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Temporal Relationship of Environmental Arsenic and *M. ulcerans* Infection in the Amansie West District

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ABSTRACT

Background: Temporal variations of infectious diseases in humans range from childhood related disorders such as measles, diphtheria and chickenpox to faecal-oral infections, such as cholera and rotavirus, vector-borne diseases. The causes of such seasonal and longer period cycles in the incidence of these diseases have long puzzled epidemiologist. Buruli Ulcer (BU), an ulcerative disease of skin, subcutaneous tissue and sometimes bone has also been linked to temporal relationships in recent times. **Methodology:** In this study, arsenic and other physicochemical parameters from streams and soils around streams were analysed over a period of 24 months for temporal relationship and BU transmission. **Results:** Results from the study showed that, mean arsenic concentration for the streams in the entire sampling community was (0.6325 mg L^{-1}; Range, 0.01-1.458). This figure exceeded the World Health Organization (WHO) recommendations for arsenic in drinking water (0.01 mg L^{-1}). The results further revealed the influence of temporal relationship with arsenic levels in all the steams. Mean arsenic levels in the streams during the dry sampling periods over the period of study were significantly high in all the communities compared to the wet sampling counterpart ($p<0.05$). **Conclusion:** Results of the study have confirmed that, the Amansie West District is generally polluted with arsenic and these levels are high during dry periods which coincide with peak periods of BU incidence in endemic regions. It has therefore indicated a temporal relationship between *Mycobacterium ulcerans* infection incidences and relatively dry periods.

Key words: Arsenic, temporal relationships, buruli ulcer, *Mycobacterium ulcerans*

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INTRODUCTION

Temporal relationships of infectious diseases in humans range from childhood related disorders such as measles, diphtheria and chickenpox to faecal-oral infections, such as cholera and rotavirus, vector-borne diseases[1]. The causes of such seasonal and longer period/cycles in the incidence of these diseases have long puzzled epidemiologists[2]. Buruli Ulcer, an ulcerative disease of skin, subcutaneous tissue and sometimes bone has also been linked to temporal relationship[3]. This neglected tropical disease is caused by *Mycobacterium ulcerans* (MU) leading to permanent disabilities such as restricted movement of affected body parts[4].

In a study published by Duker *et al.*[5] predicted that arsenic in arsenic enriched domains and farmlands in the Amansie West District was a positive covariant with BU infections[5]. Arsenic occurs naturally and ranks as 20th most abundant trace element in the earth's crust. Its wide distribution in the environment as well as association with some non-weathering-resistant mineral deposits (e.g., sulphide minerals) has contributed to its release in large amounts into the environment[6]. Arsenic was used and still being used in hardening of alloys, production of semiconductors, pigments, glass manufacturing, pesticides, rodenticides and fungicides[7]. It is also used as an ingredient of drugs for the treatment of some diseases (e.g., sleeping sickness, chronic myeloid leukemia)[8].

Research has shown that, small scale mining activities (popularly known as galamsey) which is one of the main occupation in the Amansie West District, a buruli ulcer endemic community in Ghana, cause arsenic to be released in large quantities from oxidized sulphide minerals[9]. This has resulted in high levels of arsenic in surface water, groundwater soil and vegetation. It has been reported that, changes in weather has the

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potential to determine both the level and/or particular species of arsenic in the environment at a given time[10]. It should be noted that, alterations in the weather, especially periods of high temperatures associated with draught can enhance environmental arsenic toxicity[11]. This therefore supports the notion that, dry periods are preparatory stages in which arsenic-rich beds (pyrites and arsenopyrites) are exposed to air and subsequently oxidized[12].

In a study published[13] where the susceptibility of arsenic exposed ICR mice to buruli ulcer development was investigated, Gyasi *et al.*[13] established that high levels of arsenic could make mice susceptible to BU infection. Although, a plethora of studies has gone into arsenic contamination in the environment, whether these arsenic levels in the environment has a positive correlation with temporal relationship linking *Mycobacterium ulcerans* infections is yet to be fully explored. This present study therefore, aimed at the analysing arsenic and other physicochemical parameters in the environment (water and soil) over a period of 24 months to assess its temporal relationship to buruli ulcer infection in the Amansie West District, Ghana.

