# Mining and Heavy Metal Pollution: Assessment of Aquatic Environments in Tarkwa (Ghana) using Multivariate Statistical Analysis





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# Mining and Heavy Metal Pollution: Assessment of Aquatic Environments in Tarkwa (Ghana) using Multivariate Statistical Analysis

**Armah Frederick Ato**
University of Cape Coast, Ghana

**Obiri Samuel**
Centre for Environmental Impact Analysis

**Yawson David Oscar**
University of Cape Coast,Ghana

**Pappoe Alex Nii Moi**
University of Cape Coast, Ghana

**Bismark Akoto**
University of Cape Coast, Ghana

**Abstract**

Application of multivariate statistics for the interpretation of surface and groundwater data from Tarkwa, a mining community in the Western region of Ghana, is presented in this study. Effluents from extractive industries established over the last half century within the study area are directly discharged onto surrounding land and surface water bodies constituting point and non-point sources of contamination for groundwater in the study area. In the Tarkwa mining area, large deposits of mine wastes, ore stockpiles and waste rocks have become a heap around the place. Twelve parameters including trace elements (Cu, Mn, Cd, Fe, Pb, As, Hg and Zn) and physico-chemical parameters (pH, conductivity, turbidity and total dissolved salts) were monitored on 49 sampling points including surface and groundwater. Data set was analysed using factor analysis (FA). FA identified four factors responsible for data structure explaining 69% of total variance in surface water and two factors in groundwater explaining 79%, and allowed the grouping of selected parameters according to common features. This study underscores the value of multivariate statistical analysis for evaluation and interpretation of the data with a view to stimulating better policy outcomes and decision-making that positively impacts water quality and thus prospectively diminishes the pollution caused by hazardous toxic elements in mining environments.

*Keywords*: Gold mining, water pollution, heavy metals, multivariate statistical analysis, Tarkwa, Ghana.

# 1. Introduction

Both anthropogenic pressures and natural processes account for degradation in surface water and groundwater quality (Carpenter et al 1998). In Ghana, contaminations of surface and ground water bodies have particularly been experienced in gold mining communities (Davies et al. 1994; Kuma 2007; Manu et al 2004; Kuma and Younger 2004; Obiri 2007). Gold mining has played a significant role in the socioeconomic life of Ghana for the past hundred years (Akabzaa et al. 2005). However, gold mining in recent times has become unpopular as it is regarded as a significant source of Hg, Pb and heavy metal contamination of the environment owing to activities such as mineral exploitation, ore transportation, smelting and refining, disposal of the tailings and waste waters around mines (Essuman et al 2007; Hanson et al 2007; Obiri 2007; Singh, Koku and Balfor 2007). In the Tarkwa mining area, large deposits of mine wastes, ore stockpiles and waste rocks have become a heap around the plants. Weathering of the heaped waste materials result in the release of toxic chemicals into the environment especially, into aquatic bodies. Such harmful metals released from mine tailings include mercury, arsenic, lead and cadmium among others. Heavy metal pollution within mining communities of Ghana has been extensively studied (Adimado and Amegbey 2003; Akabzaa et al. 2005; Carbo and Serfor - Armah 1997; Essumang et al 2007; Hilson 2002; Manu et al 2004; Obiri 2007; Yidana et al 2008). The application of multivariable statistical methods offers a better understanding of water quality for interpreting complicated data sets (Zhang et al 2009). However, wide-ranging applications of different multivariable statistical methods and sources apportionment have not been fully explored in surface and ground water studies in Ghana (Yidana et al 2008). Multivariate statistical techniques have become widely accepted in water quality assessment and sources apportionment of water bodies over the last ten years (Vega et al. 1998; Wunderlin et al. 2001; Grande et al. 2003; Simeonov et al. 2003; Pekey et al. 2004; Singh et al. 2004; Astel et al. 2006; Kowalkowski et al. 2006; Shrestha and Kazama 2007). Consequently in this study, data sets on surface and ground water obtained from June 2007 to June 2008 from the Tarkwa mining area in Western Ghana are analyzed with Factor Analysis after using a rank transform to eliminate non-Normality. The objective of the study is to reveal information about: (1) the natural and anthropogenic origin of contaminants in surface and ground water, (2) the possible non point sources of contamination, (3) the contributions of possible sources to concentrations of the determined parameters in the Tarkwa mining area.

# 2. Materials and methods

## 2.1. Study area

Tarkwa (6° 43' 0" N, 1° 37' 0" W) is a town in the southwest of Ghana, located about 190 km west of Accra. As of 2005, it was estimated to have a population of 40,397. It is a noted centre of gold and manganese mining. Tarkwa Mine which is a large open-caste gold mine is situated to the North West of the town and Nsuta manganese mine is situated to the East of the town. Located in a predominantly agricultural and mining region, it is a marketing centre for rice, cassava, bananas, rubber, sugar, corn (maize), cocoa, copra, palm kernels, and kola nuts. The cityÕs industries produce various building materials and consumer goods. Gold mining in the area dates back to the 10th century AD (Hilson 2006), and other minerals extracted include manganese, bauxite, diamonds, iron ore, asbestos, and chromite. Tarkwa Mine mines several low grade conglomeratic "reefs" of Tarkwaian type (Eisenlohr and Hirdes, 1992). These reefs are of mid-Proterozoic age. Tarkwa Mine has the distinction of being the largest gold mine in Ghana since 2007. Approximately 24 tons of gold is produced annually and 100 million tons of earth is moved to achieve this production rate. Figure 1 shows a map of the study area.

