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Small-Scale Gold Mining and Heavy Metal Pollution: Assessment on the Physicochemical Parameters in the Surface Water Resources in Surigao City

Levitah Mapatac* and Teresita Atega

College of Mathematics & Natural Sciences, Caraga State University, Butuan City, Philippines

*Correspondence: lcmapatac@carsu.edu.ph

Abstract

The study aims to evaluate the physicochemical properties such as temperature, conductivity, resistivity, salinity, total dissolved solids (TDS), total suspended solids (TSS), and dissolved oxygen (DO), and the heavy metals concentration of Lead, Copper, Cadmium, Mercury, and Nickel along artisanal gold mining sites in the waterways in Surigao City. Through panning and amalgamation process, research has found out that among 54 barangays in Surigao City, Barangay Mat-I has gold deposits. Nineteen sampling stations with ten physicochemical parameters and five heavy metals were identified during wet and dry conditions. Results showed that pH, salinity, resistivity, TDS, TSS, DO, BOD, and COD exceeded the limit due to the presence of heavy metals like Hg, Pb, Ni, and Cd set by DENR Administrative Order (DAO) No. 34 standard and Philippine Clean Water Act of 2004 for surface water and statistical analysis using PCA multivariate.

Keywords

artisanal gold mining, physicochemical, heavy metals, multivariate PCA

INTRODUCTION

The Philippine Clean Water Act of 2004 defines water quality as the characteristic of water that defines its use and is measured in terms of physical and chemical characteristics by which the acceptability of water is evaluated in order to classify water resources and their beneficial use. Several ambient standards for measuring water quality have been formulated by the Department of Environment and Natural Resources (DENR). DENR Administrative Order (DAO) No. 34, issued in 1990, includes classifications for both surface and coastal water. According to Environmental Management Bureau (EMB), under this DAO, 33 parameters define the desired water quality per water body classification. As defined in the Philippine National Standards for Drinking Water (PNSDW) these parameters include dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and heavy metals for inland surface waters and salinity (chloride content) for groundwater. Since salinity is not directly related to pollution, it is also used as a common parameter for groundwater quality assessment to measure the level of contamination from saline water (Rao, 2007).

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In Barangay Mat-i, Surigao City (Figure 1), tunneling and gold panning, or simply panning is currently done. This is a form of placer mining and traditional mining that extracts gold from a placer deposit using a pan extracted from streams and mountainsides through sluices and panning. Panning is the process used by miners to separate the gold dust from the crushed ore by continuously shaking the pan (Figure 2). Two groups of people were responsible for the mining activity in the area: the Mamanwa people, who had claimed the so-called Ancestral Domain, and the NAGAMI group, who had applied for a "Minahang Bayan" which used both tunnel and placer mining.

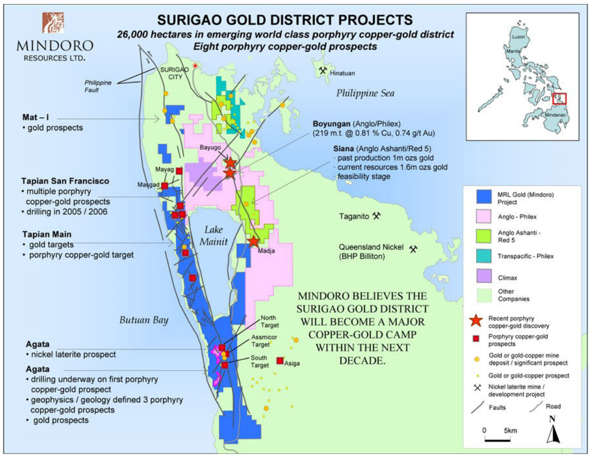

Figure 1. *Surigao City identified mining areas*

Figure 2. *Barangay Dose in Mat-i, Surigao City having a mining activity by panning wherein all ages are busy moving their panner in a circular manner*

Tunnel mining and the watershed boundary were so close that they could easily penetrate by tunneling the area within the watershed boundary, which contains high-grade ore, as evidenced in the previous illegal mining activities. Since mining uses logs to prop up their tunnels, the Surigao Water District officials were apprehensive that the mining activities could also denude the remaining forest cover in the watershed, which is the main source of the water system in the entire Surigao City. They also fear that chemicals and other hazardous substances used in processing will contaminate the environment and will surely affect the quality of our water. All effluence, run-off mine, and mill waste carrying toxic materials will eventually be in the course of the Surigao River–the future water source of the city. However, NAGAMI people from our interview stressed that they never allowed the use of any harmful chemicals such as mercury by amalgamation or cyanidation process for gold extraction.