MATERIALS AND METHODS

Study area: The Amansie West District within the Ashanti Region, Ghana, was chosen for the study. The study communities were limited to Yawkasakrom, Bonsaaso and Tontokrom (endemic communities). Others include Yawhemekrom, Manso Mim and Manso Akropong (non endemic).

Sample collection: Water and soil samples from streams where study participants wash hands and feet (sometimes drink) on their way to their house from farms and galamsey sites were collected from February 2010-February 2012. With the help of Global Position System (GPS 76, Garmin, 2001, 2101 C129 Series User Manual Download the Official User), 6 streams and soils around these streams from the 6 selected communities were selected. Sampling was done 6 times for all the communities within a period of 24 months. Monitoring was limited to equal periods of dry and wet seasons.

Water samples: Five hundred mililiter capacity sampling bottles were washed, disinfected (by rinsing with 5 mL of concentrated H_2SO_4) and carried in a cool ice chest. Bottles were submerged under the stream, vigorously agitated after which there were filled. With the help of field DO meter and conductivity meter, Total Dissolved Solids (TDS), conductivity and pH were determined *in situ* and recorded. Water samples were acidified with 5 mL nitric acid on site prior to laboratory determination. Samples were kept in cool ice box packed with ice blocks and quickly transported to the laboratory for analysis.

Soil samples: Composite soil samples from 10 different spots at a depth of about 10 cm from the top soil within 5 m radius from each stream at a particular sampling were separately collected randomly with a sterile mini shovel from the 6 selected communities. They were then pooled together and mixed after which about 50 g was taken in a sterile white polythene bag. Each soil from a designated community was separately labelled and kept on ice after which they were quickly transported to the laboratory for analysis.

LABORATORY ANALYSIS FOR ARSENIC

Digestion of water: Five hundred millilitres of acidified water collected from streams in the six study communities were taken out of the cool ice chest and placed on an analytical bench in the laboratory. Then after, 5 mL of concentrated nitric acid were added, placed on heated water bath till the samples volume reduced to 50 mL. Samples were then filtered through a 45 micron Whatman's No. 1 filter paper into sterile container and stored for onward analysis with the Varian 220 (SpectrAA 220) at Anglo Gold, Obuasi, Ghana.

Digestion of soil: To 1 g of the soil sample, 30 mL of digestion ions in the ratio of 9: 4 (Nitric acid: Per chloric acid) was added. The resulting supernatant was digested on a heated water bath until the soil became clear whiles ensuring that, the soil did not dry out in the conical flask by toping up occasionally with distilled water when volume decreased below 20 mL. Upon obtaining a clear solution, the resultant solution was topped up to 50 mL, filtered with 45 micron Whatman's No. 1 filter paper and stored for onward analysis with Varian 220 (SpectrAA 220).

Determination of arsenic: Arsenic in water and soil after digestion was placed in a labelled sterile test tube, tightly covered and transported to the Environmental Monitoring Laboratory at the Anglo-Gold Ghana Limited (Obuasi, Ghana). Arsenic levels from these samples were determined using the injection of hydride generation Atomic Absorption Spectrophotometer (Varian 220, SpectrAA 220).

RESULTS

Results from analysis of arsenic and other related physicochemical parameters from streams and soils around streams monitored over a period of 24 months (i.e., during wet and dry sampling periods) showed that,

mean arsenic concentration for the streams in the entire sampling community was (0.6325 mgL^{-1}; Range [0.01-1.458]). This figure exceeded the World Health Organization[4] and Ghana Environmental Protection (GEPA) recommendations for arsenic in drinking water (0.01 mgL^{-1}). Mean arsenic concentration for soils around streams for the study communities within the Amansie West District during the period of sampling was (0.9045 mg kg^{-1}) as shown in Table 1. Electrical conductivity when monitored however also showed a mean value of 136.8 µsec cm^{-1} with a range and standard deviation of (68.8-523.9) and (82.4), respectively falling below WHO and GEPA recommendations (1,000 mg L^{-1}) for drinking water (Table 1). Mean Total Dissolved Solids (TDS) recorded for all the six streams selected for sampling during the study was 61.92 mg L^{-1}. Acidity analysis of the streams in the six sampling communities selected from the Amansie West District during the 24 months period also showed a mean pH of 6.7, standard deviation and standard error of mean of (0.4481), [0.07468], respectively as shown in Table 1 below. This figure was within the WHO and GEPA recommendations for drinking water (Table 1).

