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A PRELIMINARY STUDY OF SOURCES OF ARSENIC CONTAMINATION IN SOUTHWEST CAMEROON

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An important objective of this study is to understand the geological, hydrogeological and geochemical factors that contribute to the mobilization of arsenic in groundwater in the Ekondo Titi study area. Understanding the source, mechanism of mobilization, and transport of arsenic is important for evaluating the current threat to public health and for planning future water management. The survey conducted in Ekondo Titi reveals the occurrence of arsenic with concentration ranging from 0.1 mg/l in shallow aquifers to 2 mg/l in deeper aquifers. The mode of occurrence is geogenic and the arsenic is released into groundwater from iron oxyhydroxide by reductive dissolution, linked to oxidation of organic matter in the aquifer sediments. Computation of the risk factor shows that about 4000 people are probably at risk of arsenic poisoning.

INTRODUCTION

The provision of safe drinking water as well as water of acceptable quality in rural areas of Cameroon for human consumption remains a very crucial problem. For human consumption the most important parameter is water quality. Water quality is emerging as a key issue in Africa due to the prevalence of water borne diseases, especially gastroenteritis which is related to faecal pollution and inadequate hygiene (Tebbutt, 1983). Such problems are usually related to poor well siting and construction as well as to insufficient water and water distribution. Yet in addition to these human-induced pollution problems, water supplies may also have natural quality problems which are related to local geology. Interactions between water and rock-forming minerals during groundwater circulation may lead to the buildup of harmful concentrations of some metals that may exceed limits of general acceptability for domestic use (Edmunds and Smedley, 1996).

In Ekondo Titi more than 40.000 people live in an area of 192 km^2. Land use is dominantly agricultural but urbanization and industrialization are proceeding rapidly. Until the 1970s, drinking water was drawn dominantly from surface-water sources, and waterborne diseases such as cholera and dysentery caused hundreds of deaths. However during the last decades over 80% of potable water needs in Ekondo Titi have been provided by about 300 private and public wells tapping shallow aquifers, which contain variable amounts of arsenic.

Arsenic was first identified in the groundwater of Ekondo Titi in 1986, following geochemical studies of shallow groundwaters (Lawrence, 1986). Unfortunately, this information was effectively unknown in Ekondo Titi until late 2000 (Scanwater, 2000). These may be due to the remoteness and sparse nature of the population. Also no scientific and systematic study has been conducted in the region pertaining to the prevalence or incidence of arsenic poisoning.

High arsenic concentrations (significantly above the provisional WHO recommended limit of 10 micrograms per liter) can lead to serious skin ailments such as hyper pigmentation and keratosis which leads progressively to cancers of the skin, to damage of internal organs, cancer and ultimately death (WHO, 1993; National Academy Press, 2001). Symptoms may take five to fifteen years or longer to develop. Arsenic is now the greatest natural contaminant of groundwater and its mitigation constitutes one of the most important challenges for groundwater quality management in the 21st century (Aalerts et al., 2003).

Arsenic acute toxicity has been known for thousands of years, but the ability to detect even very low concentrations in water has led to the discovery of the link between arsenic and cancer. The problem of arsenic toxicity in groundwater is especially alarming in several countries in southeast Asia (Indian, Bangladesh, West Bengal, Cambodia, China, Pakistan, Taiwan, Thailand and Vietnam) making arsenic contamination the largest environmental health disease of the past century (Chen et al., 1999). Arsenic contamination is not only a health hazard for the people, it also hinders their economic and social development.

Although the health effects associated with chronic arsenic exposure have been reasonably well characterized in those areas around the world with high arsenic levels in drinking water, the association of adverse health effects with arsenic exposure in Cameroon is less clear. This is primarily due to the lower exposure levels in the great majority of Cameroon drinking water supplies, and the lack of research studies that look for health effects in arsenic exposed persons. Hence, there is a need to improve our understanding of the genesis of high arsenic groundwater from the various aquifers in order to develop strategies to improve the socioeconomic status of the affected areas. The objective of this paper is to provide an overview of the possible sources and mechanisms of the release and migration of arsenic in groundwaters in the Ekondo Titi area, the impact of arsenic contaminated groundwater on human health, and possible methods of remediation.

