# Water Quality Index in the Tarkwa Gold Mining Area in Ghana

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***Abstract:*** *Water quality and human health are inextricable linked. The present study assessed the water quality index (WQI) based on physicochemical analyses 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 was 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 two-component system that explains approximately two-thirds of the total variance in the data. The analysis reveals that the groundwater of this urban mining area needs some treatment before consumption.*

***Key words:*** *water quality index, mining, multivariate statistics, groundwater, contamination*

## 1. Introduction

Without human influences water quality would be determined by the weathering of bedrock minerals, by the atmospheric processes of evapo-transpiration and the deposition of dust and salt by wind, by the natural leaching of organic matter and nutrients from soil, by hydrological factors that lead to runoff, and by biological processes within the aquatic environment that can modify the physical and chemical composition of water (Lumb et al., 2010; Tiwari and Nayak, 2002). Drinking water quality guidelines and standards are designed to enable the provision of clean and safe water for human consumption, thereby protecting human health. These are usually based on scientifically assessed acceptable levels of toxicity to either humans or aquatic organisms. Declining water quality has become a global issue of concern as human populations grow, industrial and agricultural activities expand, and climate change threatens to cause major alterations to the hydrological cycle (APHA 1989, 2002). Water quality management contributes both directly and indirectly to achieving the targets set out in all eight Millennium Development Goals (MDGs), although it is most closely tied to specific targets of the goal 7, to ensure environmental sustainability (UNEP, ERCE, UNESCO, 2008). Indicators on water quality can be used to demonstrate progress toward the targets, by plotting trends in water quality over time and over space.

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. 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). 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). 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 any groundwater quality assessment programme is to obtain a comprehensive representation of the spatial distribution 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). That is to say that groundwater needs to be situated within the framework of space, time and place. This is imperative to sustain it for future generations. According to Lumb et al. (2011), 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 operations involved in water quality assessment are several and complex (Lumb et al. 2011). Over the years, several variants of the original water quality assessment procedure have emerged. 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).

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, many 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 comprehensive 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. WQI is recognised as one of the most effective ways of communicating information on water quality to both citizens and policy makers; to key stakeholders in the water sector (Khan 2011). 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). 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).

According to Wu et al. (2011), the selection of water quality factors must reveal the main anthropogenic activity (e.g. agriculture, domestic, mining, etc) within the monitoring area. In the case of agriculture and domestic sources nutrient enrichment via nitrogen, phosphorus, faecal coliform and ammonia are usually of concern whereas for mining, parameters such as nitrates, chemical oxygen demand (COD), sulphates, electrical conductivity, and pH of the water are important. The major issue associated with mining is acid mine drainage hence the importance of the aforementioned parameters. It is against this background that the water quality factors in this paper were chosen. Generally, in choosing water quality factors, although biological oxygen demand (BOD) is a main pollution index, it is very hard to realize on-line monitor for BOD and thus BOD cannot be listed as the monitoring items. However, BOD value can be calculated by COD value (Wu et al. 2011), so BOD can be used to simulate change of organic matter in the water.

WQI is important because it arises first from the need to share and communicate with the public, in a consistent manner, the technical results of monitoring ambient water. Second, it is associated with the need to provide a general means of comparing and ranking various bodies of water throughout the geographical region. One of the benefits of the index is elimination of jargon and technical complexity in describing water quality. The index strives to reduce an analysis of many factors into a simple statement.

The index is founded on three issues involving the measurement of the attainment of water quality objectives. The factors measure the following:

- the number of objectives that are not met
- the frequency with which objectives are not met, and
- the amount by which objectives are not met

These issues separate WQI from single factor water quality analysis.

### *1.1 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. The aims of the study were:

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

## 2. Materials and methods

### *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)

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).

