INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCES Volume 2, No 2, 2011

**Research article** **ISSN 0976 – 4402**

# Assessment of Ground Water Quality Status for the Tarkwa Mining Municipality in Ghana

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## ABSTRACT

The present study assessed the water quality index (WQI) based on physicochemical analysis of twenty-six ground water sampling stations in the Tarkwa mining municipality in Ghana. In calculating the WQI, seven parameters were considered; pH, nitrate, sulphate, total dissolved solids, chemical oxygen demand, sulphates and turbidity. WQI values range from 100.36 (sampling station B10) to 4294 (sampling station B6). The mean WQI is 825.89 (i.e. 8 times more than the upper limit for potability). All of the groundwater samples exceeded 100, the upper limit for drinking water potability. The high value of WQI at these stations could be attributed to the higher values of total dissolved solids, and turbidity in the groundwater. Approximately 35% of the samples had WQI values which were up to 5 times or more than the threshold value of 100. Fifteen percent of groundwater samples had WQI values more than ten times the threshold for potability. Pearson correlation coefficients among selected water properties showed a number of strong associations. Turbidity correlated strongly with sulphates. Similarly pH showed strong associations with EC, TDS and sulphates. Multivariate statistical (principal component and cluster) analysis suggest that the data is a three-component system that explains 72% of the total variance. The analysis reveals that the groundwater of this mining area needs some treatment before consumption, and it also needs to be mitigated against the risk of contamination.

**Keywords:** water quality index, mining, multivariate statistics, groundwater, contamination

## 1. Introduction

For many millions of rural residents, predominantly in sub-Saharan Africa, who currently lack any form of enhanced drinking water supply, untreated groundwater supplies from protected wells with hand pumps are likely to be their dominant answer in the near future. The word groundwater, in the context of this paper, is understood to connote all the water underground, occupying the voids within geological formations. Two foremost characteristics of groundwater bodies differentiate them from surface water bodies. To begin with, the comparatively slow movement of water through the ground means that residence times in ground waters are in the main orders of magnitude longer than in surface waters (UNESCO/WHO/UNEP 1992). Once polluted, a groundwater body could remain so for tens, or even for hundreds of years, for the reason that the natural processes of through-flushing are so slow. Secondly, there is a substantial degree of physico-chemical and chemical interdependence between the water and the containing material (UNESCO/WHO/UNEP 1992). It follows, thus, that in dealing with groundwater, the properties of both the ground and the water are important, and there is considerable scope for water quality to be modified by interaction between the two (UNESCO/WHO/UNEP 1992). Groundwater quality is the aggregate of natural and anthropogenic influences. The overall goal of a groundwater quality assessment programme is to obtain a comprehensive representation of the spatial distribution

*Received on September 2011 Published on November 2011*

of groundwater quality and of the changes in time that arise, either naturally, or under the demands of man (Wilkinson and Edworthy, 1981; Tiwari and Nayak, 2002). This is imperative to sustain it for future generations. According to Lumb et al. (2010), the concept of indexing water with a numerical value to communicate its quality, based on physical, chemical and biological dimensions, was developed in 1965 by US based National Sanitation Foundation (NSF). The water quality assessment process has now evolved into a set of sophisticated monitoring activities including the use of water chemistry, particulate material and aquatic biota (e.g. Hirsch et al., 1991). The operations involved in water quality assessment are several and complex (Lumb et al. 2011). Since groundwater often occurs in association with geological materials containing soluble minerals, higher concentrations of dissolved salts are normally expected in groundwater relative to surface water (Tiwari and Nayak, 2002). The type and concentration of salts and trace metals depends on the geological environment and the source and movement of the water (UNESCO/WHO/UNEP 1992).

In several mining communities in Ghana, groundwater has become the drinking water source of choice due to extensive contamination of surface water by mining activities particularly small-scale illegal mining (Armah et al. 2011, Armah 2010). Mainstream mining companies in host communities have over the last few years vigorously pursued programmes that provide groundwater-based supply systems (hand-dug wells, boreholes, etc.) to the affected communities (Obiri et al., 2010). However, a number of these alternative groundwater sources have been capped for the reason that results obtained via water quality monitoring programmes point to unacceptable levels of contaminants in the groundwater. This situation suggests the need for a broad assessment of groundwater quality within mining communities particularly, the Tarkwa municipality where mining activities are longstanding. This broad assessment is specifically relevant to the Government of Ghana’s policy to ensure access to potable drinking in all rural communities and broadly fits into the health related targets under the millennium development goals.

