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NON-CANCER HEALTH RISK ASSESSMENT FROM EXPOSURE TO CYANIDE BY RESIDENT ADULTS FROM THE MINING OPERATIONS OF BOGOSO GOLD LIMITED IN GHANA

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Abstract. Cyanide is a very toxic chemical that is used to extract gold from its ores. Wastewaters from gold mining companies such as Bogoso Gold Limited (BGL) contain cyanide and other potentially toxic chemicals that have adverse effects on human beings and aquatic organisms. This study was conducted to evaluate the human health risk assessment from exposure to free cyanide via oral and dermal contact of surface/underground water by resident adults within the concession of Bogoso Gold Limited. The chronic non-cancer health risk from exposure to cyanide in River Bogo Upstream is 230 and 43 (by Central Tendency Exposure (CTE) parameters respectively). This means that approximately 230 and 43 resident adults are likely to suffer diseases related to cyanide intoxication via oral and dermal contact respectively. For chronic exposure to River Bogo Downstream by resident adults, the non-cancer health risks are: 0.031 and 0.57 via oral and dermal contact for CTE parameters respectively, which also means that, the non-cancer health risks associated with cyanide intoxication is negligible as the hazard index is less than 1.0 via oral and dermal contacts respectively. The results showed that health risk for acute exposure to cyanide by the resident adults is very high. Hence the residents attribute most of the unexplained deaths in the communities to accidental ingestion and dermal contact of cyanide water.

Keywords: Bogoso, Dumasi, free cyanide, Prestea, River Ankobra, River Aprepre (popularly known as River Dumasi), River Bogo

1. Introduction

Gold mining in Ghana has played a central role in the socio-economic and political life of the country for the past 100 years. In Ghana, most of the mining companies have adopted the use of cyanide in extracting gold from its ore. The use of cyanide has made it possible for the mining companies to make huge profits from mining very low grades of ores. However, cyanidation as an extractive technique in gold mining in Ghana has become unpopular as a result of cyanide spillages and environmental damages the country has witnessed. Ghana has witnessed about 11 cyanide spillages between 1989 and 2004. Notably among them are:

- In 1989, Obenemase Mines near Konongo spilled large quantities of cyanide solution, which contaminated a tributary of River Oweri.

- In 1996, large quantities of cyanide solution was spilled by Teberebe Goldfields into Angonaben stream, a tributary of River Bonsa, causing harm to human lives and aquatic organisms.
- Bogoso Gold Limited had a major spillage in 1994. Large volumes of cyanide were discharged into River Anikoko, which flows into River Bodwire. The company constructed boreholes for some of the affected communities but in places where the boreholes were not operational, the farmers were forced to drink the polluted river or streams, posing significant health hazard to them. The affected communities, especially the people of Anikoko and Brakwaline were forced to abandon their farms. The communities had to resettle in other communities, as they could not contain the effects of the spillage.
- Again, on October 23rd 2004, there was another spillage by BGL. The spillage was from the new tailings dam of the company into River Aprepre, which flows into other rivers including Egya Nsiah, Bemanyah, Manse and Ankobra. This river flows into the big River Ankobra. The cyanide spillage has affected Dumase and other towns including Goloto, Juaben and Egyabroni. Some residents of Dumase and other villages picked and ate dead fishes, crabs, shrimps and other aquatic organisms that were found floating on the surface of the river.

In all these cases, members of the affected communities drank the cyanide-contaminated water from the rivers and the streams before they were told of the cyanide spillage and hence they showed the symptoms of cyanide intoxication (Amegbey and Adimado, 2003). However, operators of mining companies maintain that cyanide breaks down quickly into less toxic forms; as such the effects of cyanide spillage on human beings in the communities are minimal. This claim is also collaborated by the regulators (i.e., Ghana Environmental Protection Agency, Chamber of Mines and the Mines Department). The breakdown of spilled cyanide is very slow. The breakdown compounds are potentially toxic to fish, aquatic organisms, and human beings and may persist in the environment for long periods of time (Moran, 1998). They can also be absorbed or bioaccumulate in plant, human beings and other aquatic organisms which are found in mining communities where cyanide spillages had occurred (Moran, 1998; Heming, 1989; Eisler, 1991). Food crops such as cassava, cocoyam, just to mention a few which are grown in areas absorb these toxic chemicals or cyanide and their derivatives (Adzei and Golow, 2002; Eisler, 1991).