One of the limitations of the study was the identification of the effect of underground mining on the wells or the downside of the aquifers on the human health and safety since they contribute to the pollution of the water system due to the existence of amalgamation in mining activities such as torching as the final process for the small-scale mining activities and the increase in noise level, dust, and ventilation. This has the same observations with some studies that chemical modification of the effluent on the ground water systems (Glenn et al., 1999; Glynn & Plummer, 2005; Vengosh & Keren, 1996).

Thus, the main objective is to assess the concentration of heavy metals associated with small-scale gold mining, such as Lead, Copper, Cadmium, Mercury, and Nickel, as well as the physicochemical parameters that affect as contaminants along the surface water in Barangay Mat-i, Surigao City. The end purpose was to evaluate the degree of contamination in the waterways along the mining areas that could be affected by small-scale mining activity.

METHODS

Sampling Sites and Time

The physicochemical characteristics of Mat-i Surigao City waterways were investigated in two sampling times - one in May and another in July- as representatives of dry and rainy seasons, respectively. The typical maps of the mining areas were selected (Figure 3), and the waterways that marked the pathway were sampling sites that needed to be monitored on the water quality with regard to the mining activities of the two mining groups. There were 19 sampling sites such as Sabang, Rizal, Lumintao, Tagbungon, Bonifacio, Kaningag, Trinidad, Pacemco, Mabuhay, Hubasan River, Mixing Pinaypayan, Tagbasingan Creek, Pinaypayan Creek, Creek 1 Downstream, Katigahan Creek, Mixing Parang-parang, Kapinohan Creek, and Parang-parang Daku. Physicochemical analysis was done using Temperature, pH, Salinity, Conductivity, Resistivity, TDS, TSS, DO, BOD, and COD, and heavy metals in terms of lead, copper, cadmium, mercury, and nickel.

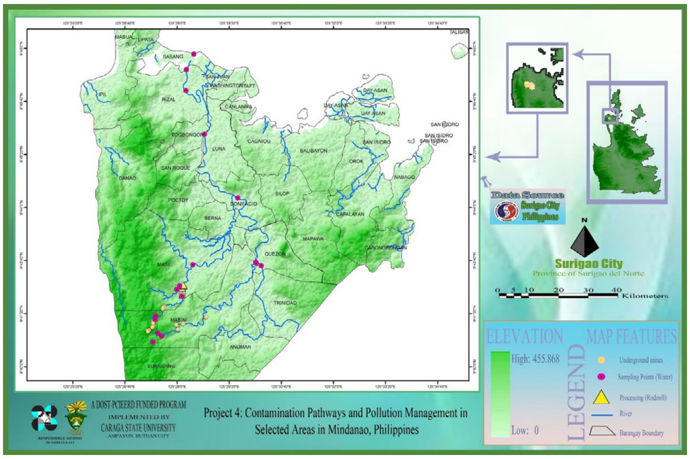

Figure 3. *Sampling sites of the different waterways along Barangay Mat-i, Surigao City conducted in the study under the Project 4 funded by DOST-PCIERD on Contamination Pathways and Pollution Management in Selected Areas in Mindanao, Philippines*

Sampling and Analytical Methods

Stream and well water pH, temperature, Eh, and conductivity were determined in the field using a series of temperature-compensated electrodes and meters. Water samples for chemical analysis were filtered rough 50mm diameter Sartorius Sartolab P 0.45μm disposable SFCA membranes using 50ml disposable syringes and collected into 250ml Nalgene LPDE bottles. Some water samples for analysis at the BGS were collected using 25mm diameter, 0.45μm Millipore cellulose acetate membranes into 30ml

Nalgene HPDE bottles. At each site, the suite of water samples collected included: (1) 250ml filtered water preserved with 1% v/v HNO_3 (*Merck*) for determination of Hg, Cu, Cd, Pb, Cd; and (2) 250ml unfiltered water with pH adjusted to 12 with solid NaOH for CN analysis. A number of 30 ml samples were filtered and preserved with 0.3ml conc. HNO_3 + 0.3ml 0.2 vol.% K_2CrO_7 were collected for total Hg analysis at the BGS by a UK Accreditation Services cold vapor atomic fluorescence spectroscopic (CVAFS) method to a practical detection limit of 30ng/L using a PS-Analytical AFS from FAST Laboratory- an ISO accredited laboratory. Quality control was achieved by analysis of duplicates, blanks, aqueous quality control standards, and AQUACHECK proficiency testing samples.