### Objectives of the study

The study assesses the quality of drinking water from ground sources by calculating the water quality index (WQI) of twenty-six sampling points in a major mining municipality in Ghana. WQI may be defined as ‘a rating that reveals the composite influence of a number of water quality parameters on the overall water quality’ (Shankar and Sanjeev, 2008). WQI is recognised as one of the most effective ways of communicating information on water quality to both citizens and policy makers; two key stakeholders in the water sector (Khan 2011). Consequently, it can be argued that WQI is central to decision-making and planning on water quality at different spatio-temporal scales. A comprehensive overview of WQI is given in Lumb et al. (2011).The following specific objectives was formulated to guide the study:

1. To determine the levels of groundwater quality parameters in the Tarkwa mining area
2. To compare the determined levels with the World Health Organisation (WHO) drinking water standards
3. To explore the variability of the water quality parameters in groundwater using multivariate statistics
4. To calculate the WQI based on the data from 26 groundwater sampling locations

## 2. Materials and Method

### 2.1 Study Area

Tarkwa (5 ° 18’ N, 1 ° 59‘1” W), is the capital of the Tarkwa-Nsuaem municipality of the Western Region of Ghana (Fig.1)

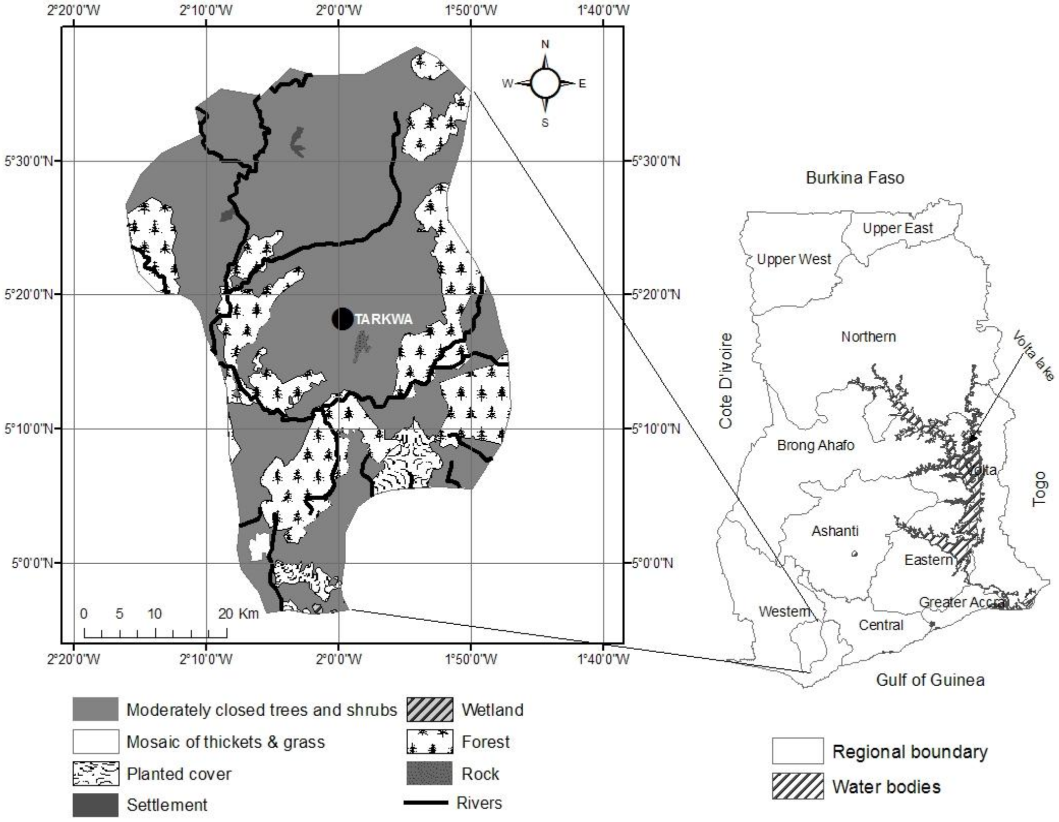

**Figure 1:** Map of Tarkwa and its environs

The area lies within an important gold belt of Ghana, which stretches from Konongo to the northeast through Tarkwa to Axim in the southwest, thus making mining the main industrial activity in the area (Kuma and Younger, 2004). The main occupation of the people is subsistence farming although rubber (latex), oil palm and cocoa are also produced. Two climatic regions border the Tarkwa-Nsuaem municipality: the southern portion falls in the south western equatorial climatic region and the northern part has a wet semi-equatorial climate (Dickson and Benneh, 2004). The rainfall pattern generally follows the northward advance and the southward retreat of the inter-tropical convergence zone that separates dry air from the Sahara and moisture-monsoon air from the Atlantic Ocean. The Tarkwa area experiences two distinct rainy periods (double rainfall maxima). The first and larger peak occurs in June, whilst the second and smaller peak occurs in October. The mean annual rainfall is over 1750mm with around 54% of rainfall in the region falling between March and July. The area is very humid and warm with temperatures between 26-30°C (Dickson and Benneh, 2004).

## 2.2 Data Collection and Laboratory Analysis

The samples investigated in this work were collected from groundwater (boreholes and wells) in the Tarkwa Nsuaem municipality of Ghana. Geo-satellite positioning of all the locations except three, were determined with a Garmin Etrex GPS. Twenty-six samples were collected.