ARSENIC CONTAMINATION AREA - EKONDO TITI

Ekondo Titi and environs are located in the coastal plain of southwest Cameroon between latitudes 4°36’-4°42’ and longitude 9°0’-9°7’ (Figure 1) with an estimated population of about 40,000 inhabitants. The main relief units can be differentiated into hilly topography in the north and flat low-lying land in the south. The topography is characterized by volcanic hills ranging in elevation from 1000-1500 m which form the Rumpi hills, a series of plateaus separated by gorges and narrow valleys forming a morphological feature along the Cameroon Volcanic Line (CVL). The Rumpi hills are the remnants of cretaceous-tertiary volcanism (Dumort, 1986). The flat low-lying southern part is underlain by thick unconsolidated sands and volcanic material of recent times. The flat plain is generally known as the Lobe plain and it is highly drained and extensively exploited by agricultural plantations of palms and subsistence farming.

In the south and southwest there are salt water creeks surrounded by mangrove swamp and in the southwest the lower slopes of the recently active Mount Cameroon are found. The area is drained by the Malenge River and its tributaries flowing from the Rumpi highlands to the south and southeast jointing the Meme River. Precipitation varies throughout the area, with a maximum of 2400 mm in the highland areas in the north to virtually no rain on the Lobe plains for 3 to 4 months of the year.