## 2.2. Sampling and preparation

Forty-nine water samples-surface water (43) and groundwater (6) were collected randomly from Tarkwa and surrounding communities. The sample points were assigned serial numbers (SN) as shown in Table 1. Cond. refers to conductivity while TDS refers to total dissolved solids. Water samples were primarily collected from open streams and rivers within the catchment of the Tarkwa mines. Groundwater samples were collected from six boreholes and dug wells which were in operation during the study. The bore holes are no deeper than 80 m, with the depth being dependent upon the type and location of aquifer struck during drilling. Figure 2 shows the spatial locations of selected sampling points.

| SN | pH | Cond. | Turbidity | TDS | Cu | Mn | Cd | Fe | Pb | As | Hg (ppb) | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6.50 | 73.7 | 8 | 40.5 | 1.246 | 0.490 | 0.113 | 7.45 | 2.220 | 1.569 | 0.212 | 0.432 |
| 2 | 6.58 | 58.8 | 30 | 323 | 0.657 | 0.052 | 0.019 | 3.34 | 0.288 | 6.879 | 0.376 | 0.105 |
| 3 | 5.56 | 542 | 34 | 40.5 | 0.020 | 0.140 | 0.001 | 5.90 | 0.600 | 0.436 | 1.342 | 0.110 |
| 4 | 7.03 | 542 | 23 | 298 | 4.358 | 0.027 | 0.200 | 4.08 | 0.030 | 0.935 | 0.020 | 0.005 |
| 5 | 6.87 | 105 | 14 | 57.8 | 1.023 | 0.279 | 0.028 | 4.78 | 5.88 | 2.856 | 0.353 | 0.186 |
| 6 | 7.08 | 33.1 | 97 | 34.2 | 0.020 | 0.600 | 0.007 | 1.95 | 0.345 | 12.5 | 0.330 | 0.005 |
| 7 | 5.74 | 98.0 | 6.0 | 53.9 | 0.985 | 0.063 | 0.010 | 4.50 | 0.416 | 6.451 | 0.045 | 0.134 |
| 8 | 6.62 | 62.1 | 29 | 34.2 | 1.365 | 0.569 | 0.002 | 1.56 | 0.001 | 2.106 | 0.405 | 0.239 |
| 9 | 6.58 | 100 | 34 | 567 | 0.020 | 0.070 | 0.125 | 2.65 | 0.129 | 25.9 | 0.019 | 0.005 |
| 10 | 6.80 | 51.9 | 36 | 29.5 | 0.162 | 0.323 | 0.018 | 34.36 | 0.001 | 1.041 | 0.452 | 0.118 |
| 11 | 5.75 | 33.1 | 11 | 18.2 | 1.026 | 0.084 | 0.012 | 1.346 | 0.069 | 3.464 | 0.305 | 0.154 |
| 12 | 6.62 | 62.1 | 29 | 34.2 | 0.020 | 0.283 | 0.045 | 4.75 | 0.105 | 0.605 | 0.054 | 0.034 |
| 13 | 7.08 | 318 | 10 | 29.5 | 0.020 | 0.943 | 0.064 | 49.2 | 0.786 | 0.832 | 1.731 | 0.107 |
| 14 | 4.63 | 124 | 31 | 124 | 0.469 | 0.063 | 0.006 | 1.80 | 0.512 | 1.563 | 0.693 | 0.300 |
| 15 | 6.90 | 105 | 20 | 57.8 | 1.984 | 0.276 | 0.002 | 4.82 | 1.250 | 1.235 | 1.371 | 0.188 |
| 16 | 6.58 | 100 | 24 | 55.0 | 0.020 | 0.425 | 0.012 | 9.02 | 0.775 | 3.412 | 0.285 | 0.494 |
| 17 | 6.93 | 68.9 | 12 | 6.6 | 0.220 | 0.356 | 0.013 | 24.60 | 0.008 | 1.345 | 0.287 | 0.140 |