Sampling protocol followed acceptable standards (APHA 1989, 2002). Sampling bottles were washed with detergent and rinsed with 10% hydrochloric acid and double-distilled water prior to sampling. At each of the sampling locations, the bottles were rinsed with the water to be collected to reduce or completely eliminate any contaminations that might be introduced. At each location the water was allowed to run for some time to purge the system before being sampled. The collected samples were immediately put into ice-chests containing ice cubes (around $4^{o}$C) and conveyed to the laboratory for analysis. This procedure averts microbial growth, flocculation and reduce any adsorption on container surfaces, processes which could affect the results. Internationally accepted and standard laboratory procedures were followed in the analysis of the samples. At each sampling location, physicochemical water quality parameters (pH, conductivity, temperature, salinity and turbidity) were measured *in situ* using the appropriate instruments. Two 500ml of water samples were collected at each location into clearly labelled plastic bottles. The samples were sent to 2 independent laboratories: the Water Research Institute Laboratory and the Ecological Laboratory of the University of Ghana, both in Accra, for laboratory analysis. Each laboratory had a complete set of samples to analyse. This was done to ensure quality control and reproducibility of the results. The samples were analysed for nutrients (nitrates and sulphates) and other water quality parameters including pH, electrical conductivity, dissolved solids, turbidity, and COD. The laboratory analysis followed standard methods of analysis prescribed for the various elements and parameters.

## 2.3 Data Analysis

Descriptive statistics of groundwater quality parameters were performed using MS-Excel, and SPSS version 16. Elements of descriptive statistics of samples (distribution, dispersion, central tendency) generated included mean, range, minimum, maximum, skewness, kurtosis, variance, median, mode, standard deviation and percentiles. Descriptive statistics for the water quality parameters for the different sampling locations is shown in Table 3.

## 2.4 Calculation of WQI

The 26 groundwater samples were analysed for seven parameters namely pH, electrical conductivity, total dissolved solids, turbidity, nitrates, sulphates and chemical oxygen demand. Results of the water samples are shown in Table 1 and the WHO drinking water guideline values and corresponding unit weights assigned are shown in Table 2. The weighted arithmetic water quality index was calculated as follows:

The more unsafe a given groundwater pollutant, the lower its drinking water standard, and the unit weight $W_I$ for the *i*th parameter $P_I$ is assumed to be inversely proportional to its recommended guideline standard $Si$ ($i$=1, 2, 3....n); where n is the number of parameters (7 in this study i.e. pH, electrical conductivity, dissolved solids, turbidity, nitrates, sulphates and COD).

Equation 1 shows the relationship between unit weights and the water quality standards

$wi = k/Si = 1/Si$..........................................................................................................(1)

Where $wi$ is the unit weight

k is the constant of proportionality which is equal to unity. The unit weights for the seven parameters are shown in Table 2

Except for pH, equation 2 shows the relationship between the water quality rating ($q_i$) for the $i$th parameter PI, averages of the observed data ($V_i$) and water quality standards ($S_i$).

$$q_i = 100(V_i/S_i) \qquad (2)$$

For pH, the quality rating $q$pH can be calculated from equation 3

$$q\text{pH} = 100[(V\text{pH} \sim 7.0)/1.5] \qquad (3)$$

Where $V$pH is the observed value of pH and the symbol "~" is essentially the algebraic difference between $V$pH and 7.0.

Ultimately, the water quality index is calculated by taking the weighted arithmetic mean of the quality ratings $q_i$ as shown in equation 4

$$\text{WQI} = [\sum (q_i.w_i)/\sum w_i] \qquad (4)$$

**Table 1:** Results of groundwater samples in the Tarkwa Nsuaem Municipality

| Sample ID | Location N | Location E | pH | Electrical Conductivity (µS/cm) |
|---|---|---|---|---|
| B1 | 605579 | 580294 | 7.35 | 683 |
| B2 | 605117 | 580751 | 6.3 | 317 |
| B3 | 604899 | 580923 | 7.31 | 281 |
| B4 | 604725 | 580994 | 6.7 | 523 |
| B6 | 603057 | 580092 | 6.84 | 149.1 |
| B7 | 603193 | 579777 | 6.54 | 369 |
| B8 | 603093 | 578930 | 5.36 | 47 |
| B9 | 603299 | 579000 | 6.07 | 178.5 |
| B10 | 603276 | 578945 | 5.78 | 86.5 |
| B11 | 603365 | 578589 | 6.74 | 464 |
| B12 | 603365 | 578359 | 6.54 | 251 |
| B13 | 603370 | 577970 | 6.61 | 403 |
| B14 | 603214 | 577934 | 6.03 | 183.7 |
| B15 | 605441 | 579451 | 6.4 | 300 |
| B16 | 608415 | 579957 | 6.11 | 141 |
| B17 | 608431 | 580071 | 5.18 | 35.5 |
| B18 | 605898 | 579687 | 6.6 | 459 |
| P1 | 603531 | 580031 | 6.25 | 337 |
| P2 | 603694 | 579730 | 6.58 | 213 |
| P3 | 604223 | 580974 | 5.96 | 158.5 |
| P5 | 605811 | 579119 | 6.38 | 140.4 |
| P6 | 606027 | 579241 | 4.48 | 261 |
| P7 | 605002 | 581360 | 5.8 | 74.6 |
| AB | | | 6.93 | 68.9 |

