MERCURY AND ARSENIC POLLUTION IN SOIL AND BIOLOGICAL SAMPLES AROUND THE MINING TOWN OF OBUASI, GHANA

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Abstract. Samples of soils, plantain (*Musa paradisiaca*), water fern (*Ceratopteris cornuta*), elephant grass (*Pennisetum purpureum*), cassava (*Manihot esculenta*) and mud fish (*Heterobranchus bidorsalis*) were collected from Obuasi and its environs, which is the most active gold mining town in Ghana. The distribution of mercury and arsenic in these samples from fourteen sampling sites was determined. The annual average surficial soil concentrations of As and Hg from 14 sampling sites have the mean and SD of 12.92 ± 17.48 (range = 2.11–48.87 mg kg^{-1} d.w.) and 0.93 ± 0.58 (range = 0.29 – 2.52 mg kg^{-1} d.w.), respectively. The annual average concentrations of As and Hg from plant and grass samples show the mean and SD of 9.05 ± 17.50 (range = 0.49 – 78.71 mg kg^{-1} d.w.) and 1.85 ± 2.04 (range = 0.12 – 9.68 mg kg^{-1} d.w.), respectively. Plant/soil concentration ratios of As and Hg showed elevated values for the grass samples, especially from sites within 4 km of the Pompora Treatment Plant. The high bioaccumulation ratios of fern reflected both soil and air sources of pollution. The results substantiated a mercury and arsenic concentration gradient in the area, thereby indicating that the local environment is contaminated by mining activities.

Key words: Mercury, arsenic, soil and biological samples, mining, Ghana

1. Introduction

Sources of environmental mercury contamination include volcanic emissions (Eshleman *et al.*, 1971; Siegel and Siegel, 1978, 1984), mercury mining (Lindberg *et al.*, 1979) and industries (Lodenius and Tulisalo, 1984). Mercury is amongst the most dangerous elements. It is accumulated throughout the food-chain and can, finally reach humans. In the body, mercury is concentrated in the inner organs (Honda *et al.*, 1983) and the Central Nervous System because it has affinity for the S–H groups present in these tissues (Wood, 1974). Many concerns have been raised because of the widespread use of mercury in gold mining throughout the world. In Ghana, the activities of local and small scale miners are widespread, and mercury is introduced into the environment via amalgamation process popularly known as "galamsey".

Many naturally occurring substances contain arsenic but the concentration is generally low. Agricultural soils may contain between 0.1 and 4.0 mg kg^{-1}, river water between 0.0006 and 0.3 mg kg^{-1} and seawater between 0.0004 and 0.023 mg kg^{-1} (Gagan, 1979). Higher concentrations may be present in metal-bearing ores, particularly certain gold ores. The gold at Obuasi occurs largely as quartz ore or mineralized pyrites and arsenopyrites associated with sulphur (AGC News, 1991).

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Table I
Sampling sites, their populations and distances from the P.T.P.

Site	Village	Population	Distance from P.T.P. (km)
1	Kwabrafoso	8,618	0.31
2	Wawaase	11,206	0.44
3	Kokoteasua	3,575	1.88
4	Nyamso	1,740	3.75
5	Dadwen	2,184	4.29
6	Pomposo	3,534	4.38
7	Diewuoso	2,138	4.63
8	Odumase	3,455	5.00
9	Hia	2,116	6.56
10	Ayease	1,325	6.69
11	Domeabra	1,932	8.50
12	Akrofuom	7,516	8.75
13	Suhyenso	3,560	10.00
14	Ampunyase	6,125	17.50

The processing of the ore involves a roasting process which results in the production of poisonous arsenic trioxide and airborne particles. The discharging of this toxic oxide into the environment has led to the defoliation of some areas surrounding the mine.

No detailed study has been undertaken to determine the levels of arsenic in soil and certain biological samples, and data relating to mercury pollution in the area are lacking. Therefore, the present investigation was initiated with the objective to assess the nature, intensity and geographic distribution of environmental pollutants emanating from the mining activities at Obuasi, as it affects the town of Obuasi and surrounding villages.

2. Sampling Sites

Samples were collected once a month on or about the 15th of each month from March 1992 to February 1993. Fourteen sampling sites were involved and the populations of the sampled villages and their distances from the Pompora Treatment Plant (PTP) are given in Table I. Sites 1 and 2 are situated at the immediate south of the PTP where contamination is mainly due to the flue gases from the chimney. The Kwaberafo stream receives effluent from the treatment plant and the two sites are so situated as to receive contamination from the stream. Sites 3, 4 and 9 are located at the west of the PTP chimney whereas site 5 is at the north. Site 6 is located at the east of the PTP chimney and site 11 is at the north-east. Sites 7 and

10 are located at the south-east of the PTP chimney whereas sites 8 and 12 are at the south. The sites 13 and 14 are located at the south-west of the PTP chimney.

