Water quality analysis of rivers used as drinking sources in artisanal gold mining communities of the Akyem-Abuakwa area: A multivariate statistical approach

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Abstract:

The spatial pattern of water quality of rivers affected by artisanal gold mining but used as drinking sources in Akyem Abuakwa, was evaluated based on thirteen variables. At nine of the fifteen sampling stations, concentrations of arsenic, mercury, total dissolved solids, turbidity, water colour, nitrate-nitrogen and phosphate-phosphorus were found to be higher than WHO's limits for drinking water. Cluster analysis distinguished four water quality categories - good, fairly good, poor and grossly polluted. Only rivers Subri and Kadee were classified as "good" for drinking purposes. Discriminant analysis revealed that, in order of importance, turbidity, arsenic, temperature, phosphate-phosphorus and total dissolved solids are the most important variables for identifying drinking water quality of river sources. Principal component analysis identified five factors with eigenvalues greater than unity and accounting for more than 80 percent of water quality variability. Artisanal gold mining accounted for more than 26 percent of the variability, with arsenic and mercury as the primary contaminants in the area. Other sources of contamination are agricultural activities and domestic waste disposal. The study recommends that local water quality managers design cost-effective strategies to effectively monitor and protect drinking water resources of the study area, particularly from mining-related degradation.

Keywords: Artisanal Gold Mining; Drinking Water Quality; Multivariate Statistics; Akyem Abuakwa; Ghana

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Introduction

Protecting water resources for sustainable provision of safe and secure water to populations is a crucial developmental issue worldwide. This is because sustainable socio-economic progress is rarely possible without sufficient development of water resources to support human needs (Bruntland, 1987). However, in many African countries, including Ghana (TWAS, 2002; ELAW, 2010), not only is rising population increasing demand for safe drinking water supplies, but also most natural sources of drinking water are unprotected from pollution due to human activities (Donkor *et al*., 2006). In accord with the observation of Gyau-Boakye *et al*. (2008), surface water pollution in Ghana is particularly worrisome among small towns and rural dwellers because they are more dependent than their urban counterparts on untreated water collected largely from rivers and streams for drinking.

Artisanal gold mining refers to small-scale, largely informal mining activities that mine ores containing gold and process them to recover the gold, usually with rudimentary techniques. In spite of its significant contribution to both the local and national economy (Bermudez-Lugo, 2008), there are grave concerns about the water degradation impacts due to artisanal gold mining, besides land degradation (Schueler *et al*., 2011), loss of biodiversity and other natural resources, and deforestation (Donkor *et al*., 2006). Artisanal gold mining in Ghana, popularly known as ‘galamsey’, has been conducted ubiquitously over decades and previously involved relatively few individuals, particularly the youth within rural communities (Hilson and Potter, 2003). In recent years, however, with dwindling opportunities for employment in the formal sector, the numbers of these miners have soared (Ghana Minerals Commission, 2006) with the majority of them operating illegally in and around major rivers and streams that are sources of drinking water for communities (WRC, 2003). The impact of ‘galamsey’ on surface water contamination, particularly in relation to community drinking water supply sources, however, has received little research attention.

Accurate evaluation of multi-dimensional data such as water quality information in order to extract useful information relating to latent factors responsible for pollution and patterns in water quality characteristics could be challenging. The most appropriate approach has been the application of multivariate techniques such as principal component analysis (PCA), factor analysis (FA), cluster analysis (CA) and discriminant analysis (DA). The applications of these techniques to water quality analysis are amply demonstrated in many studies (e.g., Shrestha and Kazama, 2007; Pejman *et al*., 2009; Zhang *et al*., 2009; Armah *et al*., 2010a, 2010b; Adomako *et al*., 2011; Samsudin *et al*., 2011; Oketola *et al*., 2013).

In this paper, we analyse the effect of artisanal gold mining on drinking water quality, *vis-à-vis* other human activities, using well-proven multivariate techniques. The study was conducted in the Akyem Abuakwa Traditional Area in the Eastern Region of Ghana. In recent years, the area has been characterized by widespread artisanal gold mining activities in and along river courses. The result is that water from most rivers has become unsafe for human consumption, forcing most communities to depend on either wells or boreholes for water supply (Ghana Business News, 13 March, 2010). Specifically, the study is aimed at using multivariate statistics to analyse drinking water quality in the area by: (1) determining the kind of contaminants in rivers/streams used as drinking sources and the latent sources of contamination; (2) characterizing rivers/streams on the basis of raw water quality and; (3) determining the spatial pattern in water quality of rivers/streams used for drinking by communities. The results of the study are intended to communicate water quality information to the public and decision makers, to identify water quality problems for which special attention is needed, and to facilitate the design and development of monitoring strategies by local managers to minimize the degradation of freshwater, particularly drinking water sources in the study area.