Statistical analysis

The laboratory results were evaluated using multivariate statistical techniques of Principal Component Analysis (PCA) for the selected parameters using Minitab version 18 statistical software. Twelve variables were selected such as water temperature, pH, salinity, conductivity, resistivity, TDS, TSS, DO, BOD and COD for physicochemical parameters and five parameters for heavy metals of lead, copper, nickel, cadmium, and mercury. Five principal components were identified considering the eigen values greater than one. Since the variables were in widely different units (mg/L, pH, °C, etc.), the standard variants and correlation matrix were used to conduct the analysis. After computing the variances (eigenvalues) and the principal components (eigenvectors) of a correlation matrix, the usual procedure was to look at the first few components which accounted for a large proportion of the total variance and the graph of scree plot and loading plot to analyze the variation in the data.

RESULTS AND DISCUSSION

Table 1 shows the range, mean, and standard deviation of ten physicochemical parameters during the dry season with the standard basis for surface water under the Philippine Clean Water Act of 2004 and the Executive Order No. 192 maximum admissible limit for each parameter. Results showed among the parameters that exceeded the maximum limit under EO no. 192 are the following: temperature of 35°C from the acceptable value of 25°C to 32°C, total dissolved solid of 539mg/L with acceptable value of 200mg/L, total suspended solids of about 1,618 mg/L with acceptable value of 110mg/L, dissolved oxygen of 9.8mg/L with acceptable value of 2mg/L and chemical oxygen demand of 577mg/L with EO no. 192 admissible limit of 200mg/L. These parameters tend to affect the watershed along the Parang-parang water shed in Surigao City, which is the main source of potable water in the area.

Table 1. *Physicochemical Parameters for Surface Water during Dry Season*

Sampling Stations	Temp. (°C)	pH	Salinity (ppt)	Conductivity (μS.cm)	Resistivity (kΩ.cm)	TDS (mg/L)	TSS (mg/L)	DO (mg/L)	BOD (ppm)	COD (mg/L)
Sabang	29.0	8.2	29.3	45.5	22.0	28.3	277.0	8.5	11.0	546.0
Rizal	30.5	8.2	23.1	36.1	27.2	22.4	77.6	7.7	8.3	577.0
Lumintao	31.0	7.9	4.2	7.5	132.0	4.1	53.9	7.5	8.3	105.0
Tagbungon	30.5	7.9	0.1	226.0	4.4	109.0	23.1	8.2	7.6	21.1
Bonifacio	32.0	8.1	0.1	222.0	4.4	106.3	18.9	9.8	8.8	18.7
Kaningag	34.0	7.5	0.1	157.0	6.3	74.8	225.0	7.9	9.8	36.7
Trinidad	32.0	7.6	0.1	223.0	4.5	106.0	18.9	8.6	8.7	35.1
Pacemco	35.0	7.6	0.1	145.0	6.9	68.5	225.0	7.9	9.9	42.9
Mabuhay	33.0	8.2	0.1	236.0	4.1	115.5	18.4	7.9	9.4	11.7
Hubasan River	27.2	7.9	0.2	334.0	3.0	160.0	871.0	8.0	7.7	11.7

Table 1. *(continued)*

Sampling Stations	Temp. (°C)	pH	Salinity (ppt)	Conductivity (µS.cm)	Resistivity (kΩ.cm)	TDS (mg/L)	TSS (mg/L)	DO (mg/L)	BOD (ppm)	COD (mg/L)
Mixing Pinaypayan and Tagbasingan Creek	29.7	8.0	0.2	359.0	3.0	175.0	8.5	7.5	8.6	17.9
Tagbasingan Creek	29.8	7.9	0.1	221.0	4.5	105.0	33.9	7.6	7.8	19.5
Pinaypayan Creek	28.2	7.9	0.2	433.0	2.3	210	1319.0	7.6	7.7	42.9
Creek 1 Downstream	27.2	8.0	0.5	982.0	91.0	539.0	1617.0	7.7	6.8	42.9
Katigahan Creek	28.2	8.3	0.3	557.0	1788.0	271.0	466.0	7.7	7.4	11.7
Mixing Parang-parang	26.5	8.2	0.1	223.0	4.4	107.0	75.9	8.0	7.7	11.7
Kapinohan Creek	26.7	8.2	0.2	378.0	2.8	185.0	696.0	7.9	9.1	36.7
Parang-parang Gamay	25.0	8.0	0.2	323.0	3.1	150.0	11.4	6.9	7.3	19.5
Parang-parang Daku	25.4	8.1	0.9	179.0	5.6	85.5	20.2	7.9	8.3	17.9
Minimum	25.0	7.5	0.1	7.5	2.0	4.1	8.0	6.9	6.9	11.7
Maximum	35.0	8.3	29.3	982.0	1788.0	539.0	1618.0	9.8	11.0	577.0
Mean	29.5	8.0	3.1	278.0	155.0	138.0	319.0	7.9	8.4	85.6
Std. Deviation	0.7	0.1	1.9	50.3	102.0	26.9	109.0	0.1	0.2	38.8
Std. Acceptable Value (EO192)	25.0°C - 32.0 °C	6.0-9.0	100.0 ppt	1,500.0 µS.cm	10,000.0 kΩ.cm	200.0 mg/L	110.0 mg/L	2.0 mg/L	15.0 mg/L	200.0 mg/L