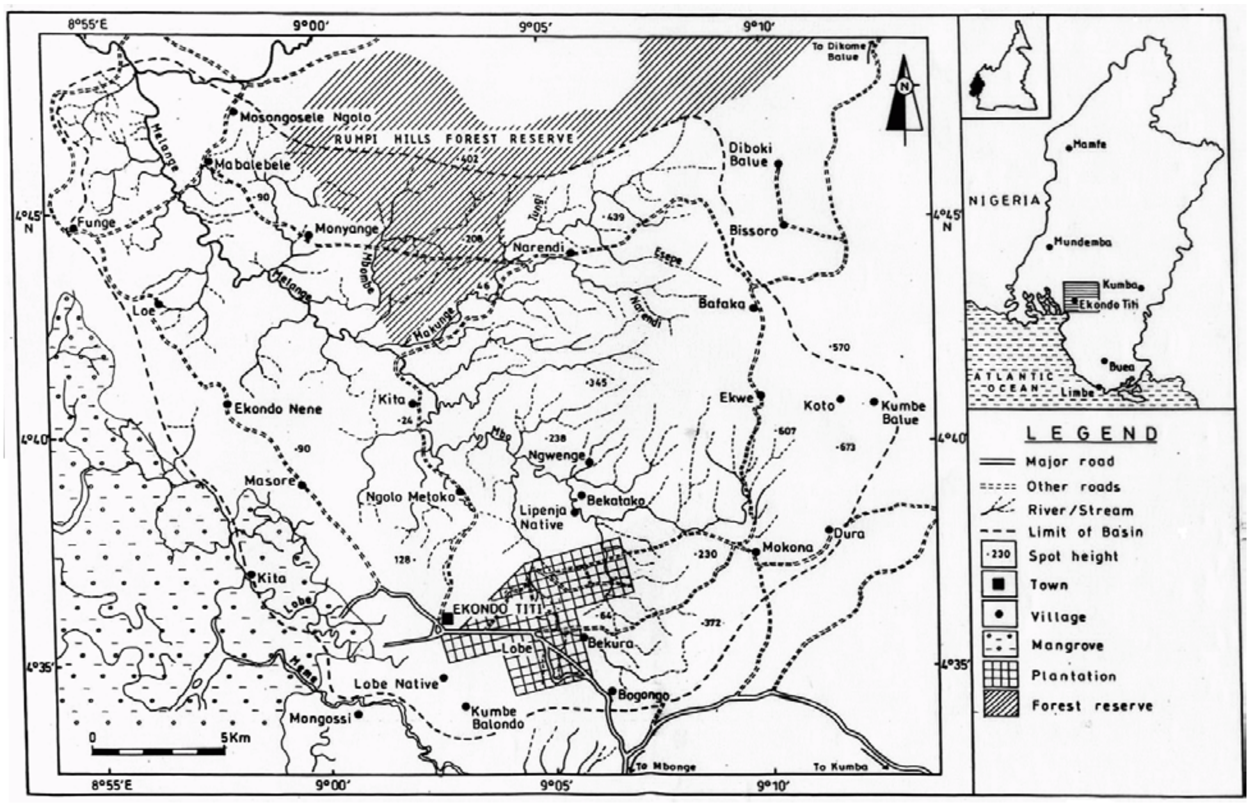

Figure 1. Location of study area.

METHODS OF STUDY

The paper draws on field studies and extensive literature review based on the published literature, but in some cases also drawing on "gray" literature where the data was believed to be of good quality and where this provided reliable information. In additional, a review was undertaken of available works of the study area, such as, Lawrence, (1986); Obenesaw et al., (1997); Dumort, (1968); Scan water, (2000); and Geofor, (2003). Representative literature and evidence was captured through this process, although in some areas these sources are sparse. Extensive literature review undertaken on arsenic health effects due to exposure to elevated arsenic consumption via drinking water has revealed serious skin ailments such as skin lesions, peripheral vascular diseases and cancer of the lungs, kidney, bladder and skin (IPCS, 2001).

Field studies involving interview of volunteers and the examination of the Medical Register for incidence of arsenic health related cases was conducted. The computation of the population exposed to elevated levels of drinking arsenic water was accessed through a search of the literature. The risk factor (Adel, 2000) for the people living in the study area was calculated using the average individual weight, individual water intake and the arsenic concentration to determine the probable population exposed to arsenic poisoning. .

GEOLOGY

The major rock formations in the study area are the Cretaceous-Tertiary sediments, Tertiary-Quaternary basalt andRecent alluvium shown in Figure 2 (Lawrence, 1986; Obenesaw et al., 1997). The Cretaceous-Tertiary sediments vary according to the environment of deposition and are essentially clastic, consisting of sands, sandstone, and conglomerates with subsidiary cays, shales, marl and lignite outcropping beyond the southern catchment limits with approximate thickness of