| 18 | 5.56 | 32.5 | 18 | 17.9 | 0.987 | 0.175 | 0.018 | 8.09 | 0.011 | 3.332 | 1.523 | 0.389 |
| 19 | 7.08 | 318 | 10 | 175 | 2.451 | 0.031 | 0.002 | 14.3 | 0.226 | 2.698 | 0.381 | 0.083 |
| 20 | 6.52 | 52.1 | 35 | 287 | 0.548 | 0.032 | 0.003 | 2.67 | 3.055 | 2.125 | 0.328 | 0.135 |
| 21 | 6.62 | 51.9 | 35 | 226 | 0.020 | 0.043 | 0.982 | 9.935 | 0.040 | 9.15 | 0.254 | 0.045 |
| 22 | 6.50 | 34.3 | 97 | 105 | 0.020 | 0.046 | 0.692 | 3.08 | 0.043 | 3.02 | 0.381 | 3.345 |
| 23 | 7.03 | 542 | 23 | 298 | 2.051 | 0.126 | 0.006 | 13.6 | 0.009 | 1.523 | 0.303 | 0.354 |
| 24 | 6.33 | 34.3 | 41 | 18.9 | 1.015 | 0.109 | 0.003 | 4.70 | 1.110 | 5.298 | 0.026 | 0.785 |
| 25 | 7.07 | 411 | 13 | 226 | 1.765 | 0.425 | 0.002 | 8.98 | 2.581 | 3.697 | 0.425 | 0.102 |
| 26 | 7.07 | 411 | 13 | 226 | 0.220 | 0.958 | 0.014 | 2.04 | 0.035 | 9.22 | 0.020 | 0.260 |
| 27 | 5.56 | 32.5 | 18 | 17.9 | 1.652 | 0.002 | 0.002 | 5.03 | 0.005 | 4.126 | 0.146 | 0.157 |
| 28 | 6.58 | 58.8 | 30 | 18.2 | 0.020 | 0.062 | 0.894 | 3.66 | 0.052 | 23.2 | 0.146 | 1.321 |
| 29 | 6.52 | 52.1 | 35 | 55.0 | 0.057 | 0.224 | 0.061 | 8.672 | 0.188 | 19.2 | 0.045 | 0.029 |
| 30 | 4.80 | 51.9 | 36 | 29.5 | 0.995 | 0.268 | 0.860 | 1.46 | 0.120 | 2.65 | 0.082 | 0.333 |
| 31 | 7.20 | 124 | 31 | 124 | 0.605 | 1.513 | 0.007 | 8.43 | 0.669 | 2.451 | 0.402 | 0.448 |
| 32 | 5.75 | 33.1 | 11 | 18.2 | 1.025 | 0.028 | 1.130 | 2.84 | 0.445 | 2.18 | 0.025 | 0.008 |
| 33 | 6.33 | 73.7 | 97 | 676 | 0.020 | 0.345 | 0.067 | 4.30 | 0.051 | 2.634 | 0.367 | 0.005 |
| 34 | 5.74 | 98.0 | 6.0 | 53.9 | 0.002 | 1.057 | 0.002 | 5.32 | 0.250 | 1.754 | 0.618 | 0.040 |
| 35 | 6.33 | 34.3 | 41 | 18.9 | 2.031 | 0.086 | 0.007 | 12.7 | 2.603 | 2.896 | 1.723 | 0.123 |
| 36 | 6.87 | 105 | 14 | 57.8 | 0.020 | 0.318 | 0.005 | 23.5 | 0.978 | 1.07 | 0.020 | 1.453 |
| 37 | 6.93 | 68.9 | 12 | 6.6 | 3.256 | 0.112 | 1.170 | 8.591 | 0.285 | 1.95 | 0.020 | 0.005 |
| 38 | 5.91 | 191 | 97 | 105 | 0.002 | 0.157 | 0.157 | 10.2 | 0.026 | 2.956 | 0.312 | 0.051 |
| 39 | 6.27 | 31.2 | 34 | 17.2 | 0.789 | 0.041 | 0.010 | 1.67 | 1.124 | 1.236 | 0.367 | 0.321 |
| 40 | 6.27 | 31.2 | 34 | 17.2 | 0.857 | 0.125 | 0.017 | 8.39 | 0.045 | 1.689 | 0.415 | 0.124 |
| 41 | 4.58 | 100 | 24 | 55.0 | 4.563 | 2.98 | 0.560 | 14.5 | 0.003 | 4.30 | 0.020 | 0.014 |
| 42 | 6.98 | 191 | 4 | 175 | 0.020 | 0.040 | 0.006 | 2.18 | 0.092 | 2.44 | 0.020 | 0.078 |
| 43 | 7.37 | 105 | 20 | 629 | 1.365 | 0.235 | 0.002 | 5.43 | 0.530 | 1.572 | 0.054 | 0.110 |

Table 1: Analytical data of surface water in Tarkwa area ($\mu$g/l)