| | | | | |
|---|---|---|---|---|
| DU | | | 5.8 | 58.8 |
| T1 | | | 7.37 | 105 |

**Table 1** continued

| Dissolved Solids (mg/L) | Turbidity (NTU) | Nitrates (mg/L) | Sulphates (mg/L) | COD (mg/L) |
|---|---|---|---|---|
| 326 | 9.9 | 0.854 | 135 | 34 |
| 158.6 | 80 | 1.325 | 62 | 48 |
| 133.3 | 370 | 1.365 | 200 | 114 |
| 255 | 70 | 2.112 | 165 | 44 |
| 73.8 | 380 | 0.856 | 205 | 99 |
| 183.1 | 32 | 1.452 | 7 | 36 |
| 22.5 | 45 | 1.246 | 12 | 53 |
| 88.1 | 5.7 | 1.625 | 2 | 101 |
| 42.4 | 6 | 1.943 | 1 | 42 |
| 231 | 11 | 1.542 | 160 | 8 |
| 123.6 | 25 | 1.236 | 2 | 93 |
| 198.7 | 22 | 1.254 | 1 | 0 |
| 85.9 | 39 | 1.365 | 28 | 11 |
| 147.5 | 37 | 0.658 | 29 | 51 |
| 68.8 | 50 | 0.954 | 23 | 28 |
| 16.9 | 25 | 2.547 | 8 | 4 |
| 216 | 90 | 1.236 | 130 | 0 |
| 164 | 70 | 1.254 | 20 | 31 |
| 182.7 | 22 | 0.884 | 8 | 71 |
| 75.3 | 370 | 1.287 | 27 | 11 |
| 65.6 | 7.1 | 1.828 | 0 | 36 |
| 122.9 | 18 | 1.069 | 28 | 42 |
| 34.6 | 8.4 | 1.336 | 8 | 44 |
| 6.6 | 12 | 1.31 | 10 | 25 |
| 323 | 30 | 1.543 | 50 | 45 |
| 629 | 20 | 1.602 | 8 | 28 |

From Table 1, it is evident that 54% of groundwater samples did not comply with the WHO standards for pH; likewise 80% of the samples were not compliant with the recommended COD limit. Furthermore, none of the samples met the requirement for turbidity.

**Table 2:** Standards and unit weights for groundwater quality parameters

| Parameter | WHO guideline (Si) | Unit weight (*wi*) |
|---|---|---|
| Nitrate (mg/l) | 10 | 0.1 |
| Sulphate (mg/l) | 250 | 0.004 |
| pH | 6.5 – 8.5 | 0.004 |
| Turbidity (NTU) | 5 | 0.2 |
| Electrical Conductivity (µS/cm) | 1000 | 0.001 |

| | | |
|---|---|---|
| Chemical Oxygen Demand (mg/l) | 20 | 0.05 |
| Total dissolved solids (mg/l) | 1000 | 0.001 |

## 3. Results

### 3.1 Descriptive Statistics and Correlation Coefficients of Observed Parameters

**Table 3:** descriptive statistics of groundwater data

| | | pH | EC | TDS |
|---|---|---|---|---|
| N | | 26 | 26 | 26 |
| Mean | | 6.3081 | 2.42E+02 | 1.53E+02 |
| Median | | 6.39 | 1.98E+02 | 1.28E+02 |
| Mode | | 5.80[a] | 35.50[a] | 6.60[a] |
| Std. Deviation | | 0.66947 | 1.66E+02 | 1.31E+02 |
| Variance | | 0.448 | 2.77E+04 | 1.72E+04 |
| Skewness | | -0.712 | 0.892 | 2.034 |
| Kurtosis | | 1.061 | 0.407 | 6.005 |
| Range | | 2.89 | 647.5 | 622.4 |
| Minimum | | 4.48 | 35.5 | 6.6 |
| Maximum | | 7.37 | 683 | 629 |
| Percentiles | 25 | 5.92 | 1.00E+02 | 68 |
| | 50 | 6.39 | 1.98E+02 | 1.28E+02 |
| | 75 | 6.71 | 3.45E+02 | 2.03E+02 |
| a. Multiple modes exist. The smallest value is shown | | | | |

**Table 3 continued**

| Turbidity | Nitrates | Sulphates | COD |
|---|---|---|---|
| 26 | 26 | 26 | 26 |
| 71.35 | 1.3724 | 51.1154 | 42.2692 |
| 27.5 | 1.3175 | 21.5 | 39 |
| 22.00[a] | 1.24[a] | 8 | .00[a] |
| 1.14E+02 | 0.41415 | 67.23471 | 3.14E+01 |
| 1.29E+04 | 0.172 | 4520.506 | 983.885 |
| 2.36 | 0.899 | 1.359 | 0.827 |
| 4.266 | 1.551 | 0.352 | 0.18 |
| 374.3 | 1.89 | 205 | 114 |
| 5.7 | 0.66 | 0 | 0 |
| 380 | 2.55 | 205 | 114 |
| 11.75 | 1.1942 | 7.75 | 21.5 |
| 27.5 | 1.3175 | 21.5 | 39 |
| 70 | 1.5578 | 79 | 51.5 |