Materials and Methods

Description of study area

The study area encompasses three administrative districts, namely Kwaebibirem (1230 km^2), Atiwa (2950 km^2) and East Akim (725 km^2), all of the Akyem-Abuakwa Traditional Area in the Eastern region of Ghana (fig. 1). The area abounds in natural resources, mainly minerals and forest products (Owusu, 2012). The major minerals are gold, diamond, bauxite, manganese and kaolin, while the forest resources include timber species such as *Tripolchiton scleroxylon*, *Milicia excels*a and *Kyaya ivorensis* (Ansa-Asare and Gordon, 2012; Owusu, 2012). The study area is generally of undulating topography and the landscape is characterized by many hills with craggy summits. The average elevation is about 550 metres above sea level and there are over 200 settlements with a population density of about 120 persons per square kilometre, far above the national average of 77 persons per square kilometre (Water Resources Commission, 2000).

The area abounds in freshwater resources and is the catchment of two major rivers, the Birim and Densu, and their network of tributary rivers. Collectively, the two rivers drain an area of about 3,875 km^2 with Bereponso, Subi, Kadewaso, Ankobirim, Ahyiresu and Pram as some of the major tributary rivers. Most of these rivers are perennial and reliably provide all-year-round drinking water to communities. Therefore, any deterioration in their water quality is a matter of concern for the local people. Their qualitative deterioration is of local concern to the populace. Unfortunately, from source to estuary, various human activities such as settlement development, mining, domestic and industrial waste disposal, and agricultural activities are contributing to their degradation, thus impairing the quality of water supply from these rivers (Owusu, 2012). Illegal gold mining in particular is ubiquitously undertaken recently in the area, thus promoting widespread pollution of rivers (Ghana Business News, 13 March, 2010; Daily Graphic, 2 August 2011).

The study area falls in the wet semi-equatorial climate, characterized by two rainfall seasons (Dickson and Benneh, 1998). The major rainy season, which is from April/May to July, peaks in June when maritime instability causes a surge of the moist south-westerly winds inland, resulting in the intensification of monsoon rains. The minor season occurs between September and November when several atmospheric disturbances give rise to local thunderstorms. The total annual rainfall is about 1700 mm with a mean of 1650 mm (Ayibotele and Tuffour-Darko, 1979; cited in Ansa-Asare and Gordon, 2012).

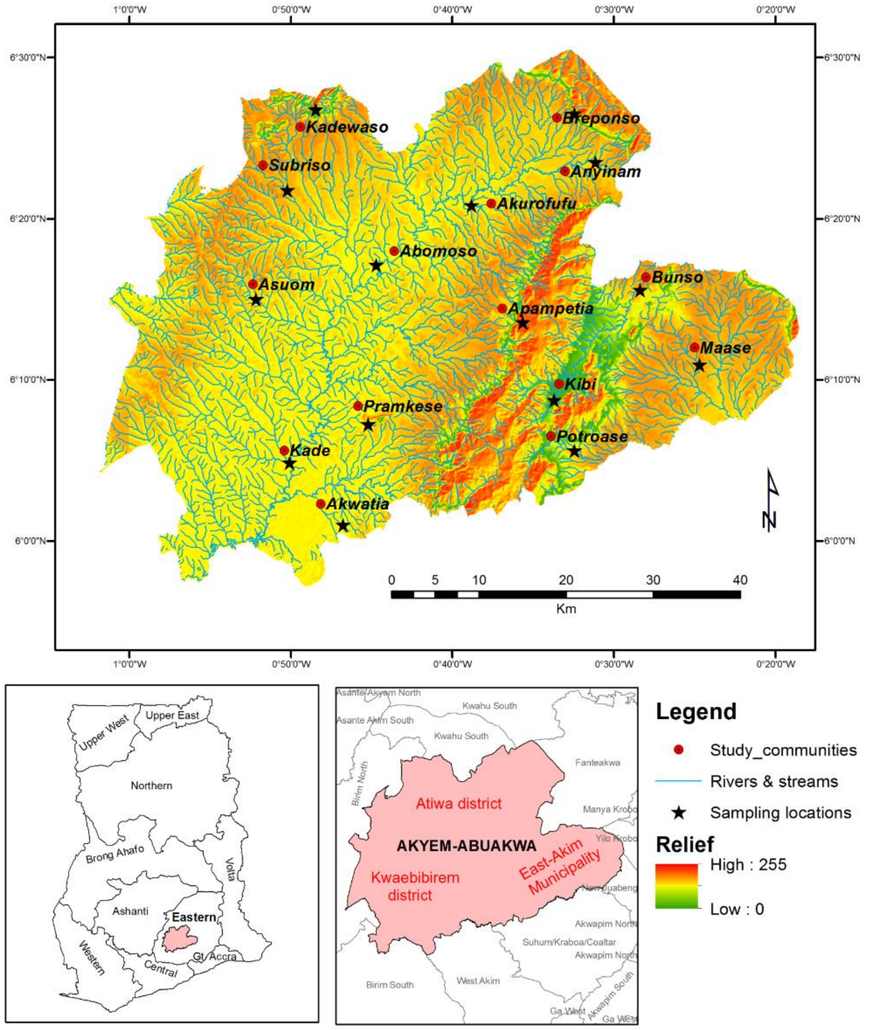

Fig 1. Map of study area indicating sampling sites, districts and study communities

The area is a major food producing centre and most of the people engage in slash-and-burn farming, cultivating food crops such as maize, cassava, yam, cocoyam, plantain, citrus and pineapple. Major cash crops grown are oil palm and cocoa (Owusu, 2012).