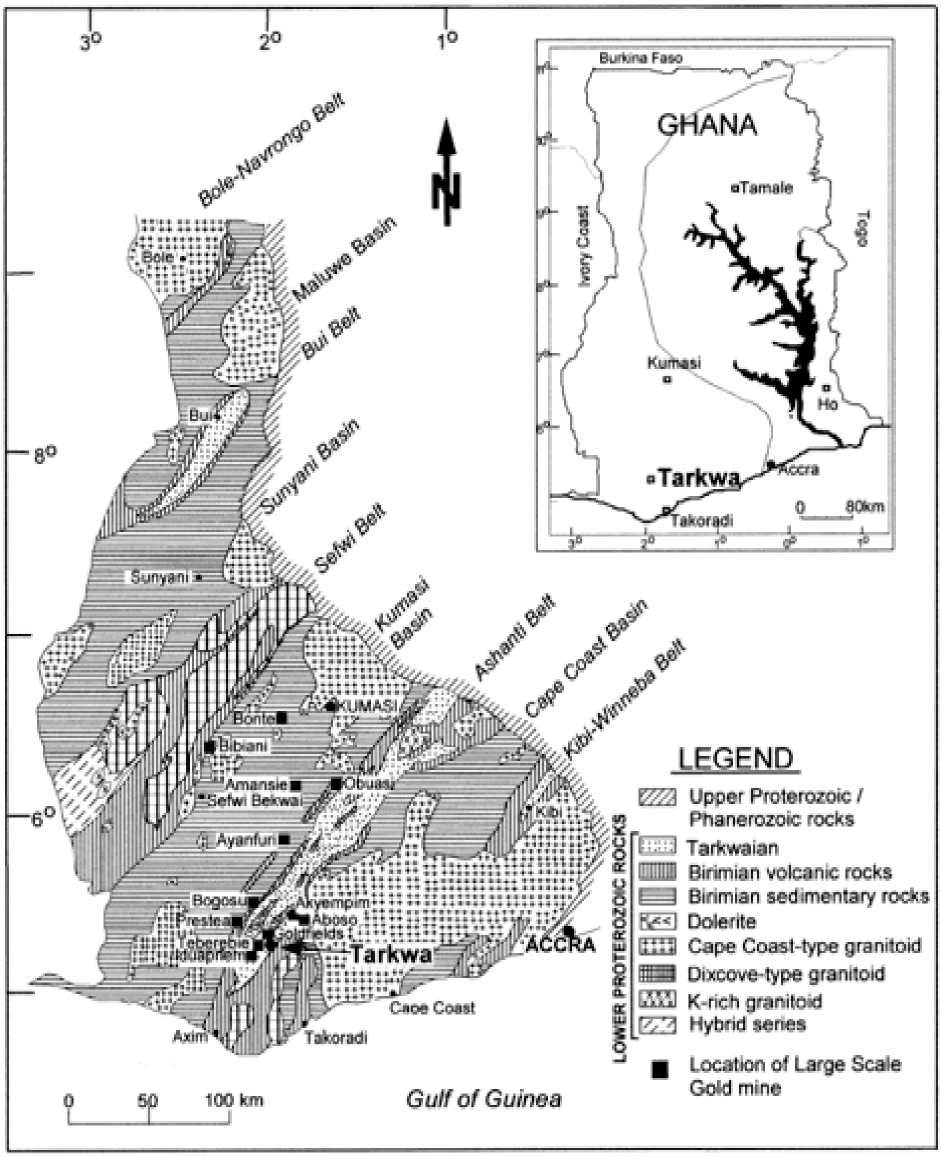


Figure 1: : simplified geological map of southwest Ghana showing the location of study area. Inset is a map of Ghana showing the location of Tarkwa (Source: Eisenlohr and Hirdes, 1992). The climate of the area is characterized by seasonal weather patterns. This involves a double wet season in April to June and October to November and a main dry season between December and February. Daily temperatures are 28 to 30ąC during the wet season and 31 to 33ąC during the dry season. Relative humidity ranges from 70 to 90%. The average rainfall value between 1994 and 2002 is 1576 mm or approximately 62 inches (Obiri, 2007).

| SN | pH | Cond. | Turbidity | TDS | Cu | Mn | Cd | Fe | Pb | As | Hg (ppb) | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7.37 | 105 | 20 | 629 | 0.389 | 0.620 | 0.011 | 13.8 | 0.067 | 0.426 | 0.210 | 0.154 |
| 2 | 7.07 | 68.9 | 30 | 57.8 | 0.020 | 0.107 | 0.028 | 4.24 | 0.070 | 0.137 | 0.020 | 0.025 |
| 3 | 5.91 | 191 | 19 | 105 | 0.048 | 0.032 | 0.005 | 13.2 | 0.105 | 1.89 | 0.020 | 0.012 |
| 4 | 6.90 | 105 | 20 | 57.87 | 0.330 | 1.057 | 0.018 | 2.34 | 0.001 | 0.752 | 0.305 | 0.389 |
| 5 | 6.20 | 105 | 34 | 654 | 0.020 | 0.129 | 0.045 | 1.89 | 0.031 | 4.343 | 3.675 | 0.897 |
| 6 | 6.50 | 73.7 | 10 | 40.5 | 0.020 | 0.127 | 0.025 | 12.4 | 0.267 | 0.259 | 0.020 | 0.457 |

Table 2: Analytical data of ground water in Tarkwa area ($\mu$g/l)