Table 2. *Heavy Metals Concentration of Surface Water during Dry Season*

Sampling Stations	Pb (mg/L)	Cu (mg/L)	Ni (mg/L)	Cd (mg/L)	Hg(mg/L)
Sabang	0.70	0.51	0.03	0.16	0.01
Rizal	0.40	0.33	0.02	0.09	0.01
Lumintao	0.20	0.16	0.03	0.03	0.01
Tagbungon	0.00	0.09	0.10	0.00	0.01
Bonifacio	0.00	0.10	0.02	0.00	0.01
Kaningag	0.10	1.55	0.08	0.01	0.01
Trinidad	0.00	0.10	0.03	0.00	0.01
Pacemco	0.00	1.83	0.03	0.01	0.07
Mabuhay	0.00	0.07	0.06	0.00	0.01
Hubasan River	0.00	0.14	0.03	0.00	0.02
Mixing Pinaypayan and Tagbasingan Creek	0.10	0.54	0.26	0.01	0.01
Tagbasingan Creek	0.00	0.68	0.16	0.00	0.01
Pinaypayan Creek	0.20	2.36	0.07	0.01	0.02
Creek 1 Downstream	0.20	0.44	0.03	0.01	0.01
Katigahan Creek	0.10	0.73	0.14	0.01	0.00
Mixing Parang-parang	0.00	0.17	0.02	0.01	0.00
Kapinohan Creek	0.20	1.68	0.02	0.01	0.01
Parang-parang Gamay	0.00	0.07	0.00	0.00	0.00
Parang-parang Daku	0.00	0.07	0.00	0.00	0.00
Minimum	0.10	0.00	0.00	0.00	0.00
Maximum	2.40	0.26	0.16	0.68	0.68
Mean	0.60	0.06	0.02	0.12	0.01
Std. Deviation	0.71	0.07	0.04	0.18	0.02
Std. Acceptable Value (EO192)	0.02mg/L	0.02mg/ L	0.02 mg/ L	0.003 mg/L	0.001mg/L

The range, mean, and standard deviation of eight physicochemical parameters during the wet season are shown in Table 3 (temperature, pH, salinity, electrical conductivity, resistivity, TDS, TSS, and DO) as mandated by the Philippine Clean Water Act of 2004 and the EO no. 192 which sets the maximum admissible limit for each of the parameters. Results showed among the parameters that exceeded the maximum limit under EO no. 192 are the following: pH from the acceptable value of 6.0–9.0 and the maximum result of 11.55, conductivity of 1,913.0μS.cm which was beyond the acceptable value of 1,500.0μS.cm, total dissolved solid of 1,167.0mg/L with an acceptable value of 200.0mg/L, total suspended solids of about 1,618.0mg/L with an acceptable value of 110.0mg/L.

Table 3. *Physicochemical Parameters for Surface Water during Wet Season*

Sampling Stations	Temp. (°C)	pH	Salinity (ppt)	Conductivity (μS.cm)	Resistivity (kΩ.cm)	TDS (mg/L)	TSS (mg/L)	DO (mg/L)
Sabang	25.6	7.8	2.7	5.5	182.0	2.89.0	277.0	7.4
Rizal	25.4	7.1	1.2	2.3	429.0	1167.0	77.6	4.9
Lumintao	26.3	7.6	1.0	1913.0	454.0	1036.0	53.9	6.5
Tagbungon	25.5	7.6	0.1	199.0	5.0	94.6	23.1	7.8
Bonifacio	27.1	7.5	0.1	186.0	5.4	88.5	18.9	8.3
Kaningag	31.2	11.6	0.1	191.0	5.2	90.8	225.0	7.2
Trinidad	27.8	7.6	0.1	175.0	5.7	83.4	18.9	9.1
Pacemco	26.6	7.6	0.1	265.0	3.8	126.0	225.0	8.2
Mabuhay	28.3	7.7	0.1	162.0	6.1	77.6	18.4	8.8
Hubasan River	24.2	7.8	0.1	252.0	4.0	120.0	871.0	8.0
Mixing Pinaypayan and Tagbasingan Creek	25.0	7.8	0.1	256.0	3.9	123.0	8.5	8.1
Tagbasingan Creek	25.4	8.2	0.1	165.0	6.0	78.6	33.9	8.1
Pinaypayan Creek	26.8	7.9	0.2	325.0	3.1	155.0	1319.0	7.6
Creek 1 Downstream	27.2	8.0	0.5	982.0	912.0	539.0	1617.0	7.6
Katigahan Creek	28.2	8.3	0.3	557.0	1788.0	271.0	466.0	7.6
Mixing Parang-parang	24.9	7.9	0.1	191.0	5.2	91.0	75.9	8.5
Kapinohan Creek	24.8	8.0	0.1	239.0	4.17	114.5	696.0	8.2
Parang-parang Gamay	23.8	8.1	0.1	202.0	4.9	96.4	11.4	8.0
Parang-parang Daku	23.5	8.0	0.01	558.0	6.3	75.5	20.2	8.3
Minimum	23.5	7.1	0.1	2.3	3.1	2.9	8.5	4.9
Maximum	31.2	11.5	2.7	1913.0	1788.0	1167.0	1618.0	9.1
Mean	26.2	8.0	0.4	359.0	202.0	233.0	319.0	7.8
Std. Deviation	0.4	0.2	0.2	100.0	104.0	74.8	109.0	0.2
Std. Acceptable Value (EO192)	25.0 °C - 32.0 °C	6.0 - 9.0	100ppt	1,500.0μS.cm	10,000.0kΩ.cm	200.0mg/L	110.0mg/L	2.0mg/L