Risk Assessment is the methodological approach in which the toxicity of a chemical is identified, characterized and analyzed. It quantifies the perceived risk posed to the defined receptors by a proposed action (Eldon and Bradley, 1992). According to USEPA Risk Assessment Guidance for Superfund (RAGS): Volume I-Human Health Evaluation Manual (HHEM), human health risk assessment consists of four distinct steps namely:

- Hazard Identification:- identifies the COC (constituent of concern) – free cyanide that makes significant contribution to exposure and health risk in the study area.
- Exposure Assessment:- evaluates the pathways by which resident adults could be exposed to free cyanide present in the study areas.
- Toxicity Assessment:- identifies which toxicity criteria have to be used in evaluating the human health risk from exposure to free cyanide in the study area.
- Risk Characterization:- this incorporates information from hazard identification, exposure assessment, toxicity assessment and risk estimation to evaluate the potential risk exposed to the individuals at the study areas.

It is against this background that it is important to assess the potential human health risks associated with exposure to cyanide from the mining operations of Bogoso Gold Limited.

2. Materials and Methods

2.1. SAMPLING PROCEDURE

Judgmental sampling techniques were adopted to select River Aprepre (River Dumasi), River Ankobra and River Bogo based on previous history of cyanide spillage and visual assessment. Random sampling technique was adopted to select the boreholes in Dumasi. The number of water samples obtained from each sampling point is shown in Table I.

The water samples from each sampling point were analyzed separately for free cyanide and the mean results of free cyanide computed.

2.2. SAMPLE COLLECTION AND SAMPLE PREPARATION

Water samples were collected from streams and rivers within the catchment area of the company into plastic bottles that have been pre-washed with detergent and

TABLE I
Sample sites and number of samples obtained

	Number of samples				
Sampling point	Zone 1	Zone 2	Zone 3	Zone 4	Total
River Aprepre (River Dumasi)	8	8	8	8	32
Bogo River upstream	8	8	8	8	32
Bogo River downstream	8	8	8	8	32
Borehole (Dumasi)	8	8	8	8	32
River Ankobra	8	8	8	8	32
Total	32	32	32	32	160

tap water, rinsed with 1:1 nitric acid and tap water. 1.5 L of the water effluent was collected from each sampling point and identification labels were fixed on each water sample collected.

The presence of oxidizing agents in the samples was detected by moist potassium iodide/starch test papers. The oxidizing agents were then removed by adding 0.1 g/L sodium arsenate solution till the potassium iodide/starch test papers gave no blue colouration.

The samples were stored in an ice-chest and later conveyed to the laboratory for analysis. The presence of sulphides in the samples was detected by moist lead acetate paper. Sulphides in the samples were removed by adding 0.1 g/L lead carbonate solution. The solution was filtered immediately using pressure filtration.

The samples were filtered using Whatman No. 0.45 μm membrane filter paper. The filtered samples were stabilized by adding 10% NaOH solution to it. The samples were stored in a refrigerator at a temperature of 4 °C (ICMI, 2002).

A blank solution was titrated against standardized 0.1 M $AgNO_3$ solution using *p*-dimethylaminobenzalrhodamine indicator solution, until the colour of the indicator changed from canary yellow to salmon blue. The titre for the blank was recorded and subsequently used. 100 mL of the sample was poured into 250 ml conical flask. 5 ml of *p*-dimethylbenzalrhodamine indicator solution was added to it. The mixture was then titrated against 0.1 M $AgNO_3$ solution to the end point. The titre at the end point was recorded. The concentrations of free cyanide in the samples were calculated as follows:

$$\mathrm{CN^-}\ \mathrm{mg/L} = (A - B)/100\,\mathrm{mL} \times (250/1000)\,\mathrm{ml} \tag{1}$$

where, A is samples titre volume of $AgNO_3$, B is blank titre volume of $AgNO_3$ (US EPA, 1991).