Analysis of results of the environmental monitoring of arsenic in the six selected communities of the Amansie West District based on season of sampling showed the influence of temporal relationship arsenic levels in all the steams. Mean arsenic levels in the streams during the dry sampling periods over the period of study were generally high in all the communities compared to the wet and these were all significant ($p<0.05$). The Nwene stream (Manso Akropong) recorded the highest mean arsenic level of (1.446 ± 0.01117 mg L^{-1}) compared to the rest of the study population. This figure was greater than that of the wet sampling period of that same community (0.01033 ± 0.00033 mg L^{-1}) and this was significant ($p<0.0001$) as shown in Table 2.

During the dry sampling period, the Abesuam stream (Yawhemekrom) recorded the lowest mean arsenic level (0.6313 ± 0.00713 mg L^{-1}) compared to the rest of the sampling communities during the 24 months of monitoring (Table 2). For the wet sampling period however, both Bonsaaso (Bonsaan stream) and Manso Akropong (Nwene stream) recorded the lowest mean arsenic level for streams during the dry sampling period (0.01033 ± 0.00033 mg L^{-1}). It should be noted that, during periods of dry sampling, the study showed that streams in all the three endemic communities had mean arsenic levels greater than 1.0 mg L^{-1} (1.072, 1.119 and 1.322 mg L^{-1}) far exceeding the WHO recommendations for drinking water of 0.01 mg L^{-1} by over 100 folds shown in (Table 2).

Analysis of seasonal related environmental monitoring of arsenic levels in soils around streams in the six selected communities from the Amansie West District over the two year period has showed that, during periods of dry sampling (i.e., periods without rains), sampled soils around all the streams monitored were greater for arsenic levels compared to their wet sampling (i.e., periods during the rains) counterpart. These variations however were generally not statistically significant. The Asuobom stream (Tontokrom) recorded the highest mean level of arsenic in soil around streams (2.785 mg kg^{-1}) during the dry sampling period

Table 1: Mean levels of arsenic (Water and soil) with some physicochemical parameters in the Amansie West District of Ghana over a period of 24 months

Parameters	Mean	Range	SD	SEM	WHO	GEPA
Arsenic (streams) (mg L^{-1})	0.6325	0.01-1.458	0.520	0.087	0.01	0.01
Arsenic (soils) (mg kg^{-1})	0.9045	0.01-2.957	0.969	0.162	-	-
Conductivity (streams) (µsec cm^{-1})	136.8000	68.8-523.9	82.400	13.730	1,000	1,000
TDS (streams) (mg L^{-1})	61.9200	25.6-146.0	25.790	4.298	500	500
pH (streams)	6.7000	5.8-7.9	0.448	0.075	6.5-8.5	6.5-8.5

SD: Standard deviation (N = 36), SEM: Standard error of mean, WHO: World health organization, GEPA: Ghana environmental protection agency

Table 2: Temporal relationship of mean arsenic levels in some streams monitored in the Amansie West District over a period of 24 months

	Dry sampling	Wet sampling	
Community	Mean arsenic (mg L^{-1})	Mean arsenic (mg L^{-1})	p-value
Endemic communities			
Yawkasakrom (Aprapim stream)	1.072 ± 0.01322	0.04000 ± 0.0300	<0.0001
Bonsaaso (Bonsaan stream)	1.119 ± 0.00612	0.01033 ± 0.00033	<0.0001
Tontokrom (Asuobum stream)	1.322 ± 0.00466	0.50070 ± 0.16140	0.0070
Non endemic communities			
Manso mim (Asuapre stream)	0.9140 ± 0.00153	0.16630 ± 0.06633	0.0004
Manso akropong (Nwene stream)	1.4460 ± 0.01117	0.01033 ± 0.00033	<0.0001
Yawhemekrom (Abesua stream)	0.6313 ± 0.00713	0.35830 ± 0.06457	0.0137

Levels of significance were determined using Students unpaired t-test. ns implies $p>0.05$ (not significant); $p<0.05$ is considered statistically significant at 95% confidence interval. Words in parenthesis, next to the communities refers the names of streams where water and soil samples were taken, Figures in preceded "±" by refers to the Standard deviation (N = 3). Wet sampling periods refers to sampling times during the rainy season whiles dry sampling period refers to sampling periods in the dry season