Field sampling and laboratory analysis

Purposive sampling was used for data collection to ensure a reasonable geographical spread of sampling sites across the area (fig.1). Using standard procedures as recommended by WHO (2006) and the American Public Health Authority (1998), water samples were collected from rivers/streams used as drinking water sources by communities at fifteen sampling sites located close to ‘galamsey’ operations (within 2-km radius). Table 1 indicates the rivers/streams sampled, the respective communities using them as drinking water sources and their geographical locations.

Table 1: Names of study communities with associated rivers and geographical location of sampling sites

Community	**Name of river or stream**	**Code***	**Geographical location**	
			Latitude	**Longitude**
Kadewaso	Kadee	K	6°25'02.28"N	0°49'54.56"W
Abomoso	Birim	Ab	6°18'03.66"N	0°43'14.36"W
Anyinam	Birim	An	6°22'56.04"N	0°32'24.20"W
Akrofufu	Birim	Ak	6°21'41.07"N	0°37'31.92"W
Breponso	Breponso	Br	6°26'33.48"N	0°33'07.25"W
Akwatia	Birim	At	6°03'15.05"N	0°48'10.95"W
Subinso	Subri	Su	6°05'42.83"N	0°54'45.42"W
Pramkese	Pram	Pr	6°09'14.85"N	0°46'16.61"W
Asuom	Apam	As	6°16'10.40"N	0°52'16.59"W
Kade	Birim	Kd	6°05'36.56"N	0°49'25.33"W
Bunso	Birim	Bu	6°17'09.22"N	0°27'34.09"W
Kibi	Densu	Ki	6°10'11.75"N	0°32'40.35"W
Potroase	Abohyensu	Po	6°05'53.63"N	0°34'19.91"W
Pampetia	Birim	Pa	6°15'44.00"N	0°37'00.21"W
Maase	Ahyiresu	Ma	6°12'40.11"N	0°26'03.81"W

***Note**: To avoid overlapping, codes were derived from names of communities instead of rivers

At each location, three samples were collected along each river/stream and composited. In all cases, sampling of water was confined to mid-stream and at a depth of about 10 to 15 cm from the surface. Plastic sample bottles were acid-washed and rinsed twice with distilled water before being used for sampling. Collected samples were stored under ice at 4˚C and transported the same day to the Ecological Laboratory Unit at the University of Ghana. At the Laboratory, each round of samples was refrigerated and stored for analysis.

All procedures for laboratory analysis were in accord with standard methods for the examination of water and wastewater (APHA, 1998). Both temperature (T) and pH were measured on the field, using a Horiba digital water quality checker (Model U.10). Electrical conductivity (EC) was estimated by a conductivity meter (Jensway Model 4020), turbidity (Turb) by a turbidimeter (HACH Model 2100P) and water colour by a portable data logging spectrophotometer (HACH DR/2010). Laboratory analysis of dissolved oxygen (DO) was by the Azide modified Winkler method; biological oxygen demand (BOD) by the dilution method and total dissolved solids (TDS) by weighing after evaporating a known volume of samples (APHA, 1998).

Nutrient levels in water samples were determined as follows: ortho-phosphate (PO_4-P) was by the ammonium molybdate and ascorbic acid method (Mackereth *et al.*, 1978), nitrate-nitrogen (NO_3-N) by hydrazine reduction followed by diazotizing to form an azodye which was measured calorimetrically (APHA, 1998), and ammonium-nitrogen (NH_4-N) by the indophenol blue method (FAO,1975). For heavy metal determination, acidified samples were digested with concentrated HNO_3 acid prior to analysis, using an atomic absorption spectrophotometer (APHA, 1998).

The suitability of rivers and streams for domestic purposes was assessed from samples, using the Raw Water Quality Index (WQI) defined by the Ghana Water Resources Commission (2003). The step-wise procedure classifies raw water quality of rivers and streams as good, fairly good, poor or grossly polluted (Darko *et al.*, 2013). The original index is based on ten rated water quality variables: T, pH, EC, TDS, DO, BOD, PO_4-P, NH_4-N, NO_3-N and faecal coliform (WRC, 2003). With the exception of faecal coliform, which was not assessed in this study, all other parameters were used to determine the index of water samples.

Statistical analysis

Statistical computations were performed with SPSS 17.0 and JMP 10.02 statistical software (SAS Institute, 2012). In this study, a single factor analysis of variance was performed to determine the significance of variability in water quality variables at the 5% level of significance. As outlined in several studies (e.g., Praus, 2007; Zhang et al., 2009; Samsudin et al., 2011; Jayawardana et al., 2012;), principal component analysis (PCA) and factors analysis (FA) were applied for data reduction and pattern recognition in order to decipher the variance in the dataset and reveal the sources of component factors. The agglomerative hierarchical cluster analysis (AHCA) was performed based on the normalized data, using Ward's method to minimize the error sum of squares between clusters (Khan, 2008), and Euclidean distance as a measure of similarity between the interdependent variables (Güler et al., 2002). The output, called a dendrogram (Juahir et al., 2010), provided a basis for identifying the data structure among observations and variables.