2.3. RECOVERY AND REPRODUCIBILITY STUDIES

To check the sensitivity and efficiency of the method used in the chemical analysis, recovery and reproducibility studies were conducted.

In the recovery studies, known concentrations of cyanide solutions were titrated against 0.1 M $AgNO_3$ after the blank titration using *p*-dimethylbenzalrhodanine indicator to salmon blue end point. Table II shows the results of the recovery studies.

From Table II, the percentage free cyanide recovered from double distilled water is between 95 to 100% with a standard deviation between 0.00 to 0.02 and standard error of 0.01. It was realised that the method used for the chemical analysis was very efficient.

To check the reproducibility of the method used, reproducibility studies were also conducted. In the reproducibility studies, double distilled water containing 1.0 mg/L cyanide solution was titrated against 0.1 M $AgNO_3$ solution after the

TABLE II
Results of free cyanide recovered in the recovery studies

Concentration (mg/L)	Amount recovered mg/L			Percentage recovered	Standard deviation
	1	2	Mean		
0.20	0.19	0.19	0.19	95	0.00
0.40	0.41	0.38	0.40	100.0	0.02
0.80	0.81	0.77	0.79	98.8	0.02
1.00	0.98	0.98	0.98	100.0	0.00

TABLE III
Reproducibility of 1.0 mg/L free cyanide solution in doubled distilled water

Replicates	Amount recovered (mg/L)
1	0.974
2	0.969
3	1.014
4	1.002
5	1.010
6	0.988
7	0.991
8	0.994
9	0.995
10	1.021
Mean	0.996

Percentage recovered = 99.6; Standard deviation = 0.017; Coefficient of variation = 1.706% and Standard error = 0.005.

blank titration using *p*-dimethylbenzalrhodanine indicator to the salmon blue end point as shown in Table III.

From Table III, the percentage of free cyanide recovered in the reproducibility studies is 99.6 with a standard error of 0.005. The standard error is less than 1, this suggest that the method employed to analyse free cyanide is reproducible.

2.4. HAZARD IDENTIFICATION

Stanton *et al.* (1986), states that oral ingestion of free cyanide is fatal to human beings in doses ranging from 50–200 mg. Cyanide toxicity results from the inhibition of cytochrome oxidase, thereby limiting the absorption of oxygen at the cellular level. The central nervous system is a major target of acute cyanide toxicity. Within a relatively short period of exposure, rapid breathing followed by depression, convulsions, paralysis and possible death may occur.

Other symptoms, such as headache, weakness, changes in the sense of smell and taste, throat irritation, vomiting, nose bleeding, scarlet rashes, etc (Stanton *et al.*, 1986) are also associated with CN^- ingestion. These symptoms are very common among the inhabitants living within the concession of Bogoso Gold Limited.

2.5. EXPOSURE ASSESSMENT

In line with US Environmental Protection Agency's risk assessment guidelines, an exposure assessment deals with the quantification of human exposure to free cyanide in surface water/ground water in the Bogoso Gold Limited concession that resident adults could impact upon. It also identifies the various exposure pathways by which resident adult in the company's operational areas are exposed to free cyanide. The human health effect of free cyanide was evaluated for resident adults in the study.

Cyanide readily combines with most of the heavy metals such as arsenic, cadmium, copper and zinc in the effluents from the company's treatment plant. There are three predominant forms of cyanide in mining effluents. These are free cyanide, weak acid dissociable cyanide (WAD) and total cyanide.

The cyanide ion and hydrogen cyanide (HCN) are often referred to as free cyanide. The weak acid dissociable cyanide refers to metal-cyanide complex of the following metals, Zn, Cd and Cu. These complexes decompose readily to release cyanide ion and the metal ions forming the complex. Total cyanide refers to the cyanide-metal complex of the following metals iron, gold and cobalt.

Of all the cyanide complexes found in mine wastewaters, only free cyanide was monitored in this study because it is the most toxic form of cyanide complexes in mine waste.