Table 3: Temporal relationship of mean arsenic levels in soils monitored around some streams in the Amansie West District over 24 months

Community	Dry sampling Arsenic (soil) (mg kg^{-1})	Wet sampling Arsenic (soil) (mg kg^{-1})	p-value
Endemic communities			
Yawkasakrom (Aprapim stream)	1.448±0.5440	0.4527±0.01734	0.1414
Bonsaaso (Bonsaan stream)	1.238±0.8540	0.4333±0.01384	0.3997
Tontokrom (Asuobum stream)	2.785±0.09293	1.1900±0.3128	0.0081
Non endemic communities			
Manso mim (Asuapre stream)	0.4053±0.3953	0.2927±0.1047	0.7966
Manso akropong (Nwene stream)	0.5340±0.5240	0.1613±0.1464	0.5310
Yawhemekrom (Abesua stream)	1.7510±0.6037	0.1640±0.09418	0.0602

Levels of significance were determined using Students Unpaired t-test. ns implies $p > 0.05$; $p < 0.05$ is considered statistically significant at 95% confidence interval. Words in parenthesis, next to the communities refers the names of streams where water and soil samples were taken, Figures preceded by ±refers to the Standard Deviation (N = 3)

Table 4: Mean arsenic levels of stream in some selected communities in the Amansie West District stratified by first and second12 months of sampling

Communities	Year 1 Mean (mg L^{-1})	Year 2 Mean (mg L^{-1})	p-value
Endemic communities			
Yawkasakrom (Aprapim stream)	0.7207±0.3556	0.3917±0.3377	0.539
Bonsaaso (Bonsaan stream)	0.7517±0.3704	0.3774±0.3674	0.5128
Tontokrom (Asuobum stream)	1.055±0.2677	0.7677±0.3201	0.5285
Non endemic communities			
Manso mim (Asuapre stream)	0.6430±0.2715	0.4373±0.2447	0.6037
Manso akropong (Nwene stream)	0.9640±0.4766	0.4927±0.4827	0.5254
Yawhemekrom (Abesua stream)	0.4930±0.1315	0.4967±0.07452	0.9818

Levels of significance were determined using students unpaired t-test. ns implies $p > 0.05$ (not significant); $p < 0.05$ is considered statistically significant at 95% confidence interval. Words in parenthesis, next to the communities refers the names of streams where water and soil samples were taken, Figures preceded by "±" refers to the standard deviation (N = 3). Year 1 and 2 refers to the first and second 12 months of sampling

compared to the rest of the streams in the 5 study communities within the district. This mean arsenic level in soil around the stream was greater than its wet sampling counterpart (1.190 mg kg^{-1}) and this was significant ($p = 0.0081$) as shown in Table 3.

Within the non endemic communities, soils around the streams of Yawhemekrom (Abesua stream) recorded the highest level of arsenic (1.751±0.6037 mg kg^{-1}) during the dry sampling period over the 24 months compared to the rest of the non endemic communities as shown in Table 3. In analysing arsenic levels in soils around streams for the 3 buruli ulcer endemic communities selected, soils around the Bonsaan stream (Bonsaaso) recorded the lowest mean arsenic levels (1.238±0.8540 mg kg^{-1}) during the dry sampling periods compared to the other two endemic communities.

Analysis of arsenic levels in streams of some selected communities in the Amansie West District during 24 months of monitoring showed that, there were no significant differences between arsenic levels monitored for the first and the second 12 months of sampling in all the selected communities. Asuobum stream (Tontokrom) recorded the highest mean arsenic level for streams recorded for the first 12 months (1.055±0.2677 mg L^{-1}) compared to the rest of the communities as shown in Table 4. The mean arsenic level recorded for Tontokrom during the first 12 months of sampling was greater than that of its second 12 month (0.7677 mg L^{-1}) though this was not significant ($p = 0.5285$). This value however, exceeded the WHO recommendations for arsenic in drinking water (0.01 mg L^{-1}).