According to Eisenlohr and Hirdes (1992), the Tarkwa ore bodies are located within the Tarkwaian System which forms a significant portion of the stratigraphy of the Ashanti Belt in southwest Ghana. The Ashanti Belt is a north-easterly striking, broadly synclinal structure made up of Lower Proterozoic sediments and volcanics underlain by the meta volcanics and meta sediments of the Birimian System(Eisenlohr and Hirdes, 1992). The contact between the Birimian and the Tarkwaian is com-

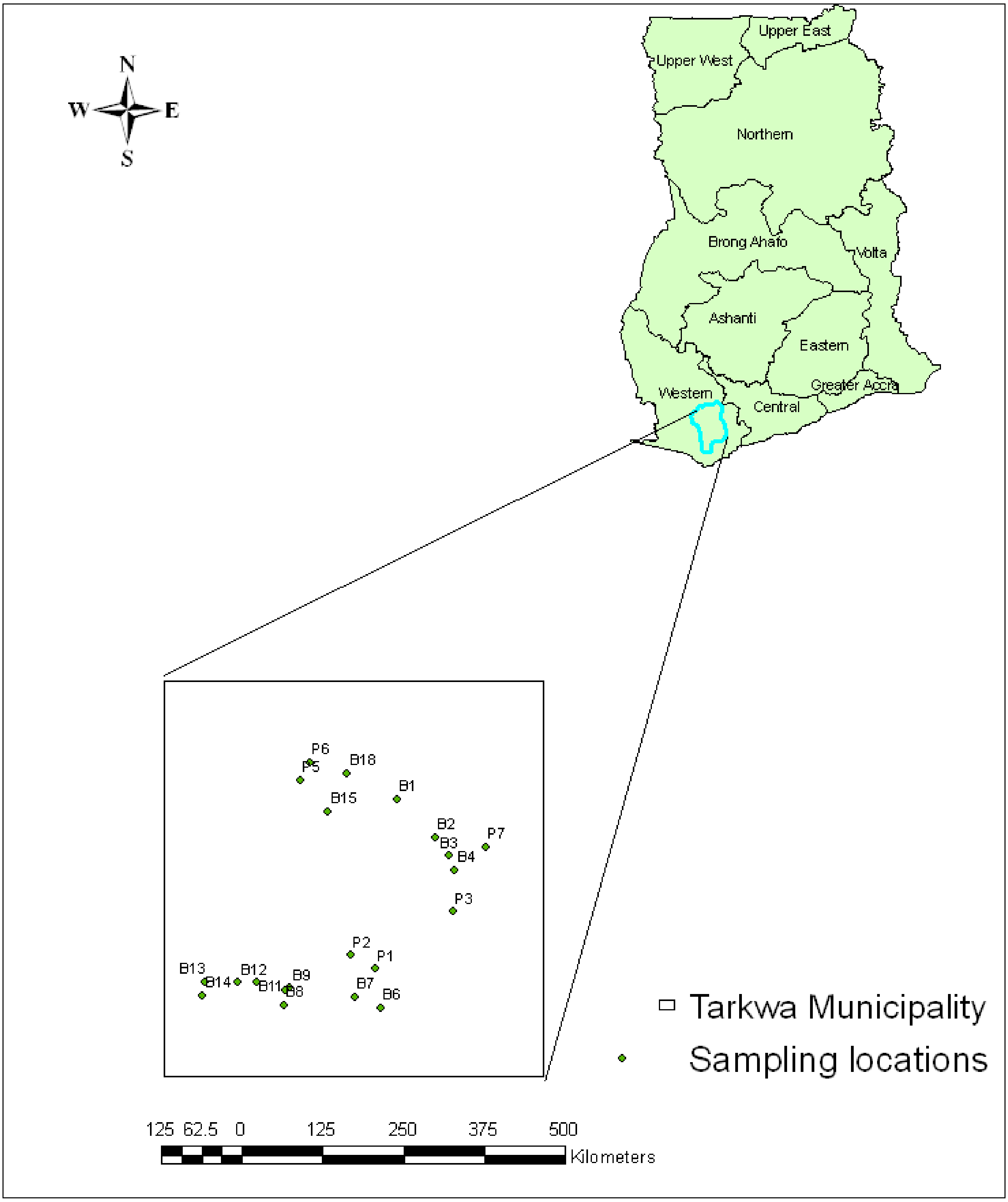


***Figure 1:*** *Sampling locations of groundwater in the study area.*

monly marked by zones of intense shearing and is host to a number of significant shear hosted gold deposits including Prestea, Bogoso and Obuasi. The local geology is dominated by the Banket Series which can be further sub-divided into a footwall and hanging wall barren quartzite separated by a sequence of mineralized conglomerates and pebbly quartzites (Eisenlohr and Hirdes, 1992). The stratigraphy of the individual quartzite units is well established with auriferous reefs interbedded with barren immature quartzites(Eisenlohr and Hirdes, 1992). The units thicken to the west and current flow parameters indicate a flow from the east and north-east.

### *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 Horiba U-53G multi-parameter water quality meter. Two 500ml of water samples were collected at each location into clearly labelled plastic bottles. The samples were sent to 2 independent laboratories 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 hazardous 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

$$wi = k/Si = 1/Si \qquad (1)$$

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 ($qi$) for the $i$th parameter PI, averages of the observed data ($Vi$) and water quality standards ($Si$).

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