Table 4. *Heavy Metals Concentration of Surface Water during Wet Season*

Sampling Stations	Pb (mg/L)	Cu (mg/L)	Ni (mg/L)	Cd (mg/L)
Sabang	0.18	0.10	0.05	0.02
Rizal	0.12	0.05	0.03	0.01
Lumintao	0.09	0.07	0.03	0.01
Tagbungon	0.05	0.06	0.02	0.01
Bonifacio	0.08	0.09	0.03	0.02
Kaningag	0.08	0.94	0.06	0.01
Trinidad	0.06	0.18	0.03	0.01
Pacemco	0.08	0.03	0.02	0.01
Mabuhay	0.07	0.02	0.02	0.01
Hubasan River	0.13	0.18	0.03	0.01
Mixing Pinaypayan and Tagbasingan Creek	0.22	0.41	0.23	0.01
Tagbasingan Creek	0.07	0.10	0.02	0.01
Pinaypayan Creek	0.27	0.17	0.30	0.01
Creek 1 Downstream	0.09	0.18	0.03	0.01
Katigahan Creek	0.12	1.33	0.06	0.01
Mixing Parang-parang	0.08	0.01	0.01	0.01
Kapinohan/ Kanmahat Creek	0.08	0.01	0.01	0.01
Parang-parang Gamay	0.18	0.10	0.05	0.02
Parang-parang Daku	0.12	0.05	0.03	0.01
Minimum	0.05	0.01	0.01	0.01
Maximum	0.27	1.33	0.30	0.02
Mean	0.11	0.22	0.06	0.01
Std. Deviation	0.06	0.35	0.08	0.01
Std. Acceptable Value (EO192)	0.02mg/L	0.02mg/L	0.02 mg/L	0.003 mg/L

Surface water samples for heavy metals (Table 2 &Table 4) collected along Mat-i, Surigao City waterways, with nineteen sampling stations, exhibited higher values than the permissible guidelines value for heavy metals specified in the Clean Water Act of 2004 series of EO192. Lead has a value of 2.40mg/L (dry season) and 0.27mg/L (wet) with an acceptable standard value of 0.02mg/L; the copper of 0.26mg/L (dry) and 1.30mg/L (wet) with a standard value of 0.02mg/L; nickel of 0.16mg /L (dry) and 0.30 mg/L (wet); cadmium of 0.68mg/L (dry) and 0.02mg/L (wet) with a standard of 0.003mg/L; and mercury of 0.68mg/L (dry) with an EO 192 standard of 0.001mg/L. Thus, the chemical signatures of water reflected the characteristics of the nature of the aquifer (Obodai et al., 2023; Pandey & Kumari, 2023), which can be suggested to be affected by pollution in the surrounding mining activities along Mat-i waterways.

Table 5. *Physicochemical Parameters Compared to DENR DAO 34 Standard for Surface Water*