Using the Mahalanobis distance-derived properties to define group membership (Johnson and Wichern, 1992), a linear discriminant analysis (LDA) was performed using the standardized dataset to assess group validity of water samples. In order to identify the variables that are most important in discriminating among the groups, a step-forward discriminant analysis with cross-validation was carried out using probabilities of F-to-enter-of 0.05 and F-to-remove of 0.10. Prior to executing the LDA, the Kaiser-Meyer-Olkin (KMO) test was performed to examine the suitability of the dataset (Kaiser, 1974; cited in Adomako et al., 2011).

As prescribed by Cao et al. (1999), all data used in the analysis were standardized to their z-scores and normalized to eliminate non-normality. Normalization of data was necessary because variables were not only measured in different units but also given equal weighting in the analysis (Chatfield and Collins, 1980; cited in Mazlum et al., 1999). Also, in this study, a correlation matrix of variables was used to address problems related to scaling and the presence of outliers (Abdi and Williams, 2010; Sapra (2010). To identify the most significant water quality parameters or factors, a PCA was performed on all 13 variables, using varimax rotation with Kaiser's normalization (Shrestha and Kazama, 2007). As is common in most applications of PCA (Chatfield and Collins, 1980; cited in Mazlum et al., 1999), in this study, components with eigenvalues less than 1 were considered ineligible and therefore excluded from further analysis.

Results and discussion

Physico-chemicals

Thirteen physico-chemical parameters were used for characterization of rivers and streams that are sources of drinking water in the study area. Table 2 is the descriptive statistics of water quality parameters considered under this study.

Table 2: Descriptive statistics of water quality parameters

Parameter	**Minimum**	**Maximum**	**Range**	**Mean**	**Std. Error**	**Std. D**
As (mgl^{-1})	1.27	4.26	2.99	2.39	0.10	0.67
BOD (mgl^{-1})	972.8	2492.6	1519.80	1522.2	53.40	358.19
DO (mgl^{-1})	6.10	6.90	0.80	6.37	0.03	0.18
EC (µScm^{-1})	163.60	397.80	234.20	280.71	8.69	58.32
Hg (mgl^{-1})	0.58	1.53	0.94	1.06	0.03	0.20
NH4-N (mgl^{-1})	27.50	116.30	88.80	68.44	3.75	25.13
NO$_3$-N (mgl^{-1})	3.50	5.40	1.90	4.07	0.22	0.74
pH	6.10	6.80	0.70	6.40	0.03	0.16
PO$_4$-P (mgl^{-1})	0.47	2.20	0.73	1.63	0.69	0.82
T(˚C)	23	27.30	4.30	24.52	0.14	0.94
TDS (mgl^{-1})	6127	15925	8798	9496	268.40	3341
Turb (mgl^{-1})	17.20	96.60	79.40	43.68	2.64	17.72
WC (Hz)	30.40	127.60	97.20	71.31	3.65	24.52

The linear correlation matrix of these parameters is shown by Table 3 while figure 2 depicts the seasonal variability in these water properties on a per community basis. Compared to a figure of 0.1 mgl^{-1} and 1.0 mgl^{-1} recommended by WHO (2006) and (USEPA, 2009) respectively, the observed results suggest a higher concentration of the heavy metal in all sampled rivers. The lowest was at Su and the highest at Ki. Table 3 indicates a high positive correlation of As with EC ($r = 0.820$; $p<0.01$) and Hg ($r = 0.556$; $p< 0.05$). In the aquatic environment, according to Gautheir (2004), arsenic is largely introduced into water by natural dissolution of arsenic-bearing rock minerals such arsenopyrite (FeAsS), realgar (AsS) and orpiment (As_2S_3). The metal may also contaminate water through atmospheric deposition of combustible materials (Chapman, 1996). Anthropogenic sources of arsenic in water include intensive agro-chemical applications, industrial effluents and wastes, alloying agents, wood preservatives and burning of fossil fuels. Usually, contributions from these anthropogenic sources are negligible compared to contamination from natural sources (Nickson *et al*., 2000). Elevated levels of As in water have also been usually associated with mining operations (WHO, 2003).

The BOD of a water body is mainly influenced by the decomposition of organic substances, the oxidation of nitrogen compounds and the photosynthetic aeration of aquatic plants (USEPA. 1976). The range and mean concentration of BOD in this study were 972.8-2492.6 mgl^{-1} and 1522.2 ± 358.19 mgl^{-1} respectively. The lowest BOD was recorded at Ma and the highest at Ab. The differences probably reflect variations in oxidative processes such as the decomposition of organic debris in the rivers. This conclusion is drawn because of the negative correlation between BOD and DO (Table 3).

DO levels in unpolluted water are normally between 8 and 10 mgl^{-1} at 25^{o}C (DFID, 1999) and concentration below 5.0 mgl^{-1} can adversely affect aquatic life. In this study, the concentration of DO in rivers ranged from 6.10 mgl^{-1} at An to 6.90 mgl^{-1} at K with a mean of 6.37± 0.18 mgl^{-1}, which indicates that DO levels in all rivers were within the recommended 5.0-7.0 mgl^{-1} range prescribed for drinking water (WHO, 2006). A strong negative correlation was found between DO and NH_4-N ($r = - 0.544$; $p<0.05$), perhaps indicating the oxidative decomposition of nitrogenous materials in the rivers. The contribution of artisanal gold mining to the observed trend is not obvious; however, it could be associated with the extensive clearing of vegetation during operations and its subsequent decomposition in water.