| Sample ID | Location N | Location E | pH | Electrical Conductivity (µS/cm) | Dissolved Solids (mg/L) | Turbidity (NTU) | Nitrates (mg/L) | Sulphates (mg/L) | COD (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| B1 | 605579 | 580294 | 7.35 | 683 | 326 | 9.9 | 0.854 | 135 | 34 |
| B2 | 605117 | 580751 | 6.3 | 317 | 158.6 | 80 | 1.325 | 62 | 48 |
| B3 | 604899 | 580923 | 7.31 | 281 | 133.3 | 370 | 1.365 | 200 | 114 |
| B4 | 604725 | 580994 | 6.7 | 523 | 255 | 70 | 2.112 | 165 | 44 |
| B6 | 603057 | 580092 | 6.84 | 149.1 | 73.8 | 380 | 0.856 | 205 | 99 |
| B7 | 603193 | 579777 | 6.54 | 369 | 183.1 | 32 | 1.452 | 7 | 36 |
| B8 | 603093 | 578930 | 5.36 | 47 | 22.5 | 45 | 1.246 | 12 | 53 |
| B9 | 603299 | 579000 | 6.07 | 178.5 | 88.1 | 5.7 | 1.625 | 2 | 101 |
| B10 | 603276 | 578945 | 5.78 | 86.5 | 42.4 | 6 | 1.943 | 1 | 42 |
| B11 | 603365 | 578589 | 6.74 | 464 | 231 | 11 | 1.542 | 160 | 8 |
| B12 | 603365 | 578359 | 6.54 | 251 | 123.6 | 25 | 1.236 | 2 | 93 |
| B13 | 603370 | 577970 | 6.61 | 403 | 198.7 | 22 | 1.254 | 1 | 0 |
| B14 | 603214 | 577934 | 6.03 | 183.7 | 85.9 | 39 | 1.365 | 28 | 11 |
| B15 | 605441 | 579451 | 6.4 | 300 | 147.5 | 37 | 0.658 | 29 | 51 |
| B16 | 608415 | 579957 | 6.11 | 141 | 68.8 | 50 | 0.954 | 23 | 28 |
| B17 | 608431 | 580071 | 5.18 | 35.5 | 16.9 | 25 | 2.547 | 8 | 4 |
| B18 | 605898 | 579687 | 6.6 | 459 | 216 | 90 | 1.236 | 130 | 0 |
| P1 | 603531 | 580031 | 6.25 | 337 | 164 | 70 | 1.254 | 20 | 31 |
| P2 | 603694 | 579730 | 6.58 | 213 | 182.7 | 22 | 0.884 | 8 | 71 |
| P3 | 604223 | 580974 | 5.96 | 158.5 | 75.3 | 370 | 1.287 | 27 | 11 |
| P5 | 605811 | 579119 | 6.38 | 140.4 | 65.6 | 7.1 | 1.828 | 0 | 36 |
| P6 | 606027 | 579241 | 4.48 | 261 | 122.9 | 18 | 1.069 | 28 | 42 |
| P7 | 605002 | 581360 | 5.8 | 74.6 | 34.6 | 8.4 | 1.336 | 8 | 44 |
| AB | | | 6.93 | 68.9 | 6.6 | 12 | 1.31 | 10 | 25 |
| DU | | | 5.8 | 58.8 | 323 | 30 | 1.543 | 50 | 45 |
| T1 | | | 7.37 | 105 | 629 | 20 | 1.602 | 8 | 28 |