Water quality parameter	DAO 34 Series 1990	Dry Season	Wet Season
Temperature °C	Should not exceed 3°C increased	25.0 – 35.0	23.5 – 31.20
pH	6.5- 8.5	7.5 – 8.7	7.1 – 11.5**
Salinity	0.4 ppt.	0.1 – 29.3**	0.1 – 2.7**
Conductivity (μS.cm)	Not exceed 1275.0	7.5 – 982.0	2.3 – 1913.0
Resistivity (kΩ.cm)	NI	2.0 – 1788.0	3.1 – 1788.0**
TDS	1000.0 mg/L	4.1 – 539.0	2.9 – 1167.0**
TSS	50.0 mg/L	8.0 – 1618.0 **	8.5 – 1618.0**
DO	5.0 mg/L	6.9 – 9.8**	4.9 – 9.1**
BOD	7.0 mg/L	6.3 – 12.1**	
COD	30.0 mg O_2/L	11.7 – 58.0**	
Hg	0.002mg /L	0.0 – 0.68**	
Cu	0.05mg/L	0.01 – 1.33**	0.01 – 1.33**
Ni	0.05 mg/L	0.01 – 0.30**	0.01 – 0.30**
Cd	0.01mg/L	0.01– 0.02**	0.01 – 0.02**
Pb	0.05mg/L	0.05 – 0.27**	0.05 – 0.27**

***Beyond DAO 34 Class C Standard; NI- not indicated*

Results presented in Table 1 and Table 4 show the temperature value of surface water samples between 25°C – 35°C and 23.5°C – 31.2°C during the summer seasons and monsoon, respectively. Surface water was a little alkaline, but the quality was beyond the limiting value of the surface water standard. The general increase of pH in a sedimentary terrain was related to the weathering of plagioclase feldspar in sediments due to mining activities in the upper portion of mining sites. That was aided by dissolved atmospheric carbon dioxide, resulting in the release of sodium and calcium, which progressively increased the pH and alkalinity of the surface water. EC varied to 7.5μS/cm – 982.0μS/cm and 2.3μS/cm – 1,913.0μS/cm. TSS value exceeded the limit for the dry and wet seasons of 8.0mg/L – 1,618mg/L and 8.46mg/L – 1,618mg/L, and TDS changed to 4.1mg/L– 539mg/L and 2.89mg/L– 1,167mg/L during summer and monsoon seasons, respectively. Salinity, pH, conductivity, TSS, DO, BOD, and TDS exceed DAO no. 34 (1,990mg/L) permissible limits. The rainy/wet season recorded higher levels of pH, salinity, TSS, EC, and TDS compared to the dry season. The reasons were the intrusion of residual solids into the aquifer, the movement of water through sediments containing higher soluble mineral matter, and the influx of industrial and municipal wastes with the incursion of seawater by the leaching out process during the transition from dry to wet season (Hussein, 2003; Jones et al., 1999; Kanfi et al., 1983). The calcium and magnesium concentrations were generally derived from the leaching of limestone, dolomites, gypsum, and anhydrite (Anithamary et al., 2012; Garrels 1976; Sankar et al., 2010). Calcium and magnesium, pertaining to their salinity, ranged between 0.07ppt – 29.30 ppt, respectively, during the monsoon sub-season and 0.07ppt– 2.74 ppt, respectively, during the summer season. Most of the groundwater samples exceeded World Health Organization's [WHO] (1984) permissible limits in Ca and Mg. The increased concentration in salinity surface water samples was due to the leaching of limestone, dolomites, gypsum, and anhydrites (Aiuppa et al., 2003; Banaszuk et al., 2011; Samsudin et al., 2008).

In this multivariate analysis study, principal component analysis was employed to investigate the factors that caused variations in the observed quality data at the Mat-i water quality monitoring station in the Surigao City water basin. This study also demonstrates the technique's usefulness in analyzing water quality data. A literature review on principal components analysis, a technique that was formerly used in the field of hydrology, has shown its appropriateness for water quality data, as confirmed by some recent case studies in the literature (Cloutier et al., 2008; Iwar et al., 2021; Yidana & Yidana, 2009).

The principal component analysis (PCA) played a significant role in this study in identifying any relationship between surface water quality and the 19 stations in Mat-i waterways. In recent years, many studies have been done using the principal components analysis in the interpretation of water quality parameters (Akinbile & Omoniyi, 2018; Helena et al., 2000; Thareja et al., 2011). PCA confirmed the above findings. Results obtained from PCA analysis are shown in Table 6. Eigenvalues greater than 1.0 were used for PCA scoring, and three scores were selected within two seasons (Table 6). For the dry season, the first principal component (PC1) explained 32.30% (dry) and 23.90% (wet) of the total variance of the data with 32.30% (dry) and 23.90 (wet) cumulative variation and positively correlated to the second principal component (PC2) that explained 21.60% (dry) and 19.90 (wet) of the total variance of the data with 53.90%(dry) and 43.80% (wet) cumulative variation. PC1(dry) was positively correlated with salinity, BOD, COD, Pb, and Cd; PC2 (dry) was strongly correlated with pH and Pb. While PC2 (wet) was strongly correlated to salinity and cadmium, and PC3 (wet) was positively correlated to salinity, conductivity, and resistivity. In the study made by Sanchez et al., (2020), PCA was used to determine the surface water condition of the Sapangdaku River, which had the same effect as the Mat-i waterways, contributing to the overall variability of physicochemical and biological parameters across the sampling area. Under the first principal component, positive loading for BOD, COD, and heavy metals showed high concentration due to the presence of organic pollutants from domestic sewage and artisanal mining activities in the vicinity.