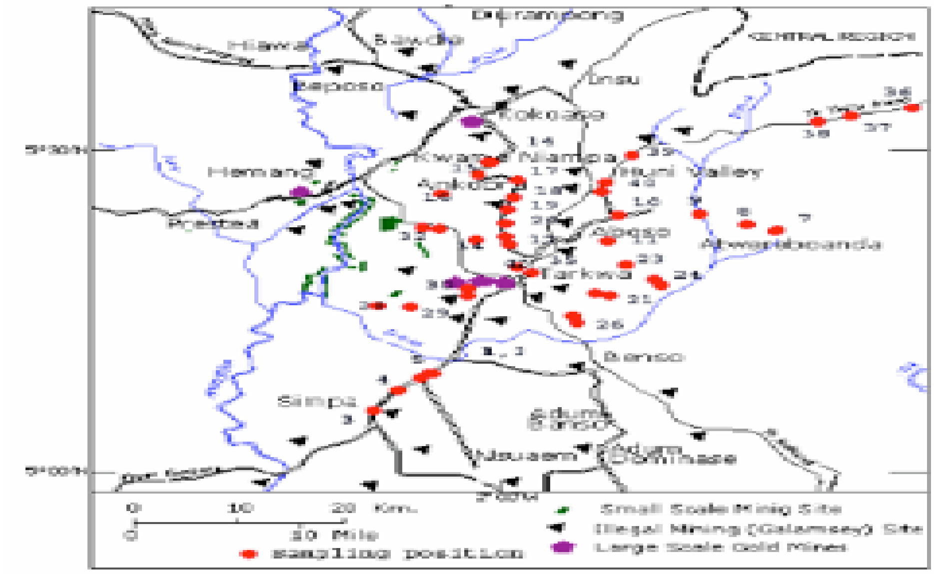


Figure 2: Spatial locations of sampling points for surface and ground water in the study area

| Parameter | GEPA | WHO |
|---|---|---|
| Manganese (mg/l) | - | 0.4 |
| Lead (mg/l) | 0.1 | 0.01 |
| Copper (mg/l) | - | 2.0 |
| Arsenic (mg/l) | 1.0 | 0.01 |
| Zinc (mg/l) | 10 | 3.0 |
| Mercury (ppb) | 0.2 | 0.01 |
| Iron (mg/l) | - | 0.3 |
| Cadmium (mg/l) | - | 0.003 |
| pH | 6.5-8.5 | 6.5-8.5 |
| Turbidity (NTU) | 5 | 5 |
| Electrical Conductivity ($\mu$S/cm) | - | - |
| Colour | 15 | 15 |
| Total dissolved solids (mg/l) | 1000 | 1000 |

Table 3: Ghana EPA and WHO Permissible background heavy metals concentrations, pH, Turbidity, electrical conductivity and total dissolved solids in aquatic environments

## 3. Data management and multivariate statistical techniques

Multivariate analysis of surface and groundwater data was subjected through Factor Analysis (FA) (Johnson and Wichern, 1998; Millard and Neerchal 2001; Yidana et al 2008). The data sets were first summarised (Table 4 and Table 5). From Table 4 and Table 5 it is observed that the values of the coefficients of variation of the variables (Cond., Turbidity, TDS and others) were much larger than 1/3 (33.33%), except the variable pH. This suggests that the data is positively skewed - very few of the measurement scores lie below the average measurement scores. A rank transform was used to eliminate non-Normality (Millard and Neerchal 2001; Yidana et al 2008). Standardization tends to increase the influence of variables whose variance is small and vice versa. All the mathematical and statistical computations were made using Statistical Package for Social Sciences version 16 (Gerber and Finn 2005).

| | pH | Cond. | Turbidity | TDS | Cu | Mn | Cd | Fe | Pb | As | Hg | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 6.410 | 133.640 | 29.698 | 126.932 | .9296 | .3391 | .171 | 8.381 | .650 | 4.453 | .388 | .299 |
| Median | 6.580 | 73.700 | 24.000 | 55.000 | .6570 | .157 | .013 | 5.030 | .226 | 2.634 | .305 | .124 |
| Std. Dev. | .688 | 147.181 | 24.221 | 165.488 | 1.119 | .523 | .338 | 9.285 | 1.118 | 5.692 | .460 | .568 |
| Range | 2.790 | 510.800 | 93.000 | 669.400 | 4.561 | 2.978 | 1.169 | 47.854 | 5.879 | 25.46 | 1.712 | 3.340 |
| Minimum | 4.580 | 31.200 | 4.000 | 6.600 | .002 | .002 | .001 | 1.346 | .001 | .436 | .019 | .005 |
| Maximum | 7.370 | 542.000 | 97.000 | 676.000 | 4.563 | 2.980 | 1.170 | 49.200 | 5.880 | 25.900 | 1.731 | 3.345 |
| Coeff.of Var. | 0.107 | 1.101 | 0.816 | 1.304 | 1.204 | 1.541 | 1.975 | 1.108 | 1.718 | 1.278 | 1.184 | 1.889 |