In general, pollution in Obuasi is either due to water pollution from the discharge of effluent from the PTP into the Kwaberafo stream or due to air pollution through the discharge of flue gases from the chimney of the PTP. The wind directions are predominantly from the south-west toward the north-east throughout the year and only rarely originate from an easterly direction.

3. Materials and Methods

Top soil, water fern (*Ceratopteris cornuta*), elephant grass (*Pennisetum purpureum*), plantain (*Musa paradisiaca*) and cassava (*Manihot esculenta*) samples were hand-picked from each sampling area and put into dark polythene bags. Fish (*Heterobranchus bidorsalis*) samples were obtained by hooking them and were immediately deep-frozen. Plantain and cassava samples were peeled and the food part cut into small pieces. All samples were dried for about three weeks. They were then ground to powder and sieved through 2-mm openings. 1.0 g of each powdered sample was treated with 10 cm^3 of 4 M HCl and heated on a water bath at 90° C for one hour. The digest became clear at this time and was filtered (Fichlin, 1990). Total mercury was determined by first acidifying the sample solutions with 1.5% HNO_3. The acidified (Hg^{2+}) solutions were then reduced with 5% tin (II) chloride solution and the elemental mercury so-formed was determined using cold vapour atomic absorption spectrophotometric method (Perkin-Elmer model 2280; Joiris *et al.*, 1991). The coefficients of variation (C.V.) of five analyses of the same samples were: top soil = 0.78%, water fern = 0.38%, elephant grass = 0.33%, plantain = 0.57%, cassava = 0.68% and mud fish = 0.32%.Total arsenic concentrations were determined by an adapted molybdenum blue method. Arsenic (III) in sample solutions was first converted to arsenic (V) by adding 10 cm^3 of 10% sodium hydroxide solution and 5 cm^3 of hydrogen peroxide (30% w/v) to 20 cm^3 sample solution. The mixture was then heated for 30 minutes to help complete conversion of arsenic (III) to arsenic (V) and to get rid of excess hydrogen peroxide (Nyamah and Torgbor, 1986). A SPEKOL II UV-visible spectrophotometer was used for arsenic determination. The coefficients of variation of five analyses of the same samples were: top soil = 0.84%, water fern = 0.42%, elephant grass = 0.66%, plantain = 0.59%, cassava = 0.43% and mud fish = 0.28%.The mercury and arsenic contents were calculated using an external standard curve. Triplicate analyses were conducted on each sample from each site and values are reported in terms of dry weight of sample.

4. Results and Discussion

The concentrations of total arsenic found in plantain, water fern, elephant grass,