Table 6. *Loadings of water quality variables on with two decimal places for PCs in the varimax rotated component matrix*

Parameters	Dry Season			Wet Season		
	PC1	PC2	PC3	PC1	PC2	PC3
Temperature	0.14	-0.39	-0.18	-0.44	-0.22	-0.07
pH	0.05	0.39	0.25	-0.38	-0.21	-0.25
Salinity	0.40	0.24	-0.50	0.03	0.36	0.42
Conductivity	-0.34	0.27	-0.22	-0.20	0.06	0.37
Resistivity	-0.11	0.20	0.03	-0.42	0.11	0.36
TDS	-0.32	0.20	0.03	-0.24	0.28	-0.08
TSS	-0.18	0.28	-0.46	-0.44	-0.22	-0.07
DO	0.13	-0.14	0.07	0.17	-0.30	-0.40
BOD	0.33	0.21	-0.17	-	-	-
COD	0.40	0.22	-0.07	-	-	-
Pb	0.33	0.32	-0.23	-0.54	-0.04	-0.09
Cu	-0.03	-0.09	-0.55	-0.14	0.45	-0.47
Ni	-0.11	-0.04	-0.01	0.23	0.19	0.06
Cd	0.40	0.24	-0.11	-0.02	0.60	-0.31
Hg	0.05	-0.29	-0.44	-	-	-
Eigenvalue	4.85	3.24	2.17	2.63	2.19	1.80
Variability (%)	32.30	21.60	15.00	23.90	19.90	43.80
Cumulative %	32.30	53.90	68.90	23.90	43.80	60.10

In the scree plot diagram between eigenvalues and the component number, values greater than 1 for eigenvalues represented high correlation and values of less than 1 meant negative correlation. In figure 4, it shows the high correlation during dry season of the four parameters of temperature, pH, salinity, and conductivity and the negative correlation to all the heavy metals namely Pb, Cu, Ni, Cd and Hg. This means that the four parameters of temperature, pH, salinity, and conductivity have positive association in terms of the quality of the surface water in Mat-i waterways. Hence, the water surface that passed the minimum standard of water analysis and parameters lesser than zero were Pb, Cu, Ni, Cd and Pb that negatively affected the water quality of Mat-i waterways where all of the heavy metals went beyond the set standard by DAO no. 34. While in the wet season, the same four parameters had an eigenvalue greater than 1 namely temperature, pH, salinity, and conductivity which passed with the standard water quality analysis. Only nickel and cadmium had equal to less than zero, meaning that they greatly affected the water quality of Mat-i waterways.

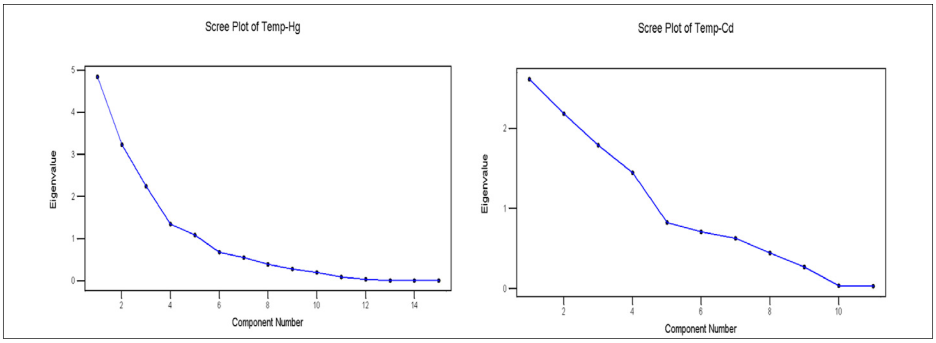

Figure 4. *Scree Plot of the Surface water with parameters from dry season to wet season*

The graph of the loading plot (Figure 5) identifies the variables that have the largest effect on the factors of surface water during the dry season in Mat-i waterways. Loadings can range from -1 to 1, and loadings close to -1 or 1 indicate that the variable has a weak and strong influence on the factor in the water quality. Pb, Cd, and salinity during the dry season (closer to 1) have big influences on the quality of water. While conductivity, TDS, and Ni (closer to -1) have loadings close to -1, indicating that this variable has a weak influence on the factors of the quality of water in Mat-i surface water during the dry season. However, for the wet season, temperature, pH, resistivity, and copper strongly influence the quality of water, and DO, Cd, Salinity, and lead have a weak influence on the water quality of the surface water (Shammas & Jacks, 2007; Sreekanth & Datta, 2010).