Table 4: Descriptive statistical data of surface water in Tarkwa area (n=43)

| | pH | Cond. | Turbidity | TDS | Cu | Mn | Cd | Fe | Pb | As | Hg | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 6.658 | 108.100 | 22.167 | 257.350 | .138 | .345 | .022 | 7.978 | .090 | 1.301 | .708 | .322 |
| Median | 6.70000 | 105.000 | 20.000 | 81.400 | .034 | .128 | .022 | 8.320 | .069 | .589 | .115 | .272 |
| Std. Dev. | .553 | 43.866 | 8.589 | 298.439 | .173 | .478 | .014 | 5.719 | .094 | 1.619 | 1.458 | .336 |
| Range | 1.460 | 122.100 | 24.000 | 613.500 | .369 | 1.025 | .040 | 11.91 | .266 | 4.206 | 3.655 | .885 |
| Minimum | 5.910 | 68.900 | 10.000 | 40.500 | .020 | .032 | .005 | 1.890 | .001 | .137 | .020 | .012 |
| Maximum | 7.370 | 191.000 | 34.000 | 654.000 | .389 | 1.057 | .045 | 13.80 | .267 | 4.343 | 3.675 | .897 |
| Coeff.of Var. | 0.083 | 0.406 | 0.388 | 1.159 | 1.256 | 1.181 | 0.643 | 0.717 | 1.039 | 1.244 | 2.059 | 1.044 |

Table 5: Descriptive statistical data of groundwater in Tarkwa area (n=6)

### 3.1. Factor analysis (FA)

Factor analysis is a multivariate analytical technique, which derives a subset of uncorrelated variables called factors that explain the variance observed in the original dataset (Anazawa and Ohmori, 2005; Brown, 1998; Yidana et al 2008). Factor analysis is used to unearth the latent structure of a set of variables. The factor analysis attempts to identify few factors that are responsible for the correlation among a large number of variables, it is also classified as a data reduction technique. The essential purpose of factor analysis is to describe, if possible, the covariance relationship among many variables in terms of a few underlying, but unobservable, random quantities called factors. The total variance of the indicator variables (the original variables) is decomposed into the following two components:

First, variance that is common with general chemical level in the surface water and groundwater is given by the square of the pattern loading (that is the correlation between any indicator and the factor); this part of the variance is referred to as the communality of the indicator with the common factor (Sharma, 1996).

Second, variance that is in common with a specific factor is the variance of the variable minus the communality. This part of the variance is referred to as the unique/specific/error variance because it is unique to that particular variable (Sharma, 1996).

The common factors are unobservable. However, we can measure their indicators and compute the correlation among the indicators with the aim to identify the smallest number of common factors (that is most parsimonious factor model) that best explain the correlation among the variables; estimate pattern loadings, communalities, and the unique variance of the indicators (Sharma, 1996).

The total number of factors generated from a typical factor analysis indicates the total number of possible sources of variation in the data. As we extract consecutive factors, they account for less and less variability. The decision of when to stop extracting factors basically depends on when there is only very little ”random” variability left. The nature of this decision is arbitrary; however, various guidelines such as the Kaiser criterion have been developed and are well documented in literature. Factors are ranked in order of merit. The first factor or component has the highest eigenvector sum and represents the most important source of variation in the data. The last factor is the least important process contributing to the chemical variation. Factor loadings (weightings) on the factor loadings tables are interpreted as correlation coefficients between the variables and the factors.

## 4. Results and Discussions

Most of the water bodies in the study area have elevated mean levels of arsenic, iron, mercury, zinc and lead which are above WHO and Ghana EPA guideline values (Table 3). High concentrations coupled with high coefficients of variation suggest anthropogenic sources for arsenic, iron, mercury, zinc and lead. Some of the water bodies sampled including the alternate source of water have low pH values. The turbidity values were higher than the WHO and Ghana Environmental Protection Agency (GEPA) permissible limits. Results for the analysis of heavy metals in surface and groundwater are presented in Table 1 and 1b, respectively. Even though Tarkwa has over 100 boreholes, the researchers could not take samples from more than six boreholes because at the time of sampling most of these boreholes were sealed off. SN 1 is close to mine tailings dam and shows relatively higher values for all the heavy metals except As and Hg when compared to SN 2 which is farther from the mine tailings dam. SN 5 is very close to an active mine site and shows relatively high concentrations for Cu, Fe, Pb, As, Hg and Zn unlike SN 6 which is farther from the active mine site. In fact, SN 6 recorded very low concentrations for Cd, Pb, As and Hg. Maximum levels for Cu and Mn were recorded at SN 30, located within an active mine zone. Maximum levels for Cd and Fe were recorded at SN 27 and SN 35 respectively. Both locations are within an active mine zone. The highest value for Pb were recorded very close to an abandoned mine pit. Although the pit is derelict, the levels of Pb were appreciable. Maximum levels for As and Zn were recorded at SN 42 and SN 38 respectively. Both locations are also within an active mine zone. The maximum value for Hg was recorded at SN 23 which is close to tailings dam downstream. In this case, it is significant to note that the Hg levels upstream were appreciably lower than levels downstream. Descriptive statistics for surface and ground water are given in Table 4 and Table 5, respectively. Statistical analysis for the data set shows their groupings in four factors for surface water (Table 6) and two factors for ground water (Table 7). The pH of surface water varies from 4.6 to 7.4 with an average of 6.4 while in ground water; pH varies from 5.9 to 7.4 with an average of 6.7. The pH values for both surface and groundwater were predominantly acidic. Samples 1 and 2 of groundwater show alkalinity (7.4 and 7.1 respectively). Nine surface water samples show alkalinity with pH ranging from 7.03 - 7.37.