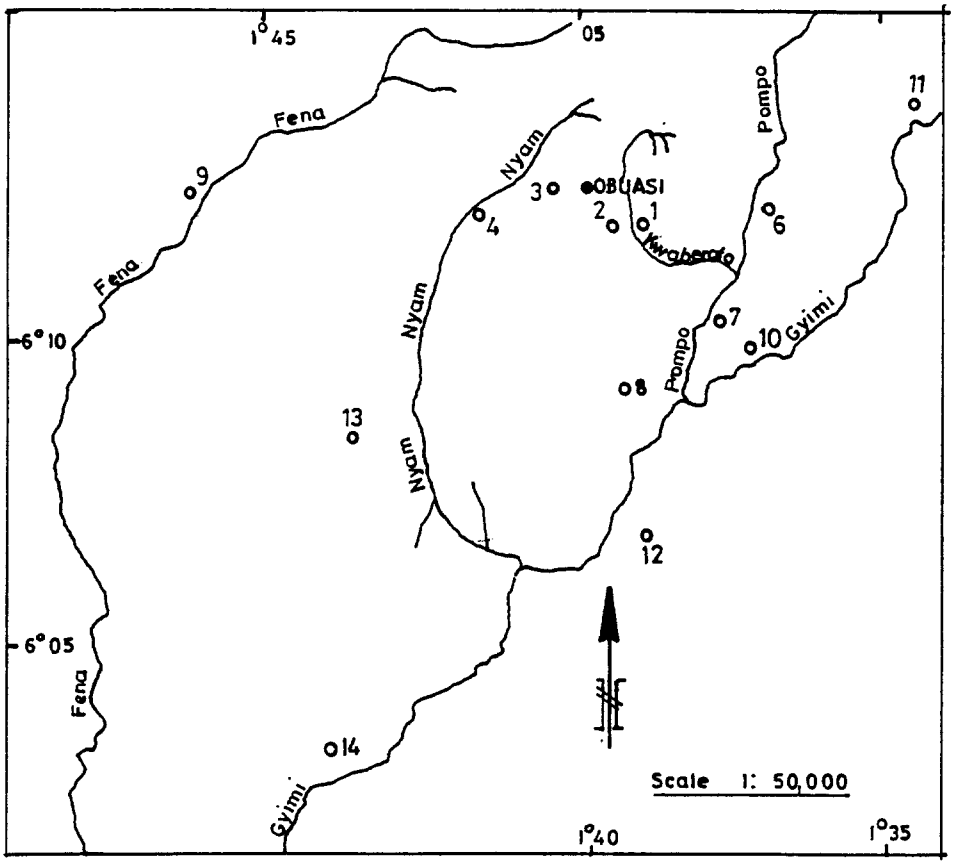

Figure 1. Location of Obuasi and Environs, showing location of sampling sites.

cassava, top soil, and mud fish collected from the fourteen sampling sites are shown in Table II; the corresponding standard deviations (SD) are also indicated. The sampling sites are shown in Figure 1. The reported values in Table II are average for twelve monthly measurements conducted on each sample from each site. An overall examination of arsenic distribution in samples showed that the highest concentrations occurred in fern and top soil. The highest values in samples of soil and fern occur within 4 km from the PTP. Sites 1 and 2 lie in the path of the wind and are affected by the flue gases. They are also situated downstream such that the Kwaberafo stream receives effluent from the PTP. Accordingly the environment surrounding these two areas is highly contaminated with arsenic. The Nyam river receives domestic and municipal waste water from Obuasi township. Its main source of pollution is, however, due to spillage from one of the slime dams. It also receives flue gases due to its close distance (about 3.75 km) from the PTP. Site 4 is situated on the bank of Nyam river and that accounts for the high arsenic concentrations in fern and top soil. The arsenic levels in top soil for the

Table II
Concentration of total arsenic (mg kg^{-1} dry weight) in samples from Obuasi and its environs[a]

Location	Plantain	Fern	Elephant grass	Cassava	Top soil	Mud fish
Kwabrafoso	–	78.7±9.9	–	–	48.9±10.9	–
Wawaase	4.3±1.2	77.6±9.9	–	–	48.3±10.9	–
Kokoteasua	3.1±0.7	22.8±1.0	15.2±0.4	2.6±0.7	23.6±1.7	–
Nyamso	3.6±1.0	50.2±10	27.4±2.0	2.5±0.6	30.7±4.9	2.7±0.6
Dadwen	1.8±0.5	6.2±0.9	2.0±0.4	1.4±0.5	3.7±0.8	1.2±0.3
Pomposo	1.4±0.2	3.2±1.2	3.2±0.8	1.1±0.2	2.9±0.8	0.3±0.1
Diewuoso	1.7±0.3	30.4±6.7	–	1.3±0.2	3.7±1.0	0.9±0.2
Odumase	1.4±0.2	3.2±1.0	1.5±0.6	1.0±0.3	2.7±0.8	0.3±0.1
Hia	1.6±0.3	4.5±1.3	1.5±0.5	1.1±0.4	3.6±1.0	1.2±0.3
Ayease	1.1±0.3	2.7±1.2	1.4±0.3	0.8±0.3	2.4±0.7	0.4±0.1
Domeabra	1.0±0.1	2.8±1.2	1.3±0.2	0.8±0.2	2.4±0.5	0.5±0.2
Akrofuom	1.4±0.5	27.8±5.8	7.2±1.2	1.1±0.1	3.3±0.9	0.7±0.3
Suhyenso	0.5±0.3	2.1±0.8	–	0.7±0.4	2.1±0.9	0.5±0.3
Ampunyase	1.3±0.3	24.5±7.9	6.5±1.5	1.0±0.3	2.7±0.6	0.6±0.2

[a] Based on three samples/site.

remaining sampling sites, though high, may be considered normal for unpolluted soil. The levels of arsenic reported by Cherian *et al.* (1990) for soil samples in India ranged from 23.2 to 103.6 mg kg^{-1}. The arsenic concentrations in fern for site 12 and site 14, though far from the PTP, were relatively high. These two sites are situated downstream to the south of the Gyimi river and the environment is thus affected by contaminated water from the Pompo river, its tributary, whose contamination originates from the Kwaberafo stream, into which effluent from the PTP is discharged. High values of arsenic were therefore recorded in fern samples collected on the bank of the river.