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

| Parameter | WHO guideline (Si) | Unit weight (*wi*) |
|---|---|---|
| Nitrate (mg/l) | 50 | 0.02 |
| 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 |

*Table 3: descriptive statistics of groundwater data (n=26)*

| Measure | pH | EC | TDS | Turbidity | Nitrates | Sulphates | COD |
|---|---|---|---|---|---|---|---|
| Mean | 6.308 | 2.418E2 | 1.528E2 | 71.350 | 1.372 | 51.115 | 42.269 |
| Median | 6.390 | 1.983E2 | 1.284E2 | 27.500 | 1.317 | 21.500 | 39.000 |
| Mode | 5.800[a] | 35.50[a] | 6.60[a] | 22.00[a] | 1.24[a] | 8.00 | 0.00[a] |
| Std. Deviation | 0.669 | 1.663E2 | 1.313E2 | 1.137E2 | 0.414 | 67.235 | 3.136E1 |
| Variance | 0.448 | 2.766E4 | 1.724E4 | 1.292E4 | 0.172 | 4520.506 | 983.885 |

*a. Multiple modes exist. The smallest value is shown*

$qi$ =100(V$i$/S$i$) ....................................................(2)

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

$q$pH = 100[(VpH- 7.0)/1.5]...............................(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 $qi$ as shown in equation 4

WQI = [∑ (q$i$.w$i$)/∑w$i$]....................................(4)

Except pH, unit weights for nitrate sulphate, turbidity, electrical conductivity, COD and TDS were calculated as the inverse of their guideline values: 1/50, 1/250, 1/5, 1/1000, 1/20 and 1/1000 respectively (see equation 1 and table 2).

### *2.5 Correlation, PCA and cluster analyses*

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. 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):

- The descriptors are normally distributed, and
- 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 4:*** *Correlation of water quality parameters in 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. Results

### *3.1 Results of physicochemical parameters*

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.

### *3.2 descriptive statistics and correlation coefficients of observed 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. Significant 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) guideline levels; clearly demonstrating anthropogenic impact.

The scatter plot (Figure 2) indicates that the data is a two-component system and this is confirmed by Table 5 as two components cumulatively explain 58% of the variance in the data.

From Table 5, only components 1 and 2 had Eigen values greater than 1 (thereby constituting the two main components).

From Figure 2, it can be observed that turbidity, COD and nitrates exhibit opposite behaviour to sulphates, pH; electrical conductivity (EC) and total dissolved solids (TDS).

The coefficients in the rotated 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 TDS. The second component shows strong positive correlations with turbidity and COD. 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, 17, 4 and 1) form the second cluster while the rest form the third cluster.