| Element | Communality | Eigen | Total variance | Cumulative total variance | Factor 1 | Factor 2 | Factor 3 | Factor 4 |
|---|---|---|---|---|---|---|---|---|
| Cu | .812 | 1.867 | 23.332 | 23.332 | .184 | .796 | -.295 | .240 |
| Mn | .610 | 1.434 | 17.929 | 41.261 | .278 | .619 | .336 | -.189 |
| Cd | .695 | 1.181 | 14.763 | 56.024 | -.552 | .394 | .239 | .421 |
| Fe | .750 | 1.035 | 12.937 | 68.961 | .572 | .009 | .649 | -.033 |
| Pb | .606 | .801 | | | .379 | -.213 | -.553 | .333 |
| As | .624 | .708 | | | -.627 | -.150 | .096 | -.446 |
| Hg(ppb) | .621 | .552 | | | .687 | -.322 | .181 | .114 |
| Zn | .800 | .422 | | | -.338 | -.301 | .394 | .663 |

Table 6: Factor analysis of surface water in Tarkwa

| Element | Communality | Eigen | Total variance | Cumulative total variance | Factor 1 | Factor 2 |
|---|---|---|---|---|---|---|
| Cu | .864 | 3.971 | 49.643 | 49.643 | -.422 | .828 |
| Mn | .893 | 2.386 | 29.824 | 79.467 | -.233 | .916 |
| Cd | .806 | .757 | | | .891 | -.110 |
| Fe | .681 | .737 | | | -.695 | -.444 |
| Pb | .734 | .148 | | | -.305 | -.800 |
| As | .725 | 4.622E-16 | | | .851 | -.031 |
| Hg (ppb) | .921 | 5.021E-17 | | | .957 | .073 |
| Zn | .734 | -1.240E-16 | | | .853 | .077 |

Table 7: Factor analysis of surface water in Tarkwa

## 4.1. Factor analysis

By factor analysis complex linear correlation between heavy metal concentration in surface and groundwater was determined, which enabled interpretation of correlation of elements in the study area. Comparisons were made within each of ground water and surface water. Elements belonging to a given factor were defined by factor matrix after varimax rotation, with those having strong correlations grouped into factors. The identification of factors is based on dominant influence. The distribution manner of individual association of element in surface and groundwater was determined by principal component method (results are shown in Table 6 and Table 7). Based on eigen values and varimax rotation four factors explained most of the variability (total variance explained was about 69% for the surface water data and 79% variance for the groundwater data).

## 4.2. Surface water

### *Factor 1*

Factor 1 exhibits 23% of the total variance of 69% with positive loading on all elements except Cd, As and Zn. This factor indicates strong association for Fe (r=0.57) and Hg (r=0.68) in surface water. Sample numbers 36, 17, 10 and 13 show Fe concentration above the average whereas Hg concentration in sample numbers 3, 15, 18, 35 and 13 are comparatively higher (above 1.3). There is strong negative loadings on Cd (r=-0.55) and As (r=-0.63) indicating an inverse relation with the metals. Based on factor analysis on surface water factor model 1 is interpreted to represent the influence of mining activity on the levels of these heavy metals in the study area. This is because Hg has the highest correlation value (0.687). Within the study area, illegal Artisanal Small Scale Miners (also referred to as galamseyers) use mercury extensively in their activities. The mercury is a steady source of contamination of the surface water in the Tarkwa area (Tschakert, 2009). The use of mercury in gold mining by the Artisanal Small Scale Miners constitutes a point source of contamination.

### *Factor 2*

Factor 2 exhibits 18.0% of the total variance with positive loading on Cu, Mn, Cd and Fe. Fe concentration varies from 1.3 to 49.2 mg/l with an average of 8.4 ppm, and Cu varies from 0.002 to 4.6 mg/l (average = 0.93 mg/l). Sample numbers 4 and 41 show comparatively higher Cu concentration (above 4.3 mg/l).

### *Factor 3*

This factor exhibits 14.8% of the total variance with strong positive loading on Fe and strong negative loading on Pb. The negative loading on Pb indicates an inverse relation with Fe in the surface water. Pb shows an average concentration of 0.65 mg/l.

### *Factor 4*

Factor 4 exhibits 13.0% of the total variance and has strong positive loading on Zn. Zn varies from 0.05 to 3.5 mg/l with an average of 0.3 mg/l.