The exposure scenario evaluated in this study is a residential setting. In this scenario, ingestion and dermal contact of surface water/ground water in the catchments area of the company by resident adults was evaluated based on both CTE (Central Tendency Exposure) and RME (Reasonable Maximum Exposure) parameters respectively. The potential receptors evaluated in this paper are resident adults living within the concession of BGL. The ages of resident adults considered in this study is between 20–31 years.

The intake of free cyanide from ingestion of water samples from the treatment plants by resident adult of the company is calculated as follows:

$$\mathrm{Intake}[(\mathrm{mg/kg-day})] = [(\mathrm{EPC} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED} \times 10 - 6)/(\mathrm{BW} \times \mathrm{AT})] \quad (2)$$

where, EPC is EPC for free cyanide in water samples (mg/L), IR is Ingestion rate of water samples (free cyanide) – mg/day, EF is Exposure Frequency (day – equivalents/year), ED is Exposure Duration (years), BW is Body Weight (kg), AT is Averaging Time (days).

The basis for each parameter used to quantify exposure for ingestion of free cyanide in water samples is described below:

EPC for Free Cyanide in Water Samples: A 95% Upper Confidence Limit (UCLM) of mean concentration of free cyanide in the water samples from each sampling point is used as the input parameter in the above equation.

Ingestion Rate (IR): This describes how often receptors in the study areas ingest water and the amount of free cyanide they ingest from the water sample in a day. Default value from the Risk 4.02 (Software will be used for this parameter).

Exposure Frequency (EF): This parameter describes how long a receptor in the study areas is exposed to free cyanide from oral ingestion of water in the study area. The EF factor used for this study is 350 days in a year since resident adults in the communities drink water from the rivers and boreholes all year out.

Exposure Duration (ED): The ED for adults that are resident in the study area is 30 years for non-cancer health effects.

Body Weight (BW): In accordance with current US EPA risk assessment guidance, the use of a mean body weight is appropriate when either CTE or RME estimates are sued to quantify exposure (US EPA, 1989). For resident adults aged 20–31 years, a mean body weight of 58.6 kg is used, based on the mean body weights for resident adult males and females in the study area. These body weights are in consistence with current US EPA guidance (US EPA, 1997a).

Averaging Time (AT): The AT used to estimate non-cancer health risk for resident adults in the study area is 30 years, based on an age range of 20–31 years. For subchronic non-cancer health risk, the AT value used is 15 years and 5 years for acute non-cancer health risk of exposure to free cyanide.

The intake of free cyanide from dermal contact of water samples from the treatment plants by adult workers of the company is calculated as follows:

$$\begin{aligned}&\text{Intake}[(\text{mg/kg} - \text{day})]\\&\quad = [(\text{EPC} \times \text{Kp} \times \text{SA} \times \text{EF} \times \text{ED} \times 10^{-6})/(\text{BW} \times \text{AT})] \qquad (3)\end{aligned}$$

Apart from SA, and Kp, the other terms in this equation have the same meanings as described above.

Skin Permeability constant (Kp): This estimates the permeability of the COCs through the skin layers into the blood stream. It is related to the solubility or binding strength of the chemical in the delivery matrix (water or soil) versus the receptors matrix and the skin stratum (Wester *et al.*, 1993b).

Skin Surface Area (SA): This refers to the skin area assumed to be available for exposure to free cyanide in water samples from the treatment plants of the company. Default values will be used from RISC 4.02 software.

2.6. TOXICITY ASSESSMENT

The US EPA has provided RfD_{oral} in its online toxicity database file for use in assessing the chronic and subchronic non-cancer health effects from exposure to cyanide via dermal or oral contact with the contaminated surface/ground water. A study by Hanzel and Howard (1955), provides the highest NOAEL (No Adverse Effect Level); 10.8 mg/kg – day for cyanide, and this value was chosen for the derivation of the RfD_{oral} for cyanide of 1.5 mg/kg a day.

In line with US EPA risk assessment guidelines for assessing dermal health effects from dermal exposures to cyanide if oral absorption of cyanide in drinking water is 100%, there is no need to adjust the oral reference dose to calculate the dermal reference dose (RfD_{dermal}). Default values were used from Risc 4.02 computerized software.