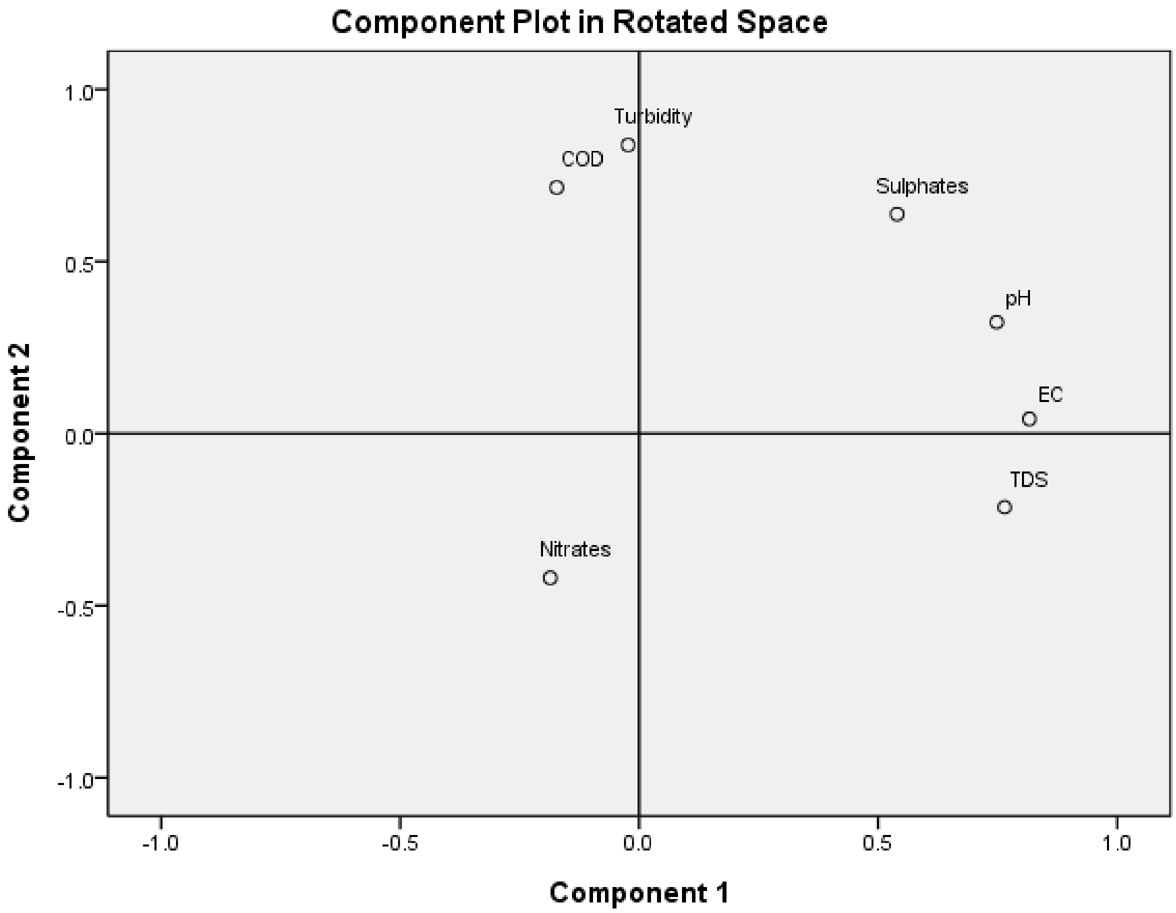


***Figure 2:*** *Loading plot of the variables extracted from the groundwater data*

***Table 5:*** *Total variance in the data explained by the main components*

| Total Variance Explained | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 2.463 | 35.180 | 35.180 | 2.463 | 35.180 | 35.180 | 2.166 | 30.936 | 30.936 |
| 2 | 1.650 | 23.578 | 58.758 | 1.650 | 23.578 | 58.758 | 1.948 | 27.822 | 58.758 |
| 3 | .951 | 13.587 | 72.345 | | | | | | |
| 4 | .802 | 11.461 | 83.806 | | | | | | |
| 5 | .562 | 8.031 | 91.837 | | | | | | |
| 6 | .390 | 5.578 | 97.415 | | | | | | |
| 7 | .181 | 2.585 | 100.000 | | | | | | |

*Extraction Method: Principal Component Analysis.*

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

| Rotated Component Matrix[a] | | |
|---|---|---|
| | Component | |
| | 1 | 2 |
| pH | .748 | .323 |
| EC | .816 | .042 |
| TDS | .764 | -.214 |
| Turbidity | -.023 | .838 |
| Nitrates | -.186 | -.420 |
| Sulphates | .539 | .637 |
| COD | -.173 | .715 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 3 iterations.