The mean EC was 280.71 µScm^{-1}, with the lowest value of 163.60 µScm-^{1} at Pa and the highest of 397.80 µScm^{-1} at Ak. Comparatively, EC values were far below WHO's permissible limits of 1500 µScm^{-1} for drinking water. The moderate conductivities of all rivers could be attributed to inorganic substances such as metallic, bicarbonate and chloride ions which were naturally introduced into water, but which subsequently precipitated out due to adsorption and as part of a self-cleansing process of water bodies (WHO, 2003). The study found a very strong positive correlation of EC with As ($r = 0.820$) and Hg ($r = 0.696$).

Hg concentration ranged from 0.58 - 1.53 mgl^{-1} with a mean of 1.06 ± 0.20 mgl^{-1}. The highest level of the metal in water was found at Kd and the lowest at K. The levels were above limits for drinking water of 0.01 mgl^{-1} WHO (2006) and 0.2 mgl^{-1} (USEPA, 2009). In the Birim North District, lying south-west to the study area, Nartey *et al*. (2011) recorded Hg concentration in the range of 0.045 mgl^{-1} and 1.881 mgl^{-1}, and concluded that in contrast to upstream samples, concentrations of Hg in downstream samples exceeded the WHO guideline limit for drinking water.

Table 3: Correlation coefficient matrix of water quality variables

	As	BOD	DO	EC	Hg	NH_4-N	NO_3-N	pH	PO_4-P	T	TDS	Turb	WC
As	1												
BOD	-0.159	1											
DO	0 .184	-0.143	1										
EC	0.820^{**}	-0.129	-0.071	1									
Hg	0.556^{*}	-0.166	0.110	0.696^{**}	1								
NH_4-N	0.292	0 .117	-0.544^{*}	0.298	0.281	1							
NO_3-N	0.485	-0.166	0.341	0.399	0.049	-0.429	1						
pH	-0.406	0 .080	0.022	-0.340	-0.332	0.258	0.036	1					
PO_4-P	0.290	-0.063	0.152	0.336	0.138	0.435	0.511	0.281	1				
T	-0.079	0.135	0.016	-0.239	-0.077	-0.082	0.139	0.481	0.315	1			
TDS	0.142	-0.110	-0.143	0.215	0.359	-0.123	0.049	-0.481	0.141	0.241	1		
Turb	0.232	-0.293	-0.250	0.214	0.373	-0.395	-0.353	0.092	0.128	0.370	0.152	1	
WC	0.262	-0.477	-0.223	0.235	0.289	-0.290	-0.208	-0.170	0.008	0.148	0.451	0.738^{**}	1

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

Nitrate and phosphorus occur in water as NO_3-N and PO_4-P respectively and both are useful for plant growth (Chapman, 1992). However, excess concentrations of phosphorus of 0.015 mgl^{-1} and nitrogen of about 0.3 mgl^{-1} are known to promote algal bloom (Klein, 1962; WHO 2003). In this study, levels of NO_3-N and PO_4-P in water samples ranged between 3.50 and 5.40 mgl^{-1} and between 0.47 and 2.2 mgl^{-1} respectively. The respective means were 4.07 ± 0.74 mgl^{-1} and 1.63 ± 0.82 mgl^{-1}. Compared to the permissible limit in drinking water of 5.0 for nitrate and a natural range of 0.005 - 0.02 mgl^{-1} for phosphorus (Chapman, 1992), levels of the two nutrients in most rivers, except Ma, Br and Su, were relatively high. The minimum recorded concentration of NH_4-N was 27.5 mgl^{-1} at site K while a maximum of 116.30 mgl^{-1} was observed at site Ab. The mean NH_4-N was 68.44 mgl^{-1} ± 25.13. Though no aquatic weeds were found in sampled rivers and streams, the high levels of these nutrients in them make them vulnerable to evasion by aquatic plants (Asante *et al.*, 2008).

Water pH ranged between 6.1 - 6.8 and the mean was 6.4 ± 0.03, suggesting acidic condition of all the sampled rivers. This is within WHO's recommended range of 6.50 - 8.50 for domestic water (WHO, 2003), suggesting that all the sampled rivers are suitable for drinking purposes.

Water temperature could vary with the season or the shading effect of vegetation, particularly woodland cover, as well as the level of biological activities in water (Ahearn *et al.*, 2005). This study recorded a temperature range of 23.0 - 27.3˚C and a mean of 24.52 ± 0.94˚C.

TDS in water samples ranged from 6127 in Su to 15925 mgl^{-1} at Po and the mean was 9496 ± 3341. TDS levels in all water samples were far above WHO's guideline for drinking water quality. According to WHO (2003), though no health based limit exists for TDS in drinking water, it becomes significantly and increasingly unpalatable when TDS in drinking water rises above 1000 mgl^{-1} and may become objectionable to the consumer at values greater than 1200 mgl^{-1}. A TDS level of less than 500 mgl^{-1} is regarded as generally good for drinking water.