## 4.3. Groundwater

Groundwater contamination can originate above or below the surface of the earth. Infiltration of polluted surface water causes contamination below the surface of the earth. When compared to water in streams and rivers, the movement of groundwater is very slow and hence once the contaminant reaches the groundwater; there is little scope for dilution and dispersion. The substances that can contaminate groundwater can be basically classified as natural and artificial.

### *Factor 1*

Factor 1 shows 49.6% of total variance with high positive loading on Cd, As, Hg, and Zn ($r = 0.85 - 0.96$). Hg concentration ranges from 0.20 - 3.7 mg/l with an average of 3.7 mg/l while that of As ranges from 0.14 - 4.3 mg/l (average = 4.2 mg/l). Factor 1 shows strong negative loading on Fe. Based on Factor analysis on ground water Factor model 1 is interpreted to represent Cadmium contaminated ground water. This is because Cd has a high correlation value (0.891) even though mercury appeared in the model to have the highest correlation value; its levels in both surface and ground water were of the order of parts per billion (Table 7). This source of contamination is largely anthropogenic. Effluents from extractive industries established over the last half century within the study area are directly discharged onto surrounding land and surface water bodies (Obiri 2007). The discharge of effluents into surface and groundwater constitute non-point sources of contamination. Cadmium is usually present in all soils and rocks. It occurs naturally in zinc, lead, and copper ores, in coal, and other fossil fuels and shales (Weiner, 2000). These deposits can serve as sources to ground waters and surface waters, especially when they are in contact with soft, acidic waters (Weiner, 2000). The ground water within the study was predominantly acidic. The adsorption of cadmium onto soils and silicon or aluminum oxides is strongly pH-dependent; increasing as conditions becomes more alkaline. When the pH is below 6-7, cadmium is desorbed from these materials. Soluble cadmium compounds have the potential to leach through soils to groundwater. Additionally, based on factor analysis on ground water factor model 2 is interpreted to represent geogenic (natural) influence on Mn. This is expected given that the aquifer host rock within the study area is of the Tarkwaian and Birimian systems which are naturally rich in Mn ores (Yidana et al 2008).

### *Factor 2*

Factor 2 shows 29.8% of the total variance with positive loading on Cu, Mn, Hg and Zn and negative loading on Pb (r=-0.8), Cd, Fe and As. The positive loading on Cu and Mn were relatively strong.

## 5. Conclusion

The above analysis demonstrates the use of multivariate statistical techniques to study the source/genesis of chemical parameters in surface water and ground water systems. Twelve parameters including trace elements (Cu, Mn, Cd, Fe, Pb, As, Hg and Zn) and physico-chemical parameters (pH, conductivity, turbidity and total dissolved salts) have been monitored on 49 sampling points from a survey conducted in surface and groundwater within the Tarkwa mining area in Ghana. Data set was analysed using factor analysis (FA). FA identified four factors responsible for data structure explaining 69% of total variance in surface water and two factors in groundwater explaining 79%, and allowed to group selected parameters according to common features.

Based on Factor analysis on surface water, Factor model 1 is interpreted to be mercury contaminated water. This is because Hg has the highest correlation value (0.687). Within the study area, illegal Artisanal Small Scale Miners (also referred to as galamseyers) use mercury extensively in their activities. The mercury is a steady source of contamination of the surface water in the Tarkwa area. The use of mercury in gold mining by the Artisanal Small Scale Miners constitutes a point source of contamination. Based on Factor analysis on ground water, Factor model 1 is interpreted to be Cadmium contaminated ground water. This is because Cd has a high correlation value (0.891) even though mercury appeared in the model to have the highest correlation value; its levels in both surface and ground water were of the order of parts per billion. This source of contamination is largely anthropogenic.

Effluents from extractive industries established over the last half century within the study area are directly discharged onto surrounding land and surface water bodies. The discharge of effluents into surface and groundwater constitute non-point sources of contamination. Broadly, most of the water bodies in the study area have mean levels of arsenic, iron, mercury, zinc and lead which are above WHO and GEPA guideline values. High concentrations associated with high coefficients of variation therefore suggest anthropogenic sources for arsenic, iron, mercury, zinc and lead. This situation makes it imperative to establish an environmental monitoring scheme to check the concentration levels of heavy metals within the Tarkwa mining area of Ghana.

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**Affiliation:**

Armah Frederick Ato
Department of Environmental Sciences-School of Biological Science
University of Cape Coast, Ghana
E-mail: atoarmah@yahoo.com

Obiri Samuel
Centre for Environmental Impact Analysis
P. O. Box AD 738
Cape Coast, Ghana
E-mail: obirisamuel@gmail.com

Yawson David Oscar
Department of Soil Science, School of Agriculture, University of Cape Coast, Ghana
E-mail: oskidoo@yahoo.com

Pappoe Alex Nii Moi
Department of Environmental Sciences-School of Biological Science
University of Cape Coast, Ghana
E-mail: anmpappoe@yahoo.com

Bismark Akoto
Department of Mathematics and Statistics-School of Physical Science
University of Cape Coast, Ghana
E-mail: bismarkakoto@gmail.com

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