### *3.2 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 is moderately contaminated; and 80< WQI < 100 implies that is excessively contaminated.

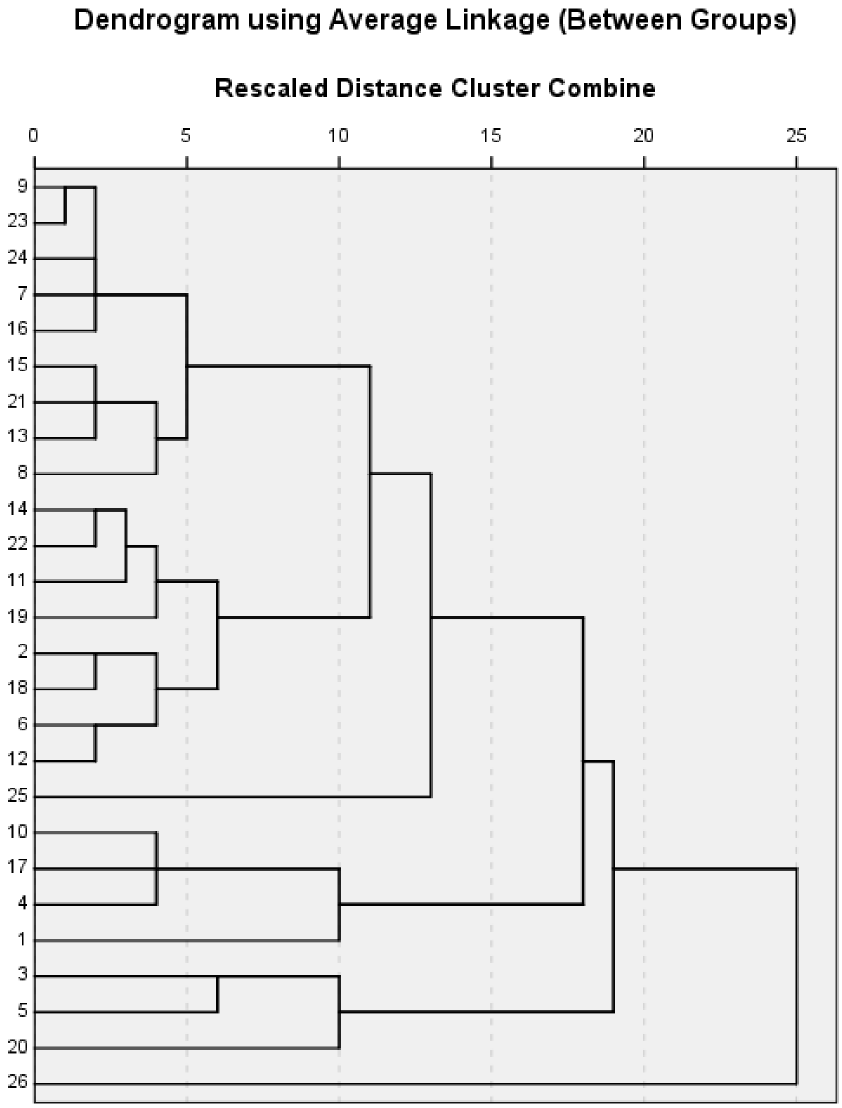


***Figure 3:*** *Dendrogram showing clustering of sampling sites based on groundwater parameter*

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

| Sample ID | EC *qiwi* | TDS *qiwi* | Turbidity *qiwi* | Nitrate *qiwi* | Sulphate *qiwi* | COD *qiwi* | pH *qiwi* | Σ *qiwi* | WQI |
|---|---|---|---|---|---|---|---|---|---|
| B1 | 0.0683 | 0.0326 | 39.6 | 0.854 | 0.216 | 8.5 | 0.093333333 | 49.36423 | **137.1229** |
| B2 | 0.0317 | 0.01586 | 320 | 1.325 | 0.0992 | 12 | -0.186666667 | 333.4718 | **926.3104** |
| B3 | 0.0281 | 0.01333 | 1480 | 1.365 | 0.32 | 28.5 | 0.082666667 | 1510.309 | **4195.303** |
| B4 | 0.0523 | 0.0255 | 280 | 2.112 | 0.264 | 11 | -0.08 | 293.3738 | **814.9272** |
| B6 | 0.01491 | 0.00738 | 1520 | 0.856 | 0.328 | 24.75 | -0.042666667 | 1545.956 | **4294.323** |
| B7 | 0.0369 | 0.01831 | 128 | 1.452 | 0.0112 | 9 | -0.122666667 | 138.3957 | **384.4326** |
| B8 | 0.0047 | 0.00225 | 180 | 1.246 | 0.0192 | 13.25 | -0.437333333 | 194.0848 | **539.1245** |
| B9 | 0.01785 | 0.00881 | 22.8 | 1.625 | 0.0032 | 25.25 | -0.248 | 49.70486 | **138.0691** |
| B10 | 0.00865 | 0.00424 | 24 | 1.943 | 0.0016 | 10.5 | -0.325333333 | 36.13216 | **100.3671** |
| B11 | 0.0464 | 0.0231 | 44 | 1.542 | 0.256 | 2 | -0.069333333 | 47.79817 | **132.7727** |