2.7. RISK CHARACTERIZATION

Non-cancer health risks are expressed as hazard indices rather than as probabilities. A hazard index compares the estimated daily exposure dose of cyanide to the oral reference dose derived by the US EPA. According to US EPA (1989), hazard index is calculated using the equation:

$$\text{Hazard Index} = \text{Intake}[(\text{mg/kg} - \text{day})/\text{RfD}(\text{mg/kg} - \text{day})] \tag{4}$$

3. Results and Discussions

The estimated non-cancer health risk for resident adults exposed to cyanide in rivers and streams in Bogoso and its surrounding areas are summarized in Table IV.

3.1. RIVER BOGO UPSTREAM AND DOWNSTREAM

River Bogo serves as the source of drinking water for residents of Bogoso who have been impacted upon negatively by Bogoso Gold Limited. The chronic non-cancer health risk for resident adults exposed to River Bogo Upstream by CTE parameters is as follows; chronic exposure 230 and 43 via oral and dermal contact respectively; RME parameters (chronic) 21 and 96 via oral and dermal contact respectively. For chronic exposure to River Bogo Downstream, the non-cancer health risks are, for CTE parameters, 0.031 and 0.57 via oral and dermal contact respectively, for RME, we have, 0.28 and 0.13 respectively via oral and dermal contact. A hazard index greater than 1.0, according to US EPA risk assessment guidelines, means that the probability for the adverse health effects associated with exposure to such chemical is very high. Hence, the resident adults are prone to

TABLE IV
Summary of non cancer health risk by resident adults exposed to cyanide in rivers and streams in Bogoso and its surrounding areas

Sample location	Exposure media	Exposure route	Chronic		Subchronic		Acute	
			CTE	RME	CTE	RME	CTE	RME
Bogo River upstream	Surface water	Ingestion	230	21	270	83	7300	120
		dermal	43	96	450	67	880	100
Bogo River downstream	Surface water	Ingestion	0.031	0.28	770	700	1900	1700
		dermal	0.57	13	150	32	370	770
River Dumasi	Surface water	Ingestion	280	26	71	640	1800	710
		dermal	52	12	14	29	350	160
Boreholer Dumasi	Ground water	Ingestion	29	53	15	31	73	140
		dermal	59	12	15	27	39	74
River Ankobra	Surface water	Ingestion	40	36	100	90	2500	2300
		dermal	74	170	19	42	490	100

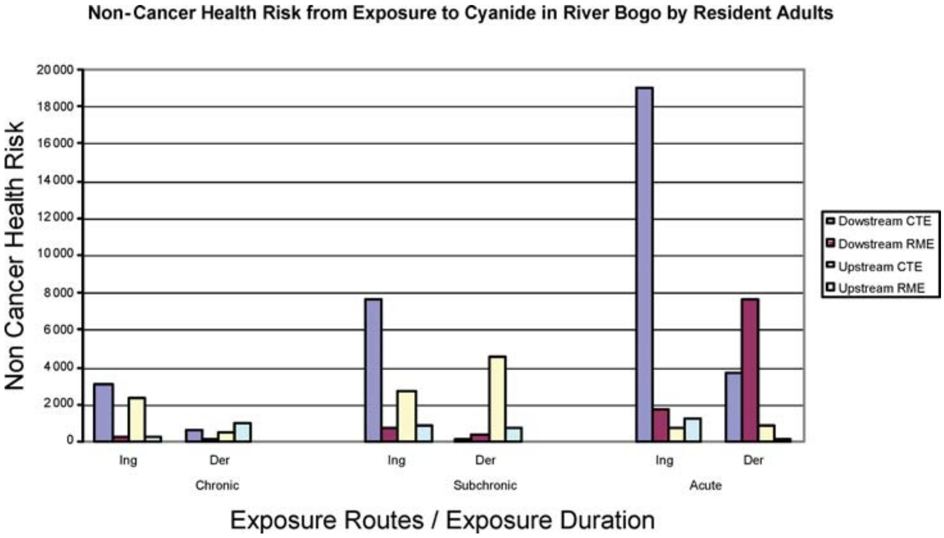

Figure 1. Non-cancer health risk from exposure to cyanide by residents of Bogoso.

the following sicknesses associated with chronic exposure to cyanide: headache, breathing difficulties, weakness and reduced haemoglobin levels. These results indicate that the probability of resident adults experiencing the above symptoms of cyanide intoxication is very high. A lot of the residents use this river for their daily activities as shown in Figure 1.