Correlation is basically the study of the association between two or more functionally independent variables. In water quality studies correlation analysis is used to measure the strength and statistical significance of the association between two or more random water quality variables. The strength of the association between two random variables can be determined through calculation of a correlation coefficient *r*. The value of this coefficient ranges from -1 to 1. A value close to -1 indicates a strong negative correlation, i.e. the value of *y* decreases as *x* increases. When *r* is close to 1 there is a strong positive correlation between *x* and *y,* both variables increase or decrease together. The closer the value of *r* is to zero the poorer the correlation. Principal component analysis and cluster analysis, coupled with correlation coefficient analysis, were used to identify possible sources of groundwater parameters. Pearson correlation coefficients among selected water properties showed a number of strong associations (Table 4). Inter-parameter relationships offer remarkable information on the sources and pathways of the species in groundwater. Good correlations (0.5 and above) are in bold face. Turbidity correlated strongly with sulphates. Similarly pH showed strong associations with EC, TDS and sulphates. Mean levels of Turbidity, pH and COD were above the World Health Organisation (WHO) permissible levels; clearly demonstrating anthropogenic impact.

**Table 4:** Correlation of groundwater data

| | pH | EC | TDS | Turbidity | Nitrates | Sulphates | COD |
|---|---|---|---|---|---|---|---|
| pH | 1 | .450* | .492* | .220 | -.212 | .461* | .166 |
| EC | | 1 | .375 | -.038 | -.225 | **.516**** | -.136 |
| TDS | | | 1 | -.145 | -.029 | .190 | -.127 |
| Turbidity | | | | 1 | -.198 | **.558**** | .344 |
| Nitrates | | | | | 1 | -.112 | -.226 |
| Sulphates | | | | | | 1 | .238 |
| COD | | | | | | | 1 |
| *. Correlation is significant at the 0.05 level (2-tailed). | | | | | | | |
| **. Correlation is significant at the 0.01 level (2-tailed). | | | | | | | |

## 3.2 Principal Component and Cluster Analyses

The term "principal component" is based on the concept that of the *n* descriptors, $x_1$, $x_2$, ... $x_n$ describing the attributes of each groundwater sample, e.g. water quality variables describing the characteristics of the water column, there exists a fundamental group of independent descriptors which determine the values of all *x* points. These fundamental descriptors are called "components", with the most important of these termed "principal components". The components must meet two conditions (although departures are tolerated if PCA is used for descriptive purposes only):

1. The descriptors are normally distributed, and
2. They are uncorrelated.

Principal Component Analysis reduces the multi-dimensionality of a complex data set to two or three dimensions by computing principal components or factors. This computation is achieved by transforming the observations from each sample (e.g. concentrations of parameters) into a "linear combination" of parameter concentrations. Principal Component Analysis produces several important outputs of which two namely eigenvalues: the variances accounted for by the component; and eigenvectors: that specify the directions of the PCA axes were considered in the analysis (Table 5). The scree plot (Figure 2) indicates that the data is a three-component system and this is confirmed by Table 5 as three components cumulatively explain 72% of the variance in the data.

**Table 5:** Total variance explained by the components

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 2.463 | 35.180 | 35.180 | 2.463 | 35.180 | 35.180 |
| 2 | 1.650 | 23.578 | 58.758 | 1.650 | 23.578 | 58.758 |
| 3 | .951 | 13.587 | 72.345 | .951 | 13.587 | 72.345 |
| 4 | .802 | 11.461 | 83.806 | .802 | 11.461 | 83.806 |
| 5 | .562 | 8.031 | 91.837 | .562 | 8.031 | 91.837 |
| 6 | .390 | 5.578 | 97.415 | .390 | 5.578 | 97.415 |
| 7 | .181 | 2.585 | 100.000 | .181 | 2.585 | 100.000 |
| Extraction Method: Principal Component Analysis. | | | | | | |