| B12 | 0.0251 | 0.01236 | 100 | 1.236 | 0.0032 | 23.25 | -0.122666667 | 124.5267 | **345.9074** |
| B13 | 0.0403 | 0.01987 | 88 | 1.254 | 0.0016 | 0 | -0.104 | 89.21177 | **247.8105** |
| B14 | 0.01837 | 0.00859 | 156 | 1.365 | 0.0448 | 2.75 | -0.258666667 | 159.9281 | **444.2447** |
| B15 | 0.03 | 0.01475 | 148 | 0.658 | 0.0464 | 12.75 | -0.16 | 161.3392 | **448.1643** |
| B16 | 0.0141 | 0.00688 | 200 | 0.954 | 0.0368 | 7 | -0.237333333 | 208.0118 | **577.8105** |
| B17 | 0.00355 | 0.00169 | 100 | 2.547 | 0.0128 | 1 | -0.485333333 | 103.0797 | **286.3325** |
| B18 | 0.0459 | 0.0216 | 360 | 1.236 | 0.208 | 0 | -0.106666667 | 361.4048 | **1003.902** |
| P1 | 0.0337 | 0.0164 | 280 | 1.254 | 0.032 | 7.75 | -0.2 | 289.0861 | **803.0169** |
| P2 | 0.0213 | 0.01827 | 88 | 0.884 | 0.0128 | 17.75 | -0.112 | 106.5744 | **296.0399** |
| P3 | 0.01585 | 0.00753 | 1480 | 1.287 | 0.0432 | 2.75 | -0.277333333 | 1483.826 | **4121.74** |
| P5 | 0.01404 | 0.00656 | 28.4 | 1.828 | 0 | 9 | -0.165333333 | 39.2486 | **109.0239** |
| P6 | 0.0261 | 0.01229 | 72 | 1.069 | 0.0448 | 10.5 | -0.672 | 82.98019 | **230.5005** |
| P7 | 0.00746 | 0.00346 | 33.6 | 1.336 | 0.0128 | 11 | -0.32 | 45.63972 | **126.777** |
| AB | 0.00689 | 0.00066 | 48 | 1.31 | 0.016 | 6.25 | -0.018666667 | 55.58355 | **154.3988** |
| DU | 0.00588 | 0.0323 | 120 | 1.543 | 0.08 | 11.25 | -0.32 | 132.5912 | **368.3088** |
| T1 | 0.0105 | 0.0629 | 80 | 1.602 | 0.0128 | 7 | 0.098666667 | 88.78687 | **246.6302** |