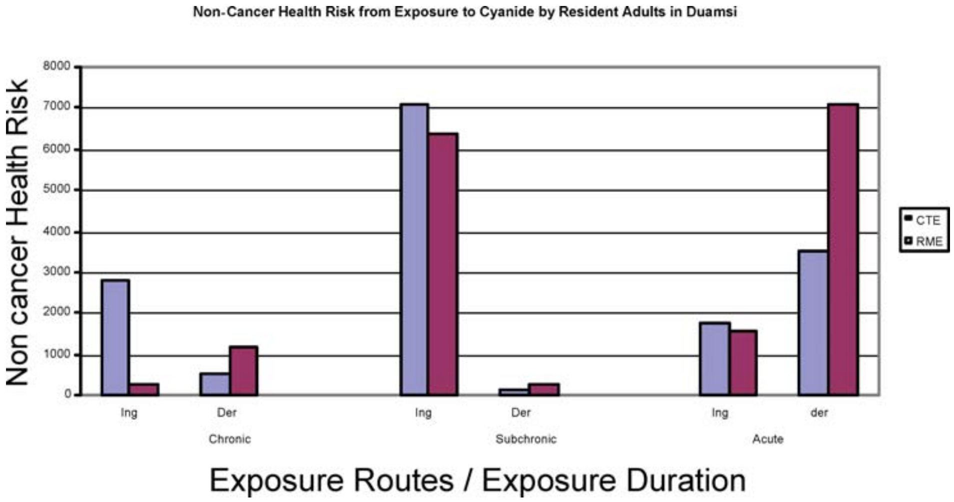

Figure 2. Non-cancer health risk from exposure to cyanide in River Dumasi by resident adults.

3.2. RIVER DUMASI

This river popularly known as River Aprepre is the only source of drinking water for the inhabitants of Duamsi. The operations of the company had impacted negatively on other sources of rivers such as *Egya Nsiah*, *Benya* and *Manse.* The estimated non-cancer health risk from exposure to this river by residents for chronic exposure durations are as follows; 280 and 52, via oral and dermal contact respectively for CTE parameters. Resident adults experience the following symptoms of cyanide intoxication after drinking water from the river. The symptoms are chronic and severe headache, irritation in the throat, iodine deficiency that has affected their thyroid gland. Figure 2 shows the non cancer health effects for other exposure durations.

The company constructed a borehole to supplement the source of drinking water. However, the leaching and seepage of cyanide solution from tailings dam constructed by company has left the community with no choice but to drink the polluted river. Figure 3 shows the non-cancer health effects from exposure to cyanide in the borehole.

3.3. RIVER ANKOBRA

This is the source of drinking water to people of Prestea and its surrounding villages. The non-cancer health risk from exposure to cyanide by resident adults is shown in Figure 4.

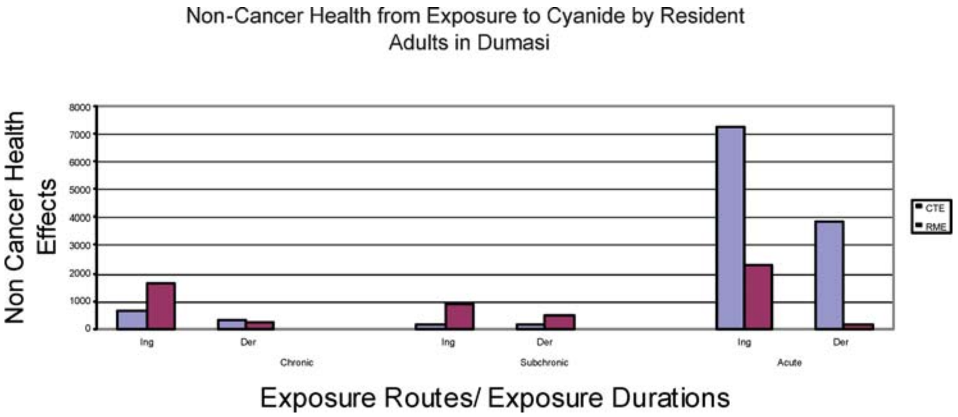

Figure 3. Non-cancer health risk from exposure to cyanide in the borehole at Dumasi by resident adults.