TDS comprises mainly inorganic salts of potassium, sodium, calcium, magnesium, bicarbonates, chlorides, sulphates and some organic matter dissolved in water, and usually arises from rock minerals, sewage, runoff and industrial effluents (USEPA, 1976).

Table 4: PCA of water quality parameters indicating the first five components and loading values

Eigenvalues explained by PCs						
	1	2	3	4	5	
	3.4348	2.8312	1.9720	1.1867	1.0834	
Percentage total variance explained by PCs						
	1	2	3	4	5	
	26.421	21.778	15.170	9.129	8.334	
	Percentage cumulative variance					
	1	2	3	4	5	
	26.421	48.200	63.369	72.498	80.832	
	Component loadings					
	1	2	3	4	5	Communalities
As	0.8389	0.2463	-0.0116	-0.1314	0.1238	0.9546
BOD	0.0395	0.2207	0.1232	-0.0333	0.6492	0.9704
DO	-0.0237	-0.1570	-0.0570	-0.1773	-0.1384	0.9832
EC	0.2241	0.0961	0. 9253	0.0098	0. 1362	0.9612
Hg	0.8048	-0.0310	-0.0275	-0.1556	0.1243	0.9373
NH$_4$-N	0.3478	-0.1680	0.1205	-0.7483	-0.2882	0.9215
NO$_3$-N	0.2450	0.0452	0.2267	0.7798	0.1658	0.9734
PO$_4$-P	0.3318	0.4087	0.7489	0.3148	0.0011	0.9475
pH	-0.3145	-0.0616	0.8275	-0.3405	0.0317	0.9785
T	-0.1892	0.0560	0.8318	0.6417	0.1558	0.9872
TDS	0.1702	0.6742	0.8772	0.1181	0.1398	0.9868
Turb	0.3375	0.5734	0.4046	0.3121	-0.0787	0.9836
WC	0.5625	0.2218	0.1847	0.4106	0.2608	0.8495

Note: Bold figures indicate significant loadings

Mean turbidity of water was 43.68 ± 17.72 mgl^{-1} and ranged from 17.2 mgl^{-1} to 96.60 mgl-^{1}. The transport of eroded contaminants such as soil particles through surface runoff from neighbouring bare farmlands could be the source of high turbidity in the river water, especially where the vegetation cover has been greatly disturbed (Peavy *et al*., 1985). There is a very strong and significant positive correlation at $p < 0.01$ between turbidity and water colour ($r = 0.738$).

Colour of water (WC) is an important physical property because of its implications for drinking water supply. Water colour ranged from 30.4 to 127.6 Hz and the mean was 71.31 ± 3.65 Hz. These values are well above the 15 Hz limit recommended for drinking water (WHO, 2003). Colour in natural water usually results from leaching of organic materials, primarily as a result of dissolved and colloidal humic substances. Iron and other corrosive metals also strongly influence water colour, either as natural impurities or as corrosion products. Highly coloured water may be due to decomposing vegetation in water (WHO, 2003).

A KMO test produced a value of 0.781, suggesting the suitability of the dataset for factor analysis and interpretation. At an eigenvalue greater than 1.0, PCA extracted 5 significant components. Components which were of eigenvalues <1.0 were considered insignificant and therefore omitted from further analysis. Table 4 shows the weights, eigenvalues and variances of the 5 components, with significant eigenvalues indicated in bold. Figure 2 is the corresponding scree plot showing the eigenvalues sorted from large to small as a function of the principal components' number.

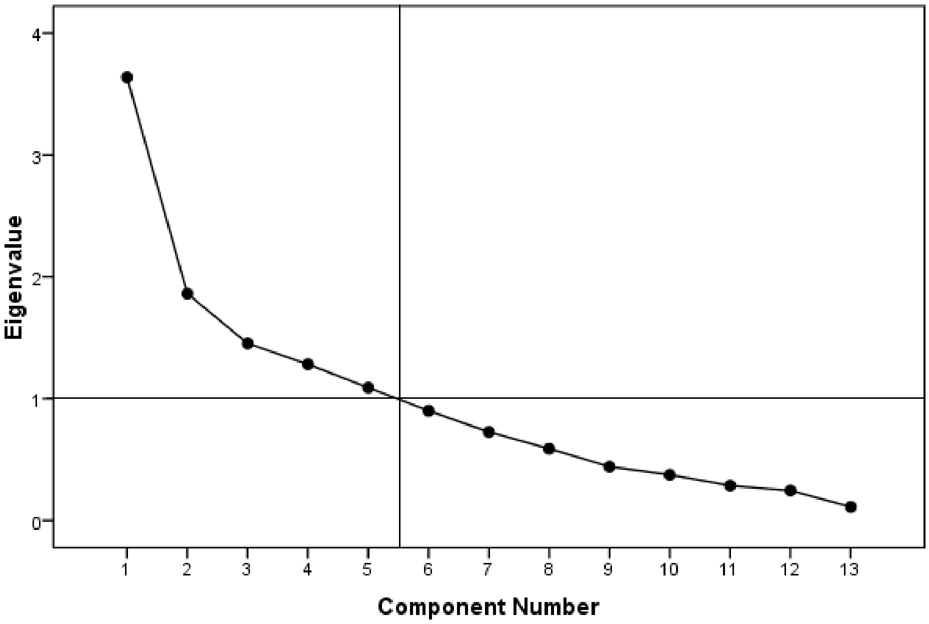

Fig 2: Scree plot showing the eigenvalues sorted from large to small as a function of the principal component number

