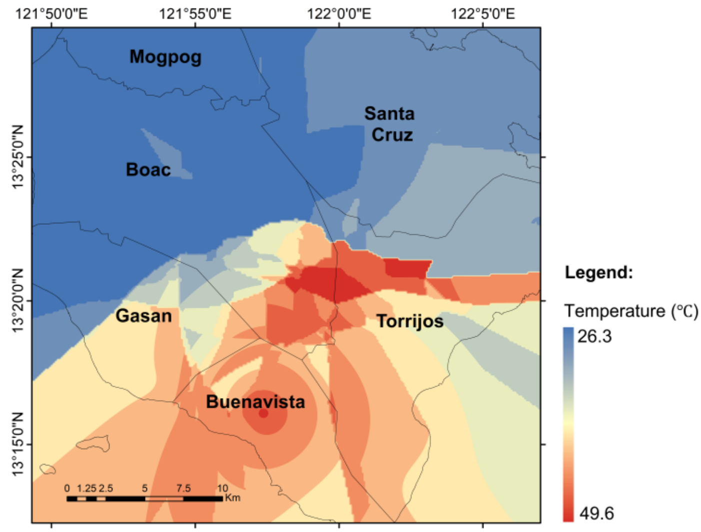

Figure 5: Spatial Concentration Map of GW pH in Marinduque Province.

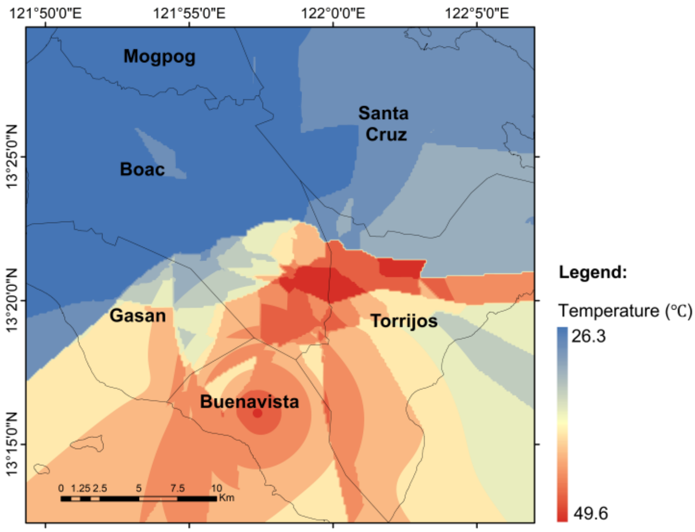

Figure 6: Spatial Concentration Map of GW Electrical Conductivity in Marinduque Province.

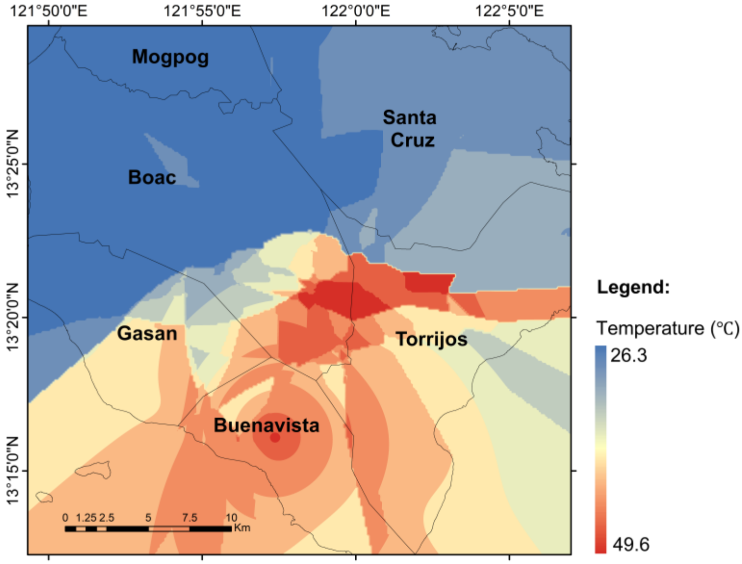

Figure 7: Spatial Concentration Map of GW Total Dissolved Solids in Marinduque Province.

The metal concentrations exhibited variations between specific locations stations. Considering the NPI values (Table 11), the top pollution index was computed at Brgy. Sumangga in the municipality of Mogpog. On the average, the highest pollution index was in the municipality of Torrijos while the least polluted municipality based on its pollution index was Buenavista as shown in Figure 8. The heavy metal intensity trend observed was Zn>Fe>Mn>Cu>Cr>Pb>Ni>Cd.