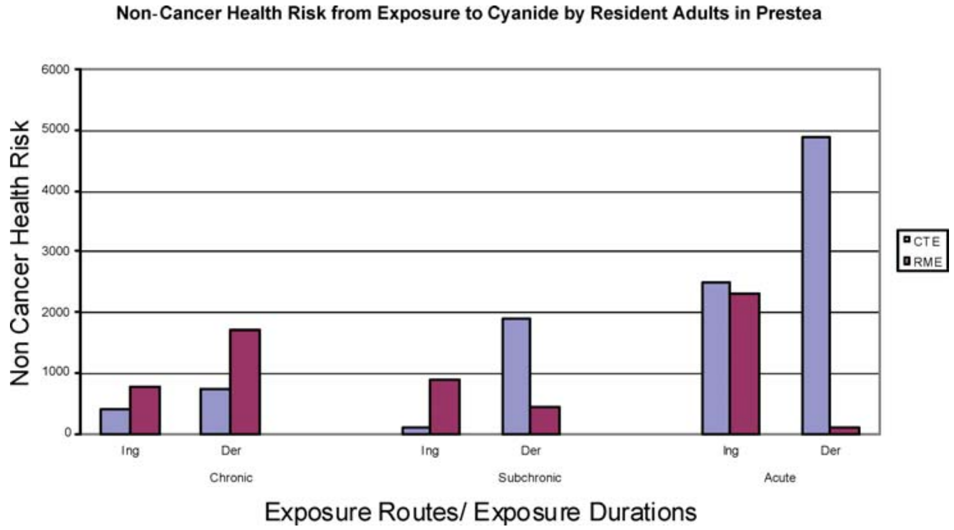

Figure 4. Non-cancer health risk from exposure to cyanide in River Anokbra by resident adults.

4. Conclusion

Given the limitations of routine analytical techniques for measuring cyanide, and the presence of breakdown cyanide forms in mine waste waters, it follows that considerable uncertainty exists regarding the actual toxicity of various cyanide forms to human beings.

As such, the chronic toxic effect from exposure to cyanide in the drinking water by resident adults is very small as compared to the acute toxic effects of cyanide. Most of the free cyanide in the streams and rivers might have broken down into less toxic compounds hence their effects are minimal. El Ghawabi *et al.* (1975) report mild to moderate thyroid enlargement and increased uptake of iodine by the thyroid in resident adults who are exposed to cyanide. Other symptoms include difficulty in breathing, headache, weakness, changes in smell and taste, throat irritation, vomiting, itching, rashes. Subchronic exposures to cyanide by resident adults showed the following symptoms: nausea, loss of appetite, vomiting nervousness, etc. Acute cyanide intoxication via oral or dermal contact with cyanide results in rapid onset of poisoning (producing almost immediate collapse), respiratory arrest and death within few minutes. The results of the study shows that, the resident adults in the study areas are at risk for acute non-cancer health risk. Though it has not been proven scientifically, the inhabitants blame the numerous unexplained deaths, which occur in the study areas to acute cyanide intoxication anytime cyanide spillage occurs. There should be strict enforcement of all mining regulations regarding the discharge of cyanide and other toxic mine waste into rivers/streams in the vicinities of mining companies. Much public education should be given to inhabitants of these communities so that they may not use these cyanide-polluted streams/rivers. Alternatively, mining communities whose source of drinking water has been impacted upon negatively by mining activities should be provided with potable source of drinking water by government and the mining companies.

The education should include the symptoms associated with cyanide exposure so that they can report early hospitals for proper medical attention. Government and mining companies should also provide good drinking water for them so as to prevent such communities from using the cyanide-contaminated waters.

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