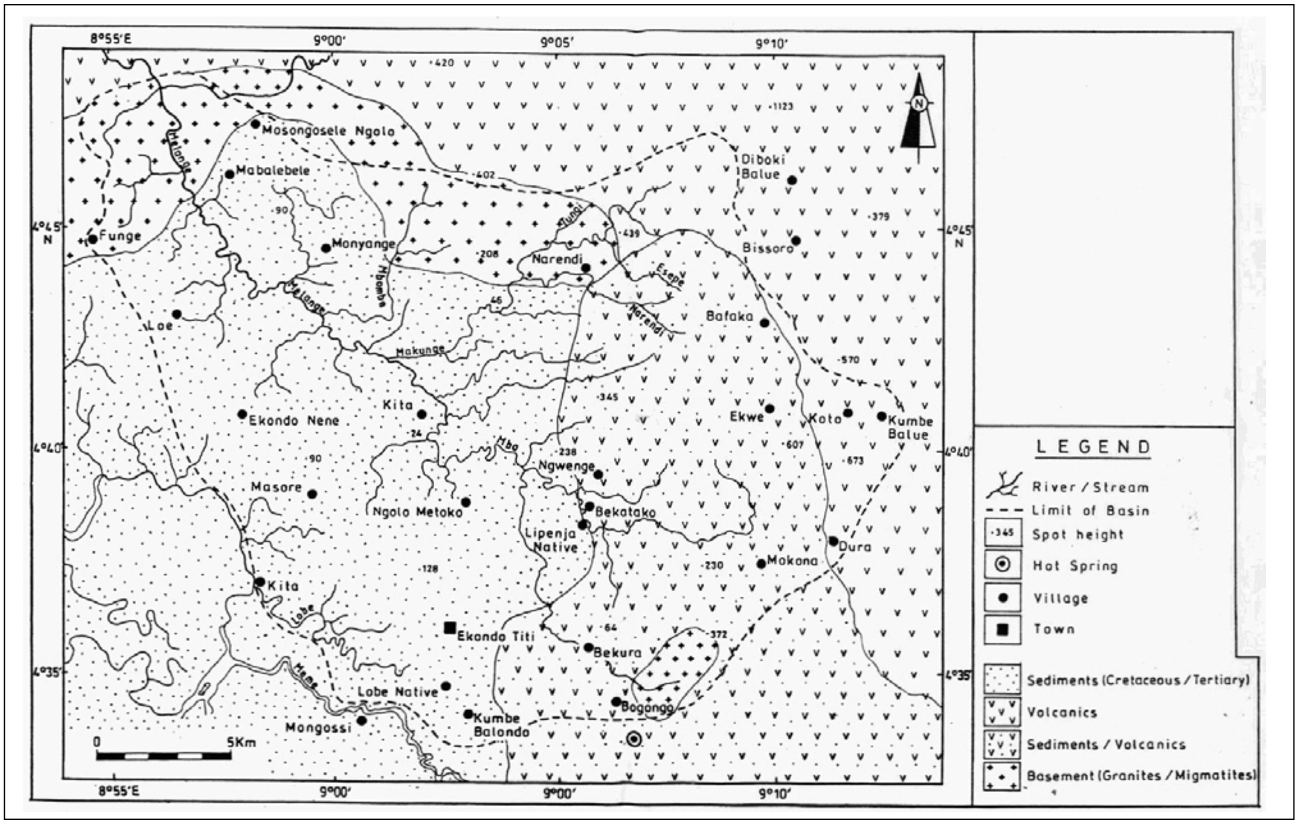

Figure 2. Geology of the study area.

60 meters (Obenesaw et al., 1997). The Tertiary-Quaternary basaltic lavas are associated with the Cameroon Volcanic Line, part of the major Foumban shear zone which intruded the sediments during the Miocene (Dumort, 1968). This magmatic activity resulted in extensive lava flows that formed the Rumpi hills in the north and intruded the sediments in the south. These extrusive events lapsed for sufficient time allowing a substantial layer of ash and basaltic lava flows to become interbedded with the extensive alluvium and lacustrine deposits. Recent alluvium is being deposited along the present coastline and margins of the Malenge-Meme River Basin.

HYDROGEOLOGY

The aquifers in the Ekondo Titi can be subdivided into two; namely a shallow and a deep aquifer (Figure 3). The shallow aquifers are the superficial deposits of the Lobe plain. The subsurface is made up of a lateritic layer and semipermeable clay-cap, followed by a thick formation of unconsolidated sand and gravels with occasional clay lenses.

The entire thickness of the superficial deposits averages about 30 m (Obenesaw et al., 1997). The clay-cap acts as an aquitard since its hydraulic conductivity is very low. The clay-cap plays an important role in governing the recharge and discharge to the underlying aquifer materials. The underlying unconsolidated sands and gravels form the main aquifers. About 90% of dug wells are mostly 2-25 m deep and rarely exceed 30 m in depth. Intense weathering in post-depositional periods has resulted in red-brown ferric-oxide cements and secondary clays, thus reducing intergranular porosity and permeability. At some sites the interlayering clays may give rise to perched aquifers within the study area. The superficial deposits are the main source of domestic water supply and contain variable amounts of arsenic. These deposits are underlain by an impermeable base of basaltic lava.