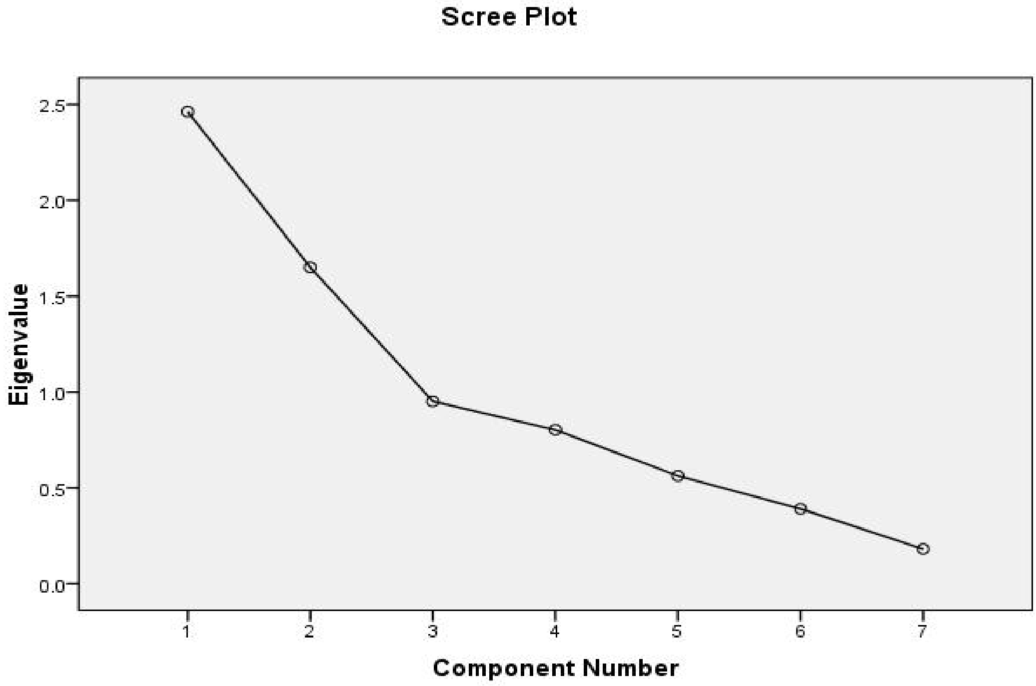

**Figure 2:** Scree plot of the components extracted from the data

**Table 6:** component matrix of groundwater quality parameters

| Component Matrix[a] | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Component | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| pH | .791 | -.195 | -.034 | .315 | -.110 | -.472 | -.032 |
| EC | .676 | -.460 | -.038 | -.401 | .347 | .007 | .221 |
| TDS | .479 | -.633 | -.034 | .432 | -.224 | .362 | .032 |
| Turbidity | .488 | .681 | .288 | -.118 | -.394 | .051 | .206 |
| Nitrates | -.402 | -.222 | .823 | .261 | .180 | -.066 | .084 |
| Sulphates | .815 | .181 | .387 | -.202 | .124 | .142 | -.277 |
| COD | .295 | .673 | -.193 | .482 | .420 | .097 | .065 |
| Extraction Method: Principal Component Analysis. | | | | | | | |
| a. 7 components extracted. | | | | | | | |