The Table indicates that nearly 80.83% of total variance in water quality data is explained by the first 5 PCs and that variables' loading spread over the PCs, suggesting a linkage of drinking water quality in Akyem-Abuakwa to several anthropogenic sources. PC1 showed a strong positive loading on As (0.84) and Hg (0.80) and a moderate loading on WC (0.56), explaining 26.4% of the total variance. Factor 1 is interpreted to represent the contamination of surface water from artisanal gold mining. Both Hg and As have been associated with surface water contamination in artisanal gold mining areas of Ghana (Armah *et al*. 2010b).

PC2 contains moderate loadings of TDS (0.67) and turbidity (0.57) and explains an additional 21.8% of total variance. This component probably represents non-point pollution from soluble rock salts alongside the transport of sediment into rivers through surface run-off. PC3 explained 15.2% of the total variance and is composed of T (0.83), TDS (0.87) and EC (0.93). This component is associated with electrical conductivity of water contributed by inorganic ions in solution and facilitated by temperature. This component explains the contribution of ions to water pH from the chemical weathering of rock-phosphates such as limestone and the subsequent impact on water acidity, facilitated by temperature. PC4 loaded strongly on NO_3-N (0.78), NH_4-N (-0.75) and moderately to PO_4-P (0.62) and T (0.64) and accounted for an additional 9.1% of the total variance. The component most possibly represents non-point source pollution from agricultural fields, especially from the application of agro-chemicals such as nitrogenous fertilizers and pesticides by farmers. The negative relationship between NH_4-N and NO_3-N could suggest a reciprocal relationship involving the conversion of ammonium into nitrate by oxidation, the reaction being temperature-dependent (Praus, 2007). With a moderate loading on BOD (0.65), PC5 explained 8.3% of total variance. The likely contaminants are organic solids and wastes, especially from domestic, commercial and agricultural origins, which reach the rivers and streams by surface run-off. The respective communalities show that all the variables were described to an acceptable level (Table 4).

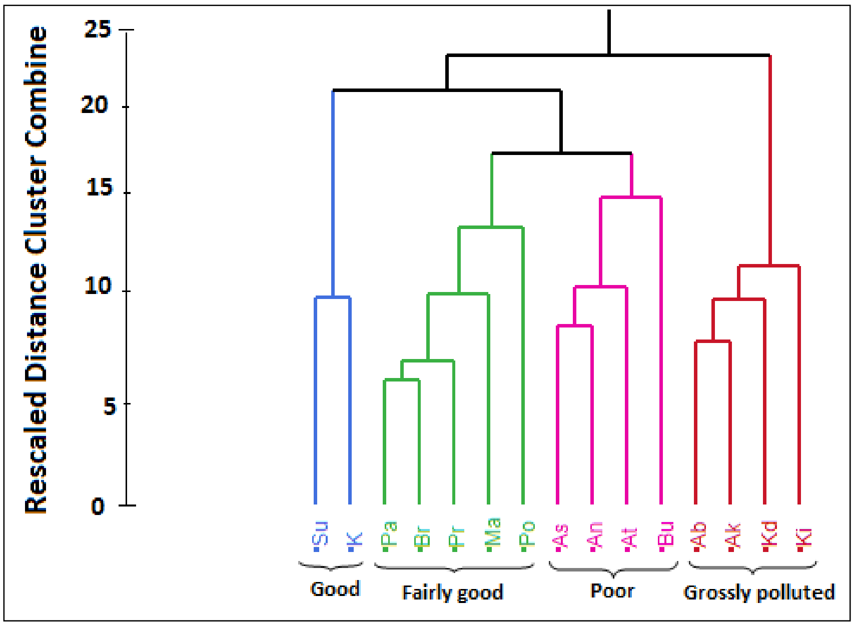

Fig 3: Dendrogram showing the clustering of rivers/streams according to their drinking water quality

Cluster analysis categorized water samples from the 15 rivers/streams into four spatially distinct groups (fig.3). Cluster membership revealed strong associations among the sources of drinking water. According to WRC's classification of raw drinking water (WRC, 2003), rivers Subri (Su) and Kadee (K) serving Subriso and Kadewaso communities respectively are of good quality. Both rivers are located in the Atiwa district (fig.1). River Bereponso (Br), also in the district, is in fairly good condition. In the same district, and along the Birim river, however, different levels of pollution were identified, ranging from poor at Anyinam (An) to grossly polluted at Akrofufu (Ak) and Abomoso (Ab).

River Pram at Pramkese (Pr) is in fairly good condition, river Apam at Asuom (As) in poor condition while Akwatia (At) and Kade (Kd) are poor and grossly polluted respectively. So far as drinking water quality is concerned, As, An, At and Bu are all of poor quality while Ab, Ak, Kd and Ki are grossly polluted. On the other hand, Kd and Po, both in the East Akim Municipality, are of fairly good quality.