DEEP AQUIFERS

The basaltic layer forms the upper boundary of the shallow aquifers acting as an aquitard and plays an important role in the exchange of water between the shallow aquifers and deep aquifers.

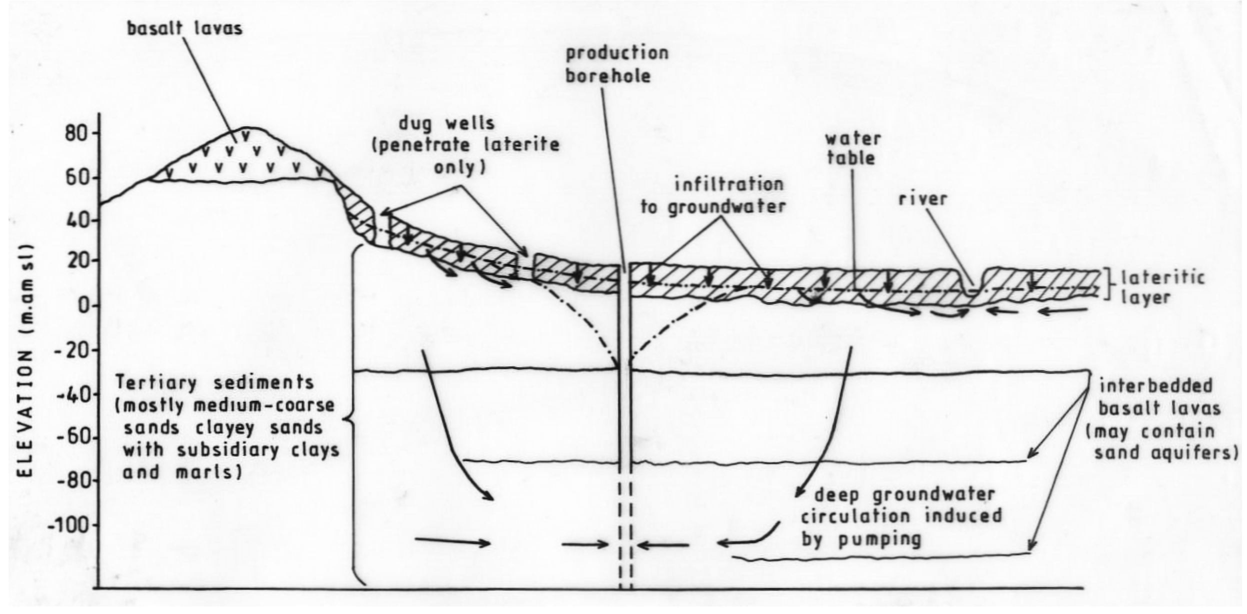

Figure 3. Hydrogeology of the study area.

The deep aquifer is essentially the fluvio-volcanic series consisting of Tertiary sands and interbedded basaltic lavas. The presence of basaltic lavas, particularly where thick, may reduce the overall permeability of the aquifer. But the basaltic sequence is sometimes subjected to tectonic activity, yielding high permeability secondary features such as joints, shears and fractures. The resulting sequence is made of the weathered regolith and ranges between 50 to 80 meters in depth (Scanwater, 2000). The occurrence of excessive iron due to extreme weathering prevents the utilization of these aquifers for domestic water supply.

NATURE OF ARSENIC AND OCCURRENCE

Arsenic is a naturally occurring metalloid element well known for both its acute and chronic toxicity (Fewtrell et al., 2005). Arsenic is usually found in the environment combined with elements such as oxygen, chlorine, carbon, hydrogen and sulfur. It has a high affinity for the sulfhydryl group. This results in arsenic accumulating in keratin-rich tissues such as skin, hair and nails (Rahnman et al., 2005). Thus arsenic levels in skin, hair and nail may be used as an indicator of arsenic exposure.