## 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. The sustainable management of water quality has policy, technical, institutional and financial components (UNEP, ERCE, UNESCO, 2008). In many developing countries restricted funding is usually combined with fragile or unstable institutions and limited technical capabilities to deal with an expanding range of water quality problems.

Advanced treatment of groundwater often is needed to reduce contaminant levels to conform to the standards. These treatments may include aeration, lime softening, ion exchange (IX), electrodialysis reversal (EDR) or reverse osmosis (RO). Each of these treatment schemes has advantages and disadvantages. Aeration removes dissolved gases such as radon and volatile compounds. Lime softening removes hardness and some of the metallic elements. Ion exchange systems can be tailored to remove most contaminants, and EDR and RO can remove virtually all compounds from the water. The task of the designer is to determine the treatment that is most appropriate and cost-effective for the consumer.

Ghana is a low income country consequently; these techniques although ideal may not be affordable to riparian communities. However, there is opportunity for utilizing several potential plant-based bioremediation options such as *Pteris vittata* Linn. and *Moringa oleifera* which are abundant in these communities.

## 5. Policy implications

The National Water Policy of Ghana is targeted at all water users, water managers and practitioners, investors, decision-makers and policy makers within the central Governmental and decentralised (district assemblies) structures, non-Governmental organisations and international agencies (Armah 2009). The policy also recognises the various cross-sectoral issues related to water-use and the links to other relevant sectoral policies such as those on sanitation, agriculture and mining. Ghana's national policy and legislation for water resources are based on an integrated approach to managing quality and quantity of surface water and groundwater, in which the need to protect water resources from unacceptable degradation is balanced with the need to use water for social and economic development. Integrated management of water, land and the environment is addressed through co-operation with other responsible departments in all spheres of government.

Specific provisions are made for the protection, use, development, conservation, management and control of water resources, within a framework of integrated management of all aspects of the water system - surface and groundwater quantity and quality -managed in conjunction with the management of land use. Integrated planning on a catchment basis is emphasised, and the responsibility for water resources will be decentralised to catchment based institutions. Charges for water use are intended to recover the costs of management activities and the costs of developing, operating and maintaining infrastructure, but provisions are made for free basic water for all, and assisting previously disadvantaged population groups to gain access to the use of water resources. Specific provisions are made for protecting water resources - rivers and streams, wetlands, estuaries and groundwater - from unacceptable degradation, whilst making water available for social and economic development (Armah et al. 2011). In the first place, it is the widespread contamination of surface water in mining communities that culminated in the need for alternative drinking water sources (Armah 2010). This widespread contamination suggests that there is a disjoint between the legislative framework and local action.

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. The Government of Ghana has established the community water and sanitation programme in order to deal with the water quality issues in various communities. An underlying principle of this initiative is its emphasis on community ownership and management (COM), which entails effective community participation in the planning, implementation and management of the water and sanitation facilities in the belief that, as custodians, communities will ensure the sustainability of these systems. A necessary condition for promoting good health requires a change in behaviours and attitudes towards hygiene and so another important aspect of the programme is to maximise health benefits by integrating water, sanitation and hygiene education/promotion (including hand washing) interventions. Yet, if the pollution of surface water persists, it is unlikely that the quality of the groundwater in the mining communities can be sustained given surface water and groundwaters interact via complex mechanisms (Obiri et al., 2010).

## 6. 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 two-component system that explains approximately two-thirds of the total variance in the data. The study concludes that the groundwater of the Tarkwa mining area requires some prior treatment before human consumption.

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