For the second year of sampling period, Bonsaaso recorded the lowest mean level of arsenic in its stream (0.3774±0.3674 mg L^{-1}) compared to arsenic levels recorded for the rest of the 5 selected communities from the district as shown in Table 4. The mean arsenic level recorded for the stream in Bonsaaso also exceeded the WHO recommendation for arsenic in drinking water (0.01 mg L^{-1}). With the exception of Yawhemekrom, all the remaining selected communities from the district in the study recorded mean arsenic levels for the first 12 months of sampling greater than that of the second as shown in Table 4. Of all the three non endemic communities during the first 12 months of environmental monitoring of arsenic, Nwene stream (Manso Akropong) recorded the highest mean arsenic level (0.9640±0.4766 mg L^{-1}). This figure however was greater than all the mean arsenic levels recorded for the second sampling period (Table 4).

When soils around the streams of the 6 selected communities from the Amansie West District was monitored for arsenic over of 24 months, Tontokrom recorded the highest mean arsenic level for soils around

Table 5: Mean arsenic levels of soil around streams in selected communities in the Amansie West District stratified by the first and second 12 months of sampling

	Year 1	Year 2	
Communities	Mean (mg kg^{-1})	Mean (mg kg^{-1})	p-value
Endemic communities			
Yawkasakrom (Aprapim stream)	1.484±0.5077	0.4163±0.03205	0.1037
Bonsaaso (Bonsaan stream)	0.4173±0.2347	1.254±0.8133	0.3791
Tontokrom (Asuobum stream)	2.416±0.4579	1.558±0.5907	0.3151
Non endemic communities			
Manso mim (Asuapre stream)	0.06967±0.05967	0.6283±0.2980	0.1399
Manso akropong (Nwene stream)	0.01033±0.00033	0.6853±0.4655	0.2207
Yawhemekrom (Abesua stream)	0.7917±0.3567	1.123±0.9209	0.7541

Levels of significance were determined using Students unpaired t-test. ns implies $p > 0.05$ (not significant); $p < 0.05$ is considered statistically significant at 95% confidence interval. Words in parenthesis, next to the communities refers the names of streams where water and soil samples were taken, Figures preceded by "±" refers to the standard deviation (N = 3), Year 1 and 2 refers to the first and second 12 months of sampling

its stream (2.416±0.4579 mg kg^{-1}) compared to soils around the rest of the streams in the study communities. This figure was non-significantly greater than that of its second year of monitoring (1.558±0.5907 mg kg^{-1}), although this was not significant (p= 0.3151) as shown in Table 5. Manso Akropong recorded the lowest mean arsenic level for soils around stream (0.01033±0.00033 mg kg^{-1}) compared soils around the streams of the rest of the study communities in the Amansie West District and this was reported during the first year of sampling as shown in Table 5.

With the exception of Yawkasakrom and Tontokrom, soils around the streams recorded for all the remaining communities during the 24 months of environmental monitoring showed that, soils around streams had mean arsenic levels greater for the second year of sampling compared to the first (Table 5). For the second year of sampling, soils around streams of Tontokrom recorded the highest mean arsenic level (1.558±0.5907 mg kg^{-1}) compared to soils around streams in the remaining communities as shown in Table 5. This was however less than the mean arsenic level recorded for soils around streams during the first year of sampling, though this was not significant as shown in Table 5.

DISCUSSION

Analysis of results from the study has confirmed that, Amansie West District, the study area of this research is polluted with arsenic. Arsenic is known to be concentrated by both natural processes and naturally-occurring microorganisms which plays an essential role in the environmental fate of arsenic in relation to mechanisms of transformations (e.g., soluble and insoluble forms, toxic and nontoxic forms)[14]. Research has shown that other activities that have also exacerbated arsenic contamination in the environment are anthropogenic sources[15]. These activities include mining, indiscriminate use of fertilizers, pesticides, herbicides and chemical spillage among many others.

Agricultural associated irrigation, especially with wastewaters, can cause a problem of build-up of mobile and potentially toxic metals (e.g., arsenic) in soils and in surface runoff. In a work published by Duker *et al.*[16] using spatial modelling, predicted that Amansie West could be polluted with arsenic[16]. Gyasi *et al.*[17] in a pilot study recently attested to the fact that, the Amansie West District could be polluted with arsenic (water and soil)[17]. In a separate earlier study conducted in the same district (Amansie West District of Ghana),[18] showed that, in a community where BU is endemic and 44% of the patients (as a result of Buruli Ulcer infections) were farmers[18], irrigation of vegetable crops, especially in the dry season was by surface waters containing 0.252-0.535 mg L^{-1} arsenic[16].