Arsenic is a chemical that is widely distributed in nature and principally occurs in the form of inorganic or organic compounds. Inorganic compounds consist of arsenite, the most toxic form, and arsenate the less toxic form. Exposure to inorganic compounds may occur in a variety of ways through certain industrial effluents, chemical alloys, pesticides, and wood preservative agents, combustion of fossil fuels, mining and dissolution in drinking water (National Research Council, 1999). The most commonly found arsenic compounds in groundwater are either trivalent arsenate (As (III)) under reducing conditions or pentavalent arsenate (As (V)) in oxidizing conditions or possibly in organic form (ATSDR, 2000). Although chemical transformation between these species occurs in the environment and in the body, the specific form ingested from drinking water may be significant because As +3 appears to be about 2-3 times more toxic than the As +5 form (ATSDR, 2000). The order of toxicity from the greatest to least being arsine, organo-arsine compounds, arsenate and oxides, arsenate, arsonium, and native arsine (Welch et al., 1988).

Arsenic intake by humans is probably greater from food (sea food) than from drinking water; however, the form present in fish is overwhelming present as organic forms of low toxicity. Drinking water therefore represents by far the greatest hazard since the species present in groundwater are predominantly the more toxic inorganic forms (Ferguson and Gavis, 1972; Smedley et al., 1996). Ekondo Titi and environs lie in the unconsolidated Tertiary to Quaternary sediments of the Lobe plain. It is possible that the alluvial sediments are enriched with arsenic bearing minerals which have been brought down from the surrounding Rumpi hills for millennia by the Meme-Malenge Rive systems.

SOURCES AND CAUSES OF ARSENIC CONTAMINATION

Several sources of arsenic concentration have been identified in different localities in the world but within the study area, the potential sources may be from.

a) The extensive use of fertilizers, pesticide, insecticides and herbicides containing arsenic compounds e.g. arsenate pesticides and phosphate fertilizer used by the Pamol plantation since 1940s.

b) Tertiary to recent sediments of the Lobe plain. These sediments are first cycled sediments which have eroded down from the surrounding Rumpi hills for millennia. They may serve as traps for arsenic bearing minerals.

c) Cretaceous-Tertiary volcanism which affected the study area may have been responsible for trapping of arsenic bearing sulfide minerals within the sediments. Associated with such volcanic activity were phreatic explosions followed by fumaroles and hydrothermal activity (Eglal et al., 1987). The arsenic bearing sulfide minerals may have occurred due to the leaching of the uprising fluids from the deeper Precambrian rocks or their overlying sedimentary rocks (Gindy, 1961). It is also possible that post-magmatic fluids which were predominantly water, CO_2, complexes of chlorides and sulfides were trapped within the sediment during crystallization (Jensen and Bateman, 1981).

MECHANISM OF RELEASE OF ARSENIC TO GROUNDWATER

Anthropogenic and geological sources have been proposed to explain the elevated arsenic concentrations in groundwater in Ekondo Titi and environs. Suggestions of anthropogenic sources do not appear to provide a general explanation of elevated arsenic in the study area (Lawrence, 1986). Therefore, only a geological source can explain the extent and magnitude of the observed arsenic occurrence in the study area.

Two main explanations for the mobilization of geologic arsenic have been proposed:

(a) Pyrite oxidation: Considers that arsenic rich pyrite and arsenopyrite in the flood plain sediments are oxidized due to water table lowering caused by intensive groundwater pumping (Das et al., 1996; Mallick and Rajepopal, 1996).