Factors 1 and 2 show a good strong relationship of pH, salinity, conductivity, TDS, TSS, DO, and heavy metals concentration of Hg, Cd, Ni, Pb, and Cu. This is indicative of mining waste incursion and agricultural runoff incursions in the study area. This agrees with the studies made by Aliyu et al. (2018) on River Lavun, Bida. Factor 2 reveals high positive physicochemical parameters for temperature and pH but with negative physicochemical parameters on TDS and salinity. This could be best considered as an anthropogenic source from domestic runoff and mining waste. Similar results were observed by Nwineewii et al. (2018). The concentration of TDS, TSS, pH, and salinity can be ascribed to the incursion of mining waste into the aquifer systems.

Furthermore, during the monsoon season, the first factor accounts for 32.30% and 68.90%, respectively, and the second factor accounts for 23.90% and 60.10%, respectively. The negative parameters could be caused by mining and natural processes such as weathering and precipitation. This was like the lead concentration reported by Dike et al. (2004) in River Jakara, Kano State. The factor analyses performed in this study have clearly indicated that mining waste incursion into the coastal aquifer is the primary source of groundwater pollution; similar observations were made by Brindha & Elango (2011), Einsiedl (2012), and Venkatramanan et al. (2012).

Aside from mining activity in Barangay Mat-i, this rural area has farming and livestock poultry sources of livelihood. According to the study of Kar and Patra, (2021), the hazardous effects of heavy metals on poultry include loss of weight, organ failure, and even death. Metal toxicity is determined by the route of exposure, length of exposure, and absorbed dosage, whether chronic or acute, due to mining activities. Though, according to the study of Mapatac (2015), medicinal herbal plants which have antibacterial, antimicrobial, and the presence of phytocompounds could serve as scavengers and additives for the presence of heavy metals such as cadmium, elemental mercury, and lead for the growth performance of broiler chicks.

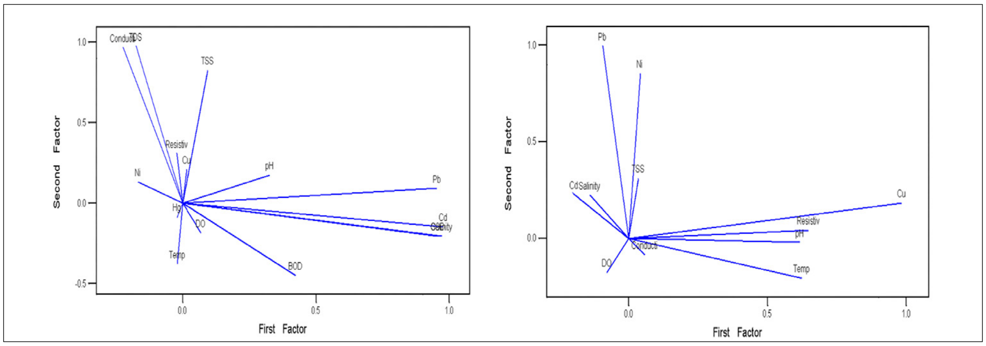

Figure 5. *Loading Plot of the Surface water with parameters during dry season and wet season*

CONCLUSION

The problem of surface water in the Surigao City district coastal region is rather complicated and is derived from excessive exploitation of the aquifer systems. The study area depends totally on the water derived from the aquifer for its irrigation, agriculture, and domestic use. Nineteen stations for surface water samples were collected near the coastal village of Mat-i, Surigao City district, during monsoon and summer seasons, and physicochemical characteristics of the samples were studied to determine the quality and the suitability of the surface water for various purposes as well as the characteristics of surface water quality. The maximum concentrations were observed near the coastal area because of mining activities in the surface water incursion. In addition, irrigation return flow also plays a major role in controlling groundwater quality in the area. The values set by DAO no. 34 and Standard Acceptable Value (EO no. 192) show the significance levels contributing to the selection of proper treatments to minimize the contamination of the groundwater in the study area. The multivariate factor analysis reveals that the groundwater from Mat-i, Surigao City area has been greatly influenced by lithologic, environmental, and mining events in the area. A continuous monitoring program of the water quality will help avoid further deterioration of the groundwater quality in this coastal region.

In place of the findings, as a non-partisan among the three groups who had a conflict with the presence of "Minahang Bayan" and the small-scale gold mining activities, I turned over the result to the Mines and Geosciences Bureau (MGB). It showed a high concentration in different physicochemical parameters of salinity, TDS, TSS, DO, BOD, and COD and a high concentration of Hg, Pb, Cu, Ni, and Cd, which was presented during the conference. It is up to the government entity to resolve issues.

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