Gyasi *et al.*[13] of researchers followed up with a study employing ICR (Imprinting Control Region) mice exposed to arsenic in place of drinking water at levels synonymous to concentrations detected in BU endemic communities in the Amansie West District. Result from the study showed that, in addition to dose dependent liver and spleen damage, there was microcytosis of the Red Blood Cell (RBC)[19]. The significantly high levels of arsenic in streams, recorded for all the study communities within the Amansie West District during the dry periods compared to that of the wet was consistent with literature[20]. This indicates a temporal relationship and environmental arsenic exposures.

The Amansie West District, the study area for this work lies within the tropical region of the world. In this district, there is a characteristic alternation of dry and wet seasons and this temporal relationship; research has shown influences the arsenic enrichment in the environment[21]. We have reported earlier Gyasi *et al.*[13] that arsenic treated ICR mice are susceptible to buruli ulcer development. It could be inferred that, high levels of arsenic in the environment during dry periods have the potential to increase the prevalence of the disease (During dry periods) in a buruli ulcer endemic community. Further reports Azcue *et al.*[22] have also

indicated that, gold mining increased considerably in the period 1980-1990 in the West African sub-region. This could translate into elevated arsenic levels in the environment and can possibly enhance susceptibility to *M. ulcerans* infection.

In a separate study,[23] undertook a study and concluded that, since 1980, new foci of BU had emerged in West Africa[23]. This as a matter of fact, coincided with an increased gold mining activity with-in the region. West Africa seems to have suffered the worst of buruli ulcer infections since 1989[24]. It was only as a result of a sharp increase in the incidence of mining activities in Ghana from 1993-1997 with subsequent increase of arsenic level in the environment that about 2,000 cases of BU was reported[18]. The high incidence of BU cases was coincident with the initial wave of legal registration of artisanal miners (1992-1996).

The non-significantly high levels of arsenic concentration in soils recorded during dry sampling period compared to the wet were also anticipated. Earlier studies have revealed that, seasonal variation affects, in general metal concentration and particularly arsenic speciation both in water and soil, apparently due to biologic uptake. Temperature changes, particularly dry spells may help to potentiate metal toxicity[11]. A drop in water levels in the tropical region of the world e.g., Amansie West District during dry seasons exposes arsenic-enriched substrate to air and are subsequently oxidized. The differences in arsenic levels in these soils however, are sometimes marginal[20].

It has been reported that, arsenopyrite and pyrites in the presence of dissolved oxygen undergoes aqueous oxidation based on many studies[12,20]. Dry period however, is a preparatory stage in which arsenic-rich beds (pyrites and arsenopyrites) are exposed to air. The rains during the wet season solubilize oxidized arsenic or secondary minerals and disseminate arsenic from soils into the ecosystem through floods or storm waters[11].

In a separate study in an arsenic-enriched environment,[25] also found that the peak period in which subsistence crops and fern contained the highest concentration of both species of arsenic (As^{3+}, As^{5+}) was the beginning of the dry season. This may imply bioaccumulation of arsenic in human tissues through ingestion of arsenic-enriched food and water in the soil which could cause, for example, immune dysfunction[26] and thereby susceptibility to bacterial infection[27].

In relation to Buruli Ulcer,[28] showed that temporal variation could influence *Mycobacterium ulcerans* infections. For example, in Australia, it was noted that the disease appeared at the end of the autumn or winter and in Papua New Guinea and Cameroun, it was also observed that, incidence of the disease increased during the dry season[29]. Amofah *et al.*[18] working in Ghana, revealed that, the peak incidence of the onset of symptoms of Buruli Ulcer infections was in September and October which incidentally happens to be the dry periods[18]. Similarly, in Côte d'Ivoire,[24] also found the peak incidence of Buruli Ulcer was in the same months. Coincidentally, this period happens to be the same era of the year where arsenic levels in water and soil recorded from our study in the Amansie West District was high. This could confirm a temporal relationship of environmental arsenic and MU infections in a BU endemic community.

CONCLUSION

Results of the study have confirmed that, the Amansie West district is generally polluted with arsenic and these levels are high during dry periods which coincide with peak periods of BU incidence in endemic regions. It has therefore indicated a temporal relationship between *Mycobacterium ulcerans* infection incidences and relatively dry periods.

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