(b) Oxyhydroxide reduction**:** This alternative “oxhydroxide reductive” hypothesis put forward by Bhattacharya et al., (1997, 2001), in India, Nickson, (1997) and Nickson et al., (1998, 2000), in Bangladesh, proposes that adsorbed arsenic is released by reductive dissolution of iron oxyhydroxides as the flood plain sediments become buried and reducing conditions develop. This latter explanation emphasizes the role of organic matter in generating strongly reducing pore waters. According to this hypothesis, the origin of arsenic is a natural process, and it seems that the arsenic in the ground has been there for thousand of years without being flushed from the deposits (Fazal et al., 2001).

POPULATION EXPOSED TO ARSENIC CONTAMINATION

The risk factor associated with drinking of arsenic contaminated water for an adult weighing 60 kg with daily intake of 5 liters of water is 0.05 multiplied by the concentration of arsenic in water measured in mg/L. It means if the concentration is 0.1 mg/L, the risk factor becomes 0.05x0.1=0.005. This implies that five individuals out of 1000 have the possibility of being affected with arsenic. If the concentration is 2 mg/L, then 10 individuals out of 100 will be affected.

If the age and the water intake are different, then the risk factor is the product of 1.75 arsenic concentrations in water in mg/L, and daily water intake in liters per day, divided by the weight of the person (Adel, 2000). Hence, for a population of about 40,000 people, the number of people being at risk of arsenic poisoning ranges from about 200 to 4000 people at arsenic concentrations ranging from 0.1 mg/L to 2.0 mg/L in Ekondo Titi.

ARSENIC-RELATED HEALTH HAZARD

The major health effects observed in the study due to chronic poisoning by small doses are mainly muscular weakness, loss of appetite, nausea and skin lesions. Epidemiological and clinical studies reported in the medical literature have confirmed the role of arsenic in the induction of skin diseases, muscular weakness, loss of appetite and nausea (Tebbutt, 1983). Immediate symptoms due to acute poisoning observed in the field included vomiting, esophageal and abdominal pain and gastrointestinal manifestations.

Secondly, impacts on health may result from agricultural activities whereby arsenic in soils or irrigation water is taken up by crops, and thereby enters the human food chain. Preliminary data on this subject are reviewed by Huq et al., (2001) who conclude that it is a matter of serious concern that requires immediate attention.

Finally, the delayed health effects of exposure to arsenic, the lack of common definitions, and of local awareness as well as poor reporting in affected areas are major problems in determining the extent of arsenic in the affected areas.

DISCUSSION

Geochemical and field studies have indicated the occurrence of elevated arsenic concentrations of 0.1 mg/L in shallow aquifers (Table 1) to 2 mg/L reported in borehole water sources (Lawrence, 1986; Scanwater, 2000). The source of these arsenic rich phases is not known but probable suggestions are that the weathered sediments of the crystalline rocks of the Rumpi hills may be the source of arsenic. The mechanism of arsenic mobilization into groundwater may be oxyhydroxide reduction. This hypothesis is supported by the field evidence (Ravenscroft et al., 2005).

- Arsenic–rich groundwaters are all strongly reducing

- Arsenic–rich groundwaters generally have high iron and bicarbonate concentrations but very little sulfate or nitrate.

- The spatial distribution of arsenic does not correlate with either depth or the intensity of groundwater irrigation, but is associated with Holocene flood plains, and particularly with fine-grained sediments.

- Maximum arsenic concentrations in groundwater are found tens of meters below the depth of the deepest water-table fluctuations, even in areas of little pumping.

- Pyrite is rather rare and where present occurs as an authigenic rather than detrital mineral,

Table 1. Chemical analyses of shallow wells in Ekondo Titi by Lawrence (1986).