These findings provide preliminary and baseline data for fluid dynamic modelling and heavy metal transport in the groundwater of Marinduque province. The dominant process in contaminant transport is hydrodynamic dispersion, in which the solution is distributed by the requirement for a liquid to move around the solid soil particles [34]. Marinduque is an island province in the Philippines made up of volcanic, igneous, and sedimentary materials. These mediums are permeable, allowing these heavy metals to pass through the groundwater [35]. Hydrodynamic dispersion of heavy metals is a directional coefficient, and its directional dependence is mainly related to the flow direction of porous media [36].

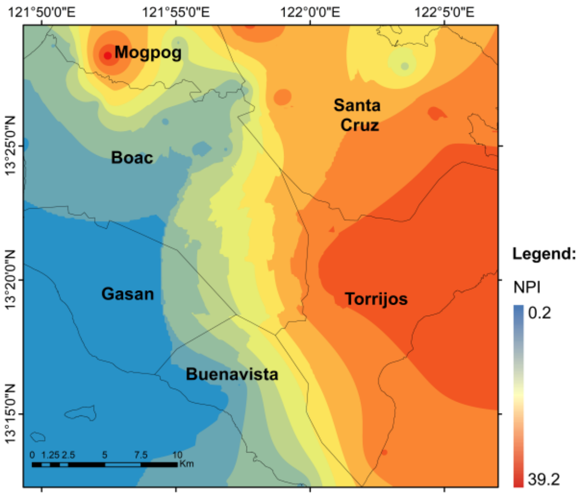

Figure 8: Spatial Concentration Map of NPI in Marinduque Province.

Table 11: Nemerow's Pollution Index for each Groundwater The metals pollution in the groundwater has been attributed to the abandoned open mine pits and the island province geological profile [37,38,39]. Sampling Locations – Part 2.

Sampling No.	Sampling Point Label	NPI	NPI Description
1	Mogpog	39.249	Severe Pollution
2	Mogpog	6.566	Severe Pollution
3	Mogpog	1.205	Polluted
4	Mogpog	1.187	Polluted
5	Mogpog	1.280	Polluted
6	Mogpog	1.040	Polluted
7	Boac	15.621	Severe Pollution
8	Boac	1.913	Polluted
9	Boac	1.422	Polluted
10	Boac	0.705	Warm
11	Boac	0.898	Warm
12	Boac	0.216	No Pollution
13	Boac	0.528	Clean
14	Buenavista	0.252	No Pollution
15	Buenavista	0.748	Warm
16	Buenavista	0.820	Warm
17	Buenavista	0.254	No Pollution
18	Buenavista	0.253	No Pollution
19	Gasan	0.266	No Pollution
20	Gasan	1.533	Polluted
21	Gasan	0.455	No Pollution
22	Gasan	0.257	No Pollution
23	Gasan	1.453	Polluted
24	Gasan	1.266	Polluted
25	Torrijos	24.900	Severe Pollution
26	Torrijos	24.054	Severe Pollution
27	Torrijos	23.400	Severe Pollution
28	Torrijos	23.712	Severe Pollution
29	Torrijos	23.581	Severe Pollution
30	Torrijos	23.693	Severe Pollution
31	Santa Cruz	23.663	Severe Pollution
32	Santa Cruz	23.395	Severe Pollution
33	Santa Cruz	23.652	Severe Pollution
34	Santa Cruz	23.672	Severe Pollution
35	Santa Cruz	0.711	Warm

Conclusion

The physiochemical parameters and groundwater metals concentration in Marinduque were assessed and evaluated. Established from the measured and calculated values, the average metal concentration of Cr, Fe, Mn, Pb, Zn was greater than the maximum admissible limit (MAL) prescribed by the PNSDW. The significant correlation between Pb:Cd, Pb:Cr, Cd:Cr, Zn:Fe, Ni:Cr, Pb:Ni suggest that source came from anthropogenic activities. The statistical analysis showed significant positive skewness and high correlation relationship. Thirteen (13) out of the thirty – five (35) sampling points were classified to have a severe pollution in reference to its Nemerow's Pollution Index. The generated spatial concentration map illustrated that the elevated metals concentration hotspot was situated at Brgy. Sumangga in the Town of Mogpog. Brgy Sumangga is a riverside barangay. The spatial distribution maps showed that the municipality of Torrijos has wide areas that have higher NPIs. The results illustrated that the groundwater quality in the province of Marinduque is at risk of groundwater quality deterioration. Based on the data and correlation presented, it could be concluded that EBK is a useful tool for groundwater quality monitoring. This tool is helpful to create strategies and programs for possible remediation and risk reduction. The use of spatial interpolation methods such as empirical bayesian kriging could provide preliminary data and assessments that can detect potential pollution trends and hotspots in each area. In future studies to examine the fluid dynamics and transport of pollutants, it is advised that temporal parameters be combined with spatial characteristics.

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