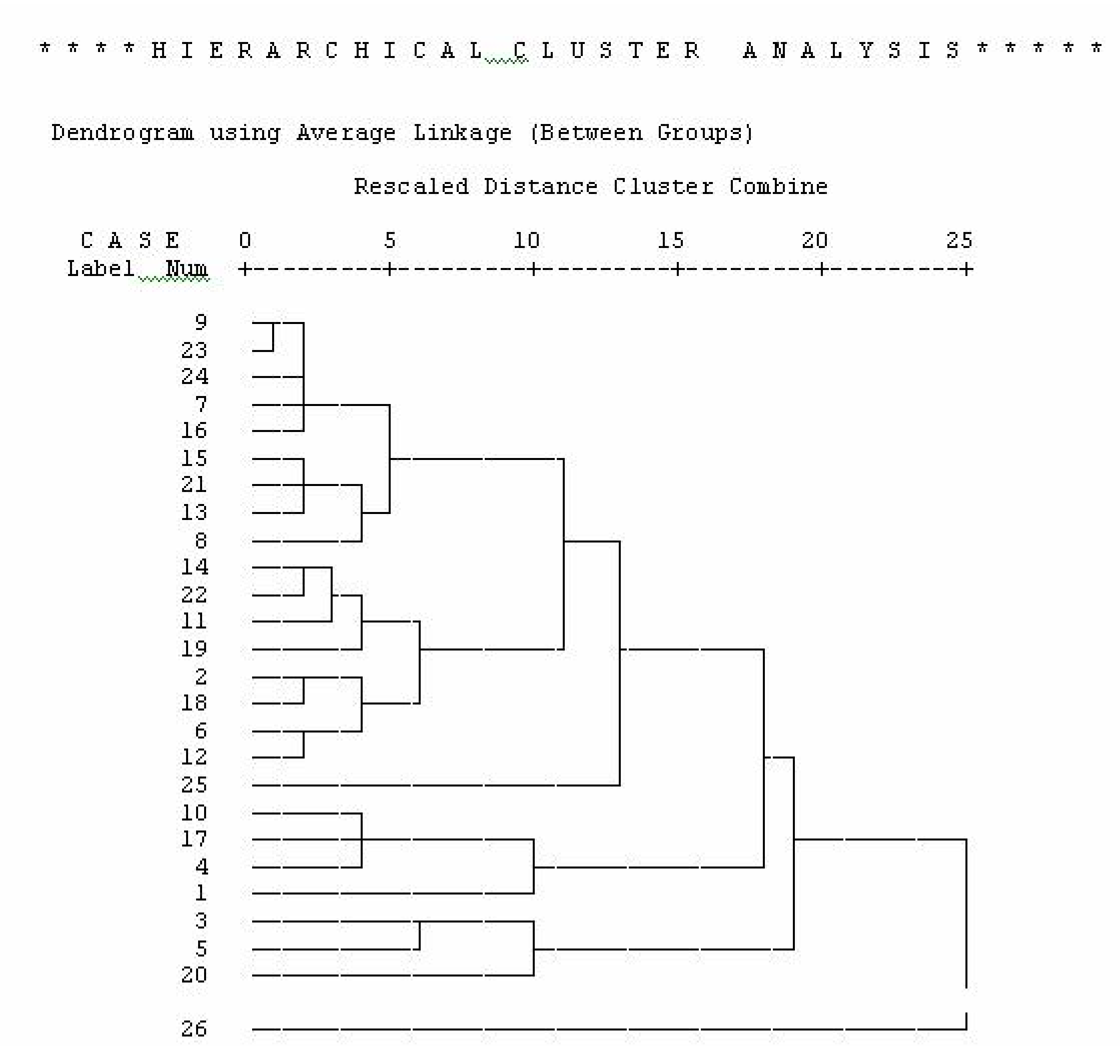

**Figure 3:** Dendrogram showing clustering of sampling sites based on groundwater parameters

The coefficients in the component matrix (Table 6) represent the correlations between the observed variables and the principal components. The first component has a strong positive correlation with pH, EC, and sulphates. The second component shows strong positive correlations with turbidity and COD and a strong negative correlation with TDS. The third component shows no strong correlations with any of the variables except nitrates. The cluster analysis (agglomerative bottom-up approach) was used to identify the spatial similarity between the sampling sites based on the levels of groundwater parameters, grouped all 26 sampling sites into three statistically significant clusters as depicted by the Dendrogram (Figure 3). The Dendrogram is essential in determining variables of significant importance and source of contamination for appropriate mitigation. From Figure 3, eighteen sampling locations are spatially similar i.e. cluster 1 (locations 9 to 25), four locations (10, 7, 4 and 1) form the second cluster while the rest form the third cluster.

## 3.3 Results of Water Quality Index calculations

The numerical value of WQI reflects its suitability for human consumption otherwise. The higher the WQI the more polluted the groundwater. WQI < 100 implies that the ground water is fit for human consumption. Conversely, WQI > 100 implies that the ground water is unfit for human consumption without treatment (severely contaminated). Generally, WQI < 50 implies that it is fit for human consumption; WQI < 80 implies that it is moderately contaminated; and 80< WQI < 100 implies that is excessively contaminated.

**Table 7:** Calculation of sub-indices and WQI for the 26 groundwater samples

| Sample ID | EC *qiwi* | TDS *qiwi* | Turbidity *qiwi* | Nitrate *qiwi* |
|---|---|---|---|---|
| B1 | 0.0683 | 0.0326 | 39.6 | 0.854 |
| B2 | 0.0317 | 0.01586 | 320 | 1.325 |
| B3 | 0.0281 | 0.01333 | 1480 | 1.365 |
| B4 | 0.0523 | 0.0255 | 280 | 2.112 |
| B6 | 0.01491 | 0.00738 | 1520 | 0.856 |
| B7 | 0.0369 | 0.01831 | 128 | 1.452 |
| B8 | 0.0047 | 0.00225 | 180 | 1.246 |
| B9 | 0.01785 | 0.00881 | 22.8 | 1.625 |
| B10 | 0.00865 | 0.00424 | 24 | 1.943 |
| B11 | 0.0464 | 0.0231 | 44 | 1.542 |
| B12 | 0.0251 | 0.01236 | 100 | 1.236 |
| B13 | 0.0403 | 0.01987 | 88 | 1.254 |
| B14 | 0.01837 | 0.00859 | 156 | 1.365 |
| B15 | 0.03 | 0.01475 | 148 | 0.658 |
| B16 | 0.0141 | 0.00688 | 200 | 0.954 |
| B17 | 0.00355 | 0.00169 | 100 | 2.547 |
| B18 | 0.0459 | 0.0216 | 360 | 1.236 |
| P1 | 0.0337 | 0.0164 | 280 | 1.254 |
| P2 | 0.0213 | 0.01827 | 88 | 0.884 |
| P3 | 0.01585 | 0.00753 | 1480 | 1.287 |
| P5 | 0.01404 | 0.00656 | 28.4 | 1.828 |
| P6 | 0.0261 | 0.01229 | 72 | 1.069 |
| P7 | 0.00746 | 0.00346 | 33.6 | 1.336 |

| | | | | |
|---|---|---|---|---|
| AB | 0.00689 | 0.00066 | 48 | 1.31 |
| DU | 0.00588 | 0.0323 | 120 | 1.543 |
| T1 | 0.0105 | 0.0629 | 80 | 1.602 |