Well Name	Field Measurements		Laboratory determinations									
	pH	EC µs/m	Na (mg /1)	K	Ca	Mg	SO_4	C1	NO_3	Si	Fe	As
Shepherd's rest	4.25	16.5	12.1	7.6	5.7	1.6	0.5	10.8	52.6	1.7	0.01	0.1
Hill top well (Ekondo Titi)	5.00	14.9	0.5	0.7	1.0	0.5	0.5	0.8	2.2	2.6	0.02	0.1
Council well (EkondoTiti)	5.8	45.7	1.2	0.7	6.9	0.4	0.7	1.0	5.5	2.4	.01	0.1
Sering (Ekondo titi)	4.9	38.1	2.3	0.8	1.3	0.8	0.5	2.9	9.3	1.6	.03	0.1
Love town well	5.7	50	1.2	0.7	7.6	0.9	1.2	3.5	3.0	.01	0.1	.03
School well Ekondo Titi	6.9	218	4.3	4.9	39.1	0.7	5.0	5.0	7.5	4.5	0. 01	0.1
Bekora village well	4.25	244	19.2	18.9	4.8	1.9	0.5	25.0	73.8	1.9	0. 01	0.1

more likely acting as a sink for, rather than a source of arsenic.

- There is a strong correlation between iron and arsenic content of the Holocene iron and sulfur.

- Sand grains in the Holocene sediments have pervasive ferruginous covering with appreciable arsenic content.

These conditions agree with the prevailing conditions in Ekondo Titi. The pronounced drought in the early 1970s and 1980s which affected the entire country, including the study area caused a remarkable lowering of the water table in the unconsolidated sedimentary deposits, due to shortage of recharge water. As the water table dropped, the arsenic-rich iron oxhydroxides remained inert. With the advent of recharge, the organic matter deposited with the sediments reduced the arsenic-bearing iron hydroxide and released arsenic into groundwater.

From the previous work, the study area is a chemically reducing environment and anoxic. In reducing areas, arsenic is strongly sorbed onto or co-precipitates with ferric hydroxide, the arsenate forms being more strongly sorbed than the arsenite forms. This results in potentially much higher concentrations of dissolved arsenic under reducing conditions, not only because of the lower sorption affinity but also because ferric hydroxide is more soluble at low Eh (Edmunds et al., 1996). This is also consistent with the data of Lawrence, (1986) (Table 1) and Scanwater, (2000), where concentrations appear to be increasing with depths from shallow wells at 0.1 mg/l to 2 mg/l at boreholes where conditions are more reducing. The increased concentration of arsenic and iron with depth has prevented the utilization of borehole water sources for domestic use (Mbotake, 2005). Many studies of groundwater and sediments have detected a correlation between arsenic concentration and both Fe and Eh (Matisoff et al., 1982; and Varsanyi et al., (1991).

The true situation of the effect of arsenic poisoning may be difficult to obtain due to a number of constraints encountered during the survey, such as a lack of qualified medical personnel, a good disease registry and social constraints. Based on the risk factor, about 4000 persons are probably affected by arsenic poisoning. The major health hazard common in the study area linked to arsenic poisoning includes muscular weakness, loss of appetite, nausea, and skin lesions. Immediate symptoms observed due to acute poisoning include vomiting and itching of the skin. The medical register indicates high cases of eczema, esophageal and abdominal pain, and gastrointestinal manifestations.

CONCLUSION AND RECOMMENDATION

The review indicates that the source of arsenic is geogenic and arsenic is released into the groundwater by reductive dissolution of iron oxyhydroxides as the flood plain sediments become buried and reducing conditions develop. This explanation emphasizes the role of organic matter in generating strongly reducing pore waters.

Arsenic contamination has not yet reached endemic levels in Ekondo Titi. Since the intensity of health effects to people has not reached such a level of evidence to compel authorities to take immediate remedial actions, more studies are needed to evaluate arsenic pollution throughout the country and to reduce the environmental risk from arsenic contamination.

The following recommendations are proposed to develop an arsenic mitigation strategy.

1. Analyzing total water supplies regarding presence of arsenic
2. Defining sources and mechanisms of arsenic occurrence in drinking water

3. Education and involvement of local residents in water quality problem solving
4. Formation of expert committees for situation analysis
5. Conducting a pilot study for removal of arsenic for rural areas.

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