A linear discriminant analysis produced three discriminating functions: discriminate function 1 (87.6% of total variance) at p-value of 0.000 and Wilk's lambda of 0.003; discriminant function 2 (9.6% of total variance) at p-value of 0.004 and Wilk's lambda of 0.094; and discriminant function 3 (2.8% of total variance) at p-value of 0.064 and Wilk's lambda of 0.466. The analysis with cross-validation correctly classified all the cases (100%). A plot of the first two discriminant factors grouped drinking water sources into four water quality classes as depicted in figure 4.

In order to identify variables that are most important in discriminating among the groups, a step-wise discriminant analysis (SDA) with cross-validation was carried out with probabilities of F-to-enter-of 0.05 and F-to-remove of 0.10. In all, a maximum of 26 steps were employed. In five-step combinations, the results indicated that the most discriminating variables for grouping the water samples in order of relevance are turbidity (α = 0.406), arsenic (α = 0.316), temperature (α = 0.100), phosphate-phosphorus (α = 0.033) and total dissolved solids (α = 0.009), α representing Wilks' lamda of significance.

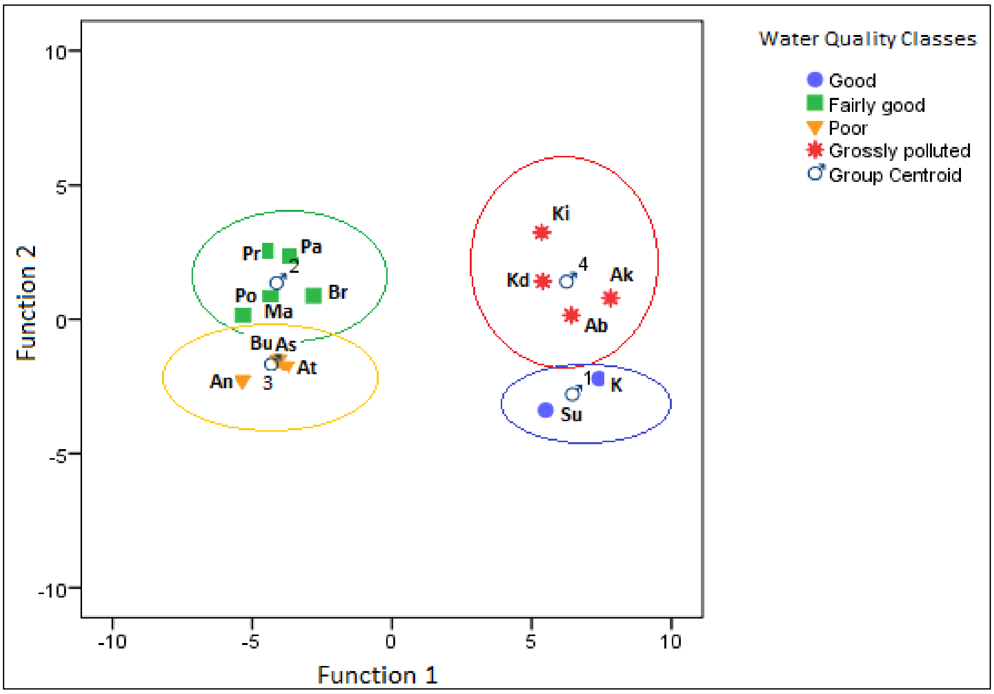

Fig 4: Plot of discriminant functions indicating water sources as belonging to four groups

Conclusion

The spatial pattern and latent sources of contamination of water from rivers and streams used as drinking water sources by communities in Akyem-Abuakwa, Ghana, were investigated using multivariate statistics. The analysis suggests that concentrations of arsenic, mercury, total dissolved solids, turbidity, water colour, nitrate-nitrogen and phosphate-phosphorus are higher in most rivers/streams used by communities as drinking water sources, compared to World Health Organization limits for drinking water. Results from PCA/FA analyses also suggest high loading of As and Hg, most likely from artisanal gold mining activities. The significant correlation of the two heavy metals supports this interpretation. The other component factor loadings (PCs 2, 3, 4 and 5) also reveal other non-point sources of pollution such as agricultural activities, lithology and domestic wastes disposal.

Cluster analysis revealed that sampled rivers/streams fall into four water quality groups, ranging from good to grossly polluted water. The application of DA confirmed the four water quality classes assigned by CA and illustrated the spatial relationship between these drinking water sources. The analysis also identified in five-step combinations turbidity, arsenic, temperature, phosphate-phosphorus and total dissolved solids as the most discriminating variables for grouping the water samples. The study demonstrates the utility of multivariate statistical techniques for spatial differentiation and identification of latent factors influencing drinking water from rivers and streams in Akyem-Abuakwa, Ghana. Nearly all rivers/streams in the Kwaebibirim and East Akim districts that are sources of drinking water to communities are polluted, largely through artisanal gold mining. This is in contrast to most rivers that are drinking sources in the Atiwa district. This information could be relevant in guiding local water quality managers to design cost-effective strategies to effectively monitor and protect drinking water sources of the study area from further degradation.

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