**Table 7 continued**

| **Sulphate *qiwi*** | **COD *qiwi*** | **pH *qiwi*** | **∑ *qiwi*** | **WQI** |
|---|---|---|---|---|
| 0.216 | 8.5 | 0.093333 | 49.36423 | **137.123** |
| 0.0992 | 12 | -0.18667 | 333.4718 | **926.31** |
| 0.32 | 28.5 | 0.082667 | 1510.309 | **4195.3** |
| 0.264 | 11 | -0.08 | 293.3738 | **814.927** |
| 0.328 | 24.75 | -0.04267 | 1545.956 | **4294.32** |
| 0.0112 | 9 | -0.12267 | 138.3957 | **384.433** |
| 0.0192 | 13.25 | -0.43733 | 194.0848 | **539.125** |
| 0.0032 | 25.25 | -0.248 | 49.70486 | **138.069** |
| 0.0016 | 10.5 | -0.32533 | 36.13216 | **100.367** |
| 0.256 | 2 | -0.06933 | 47.79817 | **132.773** |
| 0.0032 | 23.25 | -0.12267 | 124.5267 | **345.907** |
| 0.0016 | 0 | -0.104 | 89.21177 | **247.811** |
| 0.0448 | 2.75 | -0.25867 | 159.9281 | **444.245** |
| 0.0464 | 12.75 | -0.16 | 161.3392 | **448.164** |
| 0.0368 | 7 | -0.23733 | 208.0118 | **577.811** |
| 0.0128 | 1 | -0.48533 | 103.0797 | **286.333** |
| 0.208 | 0 | -0.10667 | 361.4048 | **1003.9** |
| 0.032 | 7.75 | -0.2 | 289.0861 | **803.017** |
| 0.0128 | 17.75 | -0.112 | 106.5744 | **296.04** |
| 0.0432 | 2.75 | -0.27733 | 1483.826 | **4121.74** |
| 0 | 9 | -0.16533 | 39.2486 | **109.024** |
| 0.0448 | 10.5 | -0.672 | 82.98019 | **230.501** |
| 0.0128 | 11 | -0.32 | 45.63972 | **126.777** |
| 0.016 | 6.25 | -0.01867 | 55.58355 | **154.399** |
| 0.08 | 11.25 | -0.32 | 132.5912 | **368.309** |
| 0.0128 | 7 | 0.098667 | 88.78687 | **246.63** |

## 4. Discussion

From Table 7, groundwater samples from all sampling stations had WQI greater than 100 and can therefore be considered as unfit for human consumption without prior treatment. The turbidity of the groundwater samples is mainly responsible for the very high WQI values. Approximately 35% of the samples had WQI values which were up to 5 times or more than the threshold value of 100. WQI values range from 100.36 (sampling station B10) to 4294 (sampling station B6). The mean WQI is 825.89 (i.e. 8 times more than the upper limit for potability). Fifteen percent of groundwater samples had WQI values more than ten times the threshold for potability. Shankar and Sanjeev (2008) obtained WQI values of up to 300 in the Puram industrial of India while Khan (2011) had WQI values up to 142 in Attock City of Pakistan. As expected the WQI values obtained in this study were much higher than these two studies. The present study was carried out in an area with longstanding mining activity and extensive urbanisation. While Khan (2011) considered an urban area with limited industrial activities, Shankar and Sanjeev (2008) considered an industrial area. Ramakrishnaiah et al. (2009) have recorded WQI of almost 700 in a mining area in Tumkur, India. Mean levels of Turbidity, pH and COD were above the World Health Organisation (WHO) permissible levels; clearly demonstrating anthropogenic impact. 54% of groundwater samples did not comply with the WHO standards for pH; likewise 80% of the samples were not compliant with the recommended COD limit. Furthermore, none of the samples met the requirement for turbidity. This is also expected as small-scale mining activity which tends to muddy the waters is extensive in the area. This work confirms the work of Obiri et al. (2010), Armah et al. (2010) and Armah et al. (2011) who have previously highlighted the issue of contamination of groundwater in the study area via anthropogenic activities and the need to mitigate the risks associated with humans drinking it.

## 5. Conclusion

An assessment of the water quality index (WQI) was carried out in this study based on physicochemical analyses of twenty-six ground water sampling stations of the Tarkwa mining municipality in Ghana. Seven parameters namely pH, nitrate, sulphate, total dissolved solids, chemical oxygen demand, sulphates and turbidity were used to derive WQI values. WQI values range from 100.36 (sampling station B10) to 4294 (sampling station B6). The mean WQI is 825.89 (i.e. 8 times more than the limit for potability). All of the samples exceeded 100, the upper limit for drinking water potability. The high value of WQI at these stations has been found to be mainly from the higher values of total dissolved solids, and turbidity in the groundwater. Fifteen percent of groundwater samples had WQI values ten times more than the threshold for potability. Pearson correlation coefficients among selected water properties showed a number of strong associations. Turbidity correlated strongly with sulphates. Similarly pH showed strong associations with EC, TDS and sulphates. Multivariate statistical (principal component and cluster) analysis suggest that the data is a three-component system that explains 72% of the total variance. The study concludes that the groundwater of the Tarkwa mining area requires some prior treatment before human consumption.

## Acknowledgements

I wish to express my profound thanks to Nature Today Ghana for funding this research project and to Justice Odoi for reading through the manuscript.

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