The concentrations of arsenic in food, except seafood, have been found to be generally well below 1 mg kg^{-1} wet weight (Westoo *et al.*, 1972); however, concentrations between 0.6 and 58 mg kg^{-1} dry mass have been found in some food supplements prepared from kelp (Walkiw and Douglas, 1975). Fish in the polluted waters may accumulate toxic trace metals via their food chains (Grimanis *et al.*, 1978). The bioaccumulation of metals is, therefore an index of pollution status of the relevant water body (Menzer and Nelson, 1980) and is a useful tool towards studying the effect of elevated levels of metals on aquatic organisms, especially fish (Muller and Prosi, 1977; Ozah, 1980). The reported arsenic concentrations for mud fish fall within the range 0.006–6.976 mg kg^{-1} obtained for commercial fish from freshwater lakes, Pakistan (Tariq *et al.*, 1991).

The distribution of arsenic in the samples in general, revealed the trend of decreasing concentration with increasing distance from the PTP. This is particularly

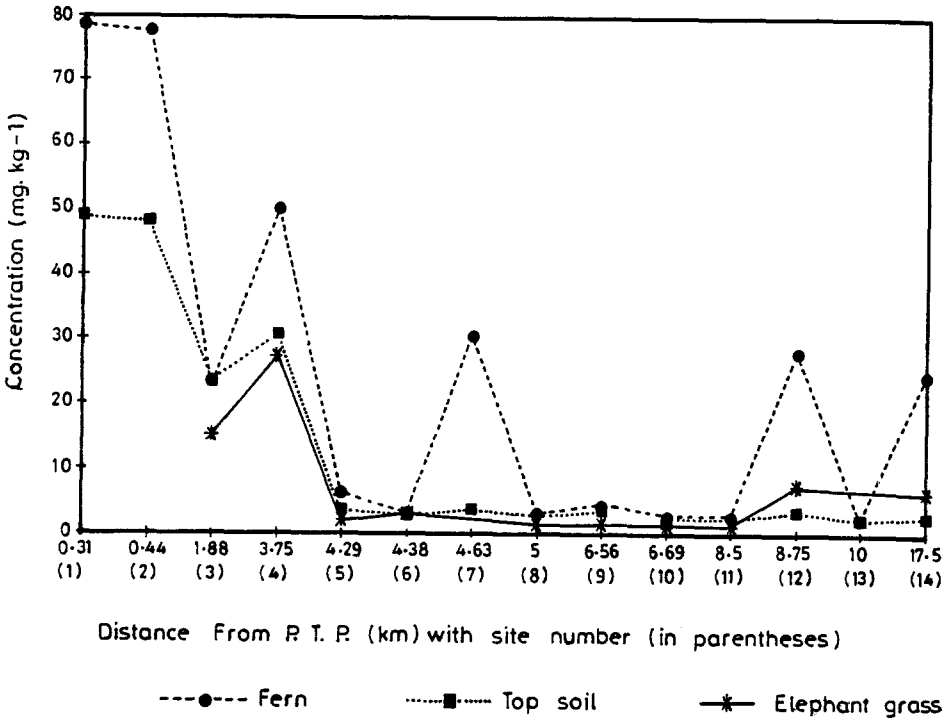

Figure 2. Variation of total arsenic concentration with distance from the Pompora Treatment Plant.

noticeable in the distribution of arsenic in plantain and cassava (Figure 3). It can be seen from Figures 2 and 3 that the concentrations of arsenic in water fern, top soil and elephant grass are significantly larger than the values recorded for plantain, cassava and mud fish. A similar situation can again be observed in the case of water fern, top soil and elephant grass which show elevated levels of mercury (Figures 4 and 5). The data clearly exhibited that arsenic and mercury distribution phenomenon in the samples could be species-specific.

The mercury concentration in plantain, water fern, elephant grass, cassava, top soil, and mud fish collected from the fourteen sampling sites are reported in Table III, together with the relative standard deviations (SD). The data reveal that the highest mercury concentrations occurred in fern and elephant grass. Mercury is not normally present in the effluent discharged into Kwaberafo stream at Obuasi since it is not used for the extraction of gold by the Ashanti Goldfields Corporation (AGC). The concentration of mercury in any particular site therefore, depends mainly on the intensity of illegal mining activities. The variation in mercury concentration with distance is therefore irregular (Figures 4 and 5). The concentrations of surficial soil mercury determined in this study appear to be higher than those reported previously. Mercury concentration as high as 0.3 mg kg^{-1} was observed in surficial soil samples collected near a geothermal plant (Baldi, 1988). However, the low levels of mercury

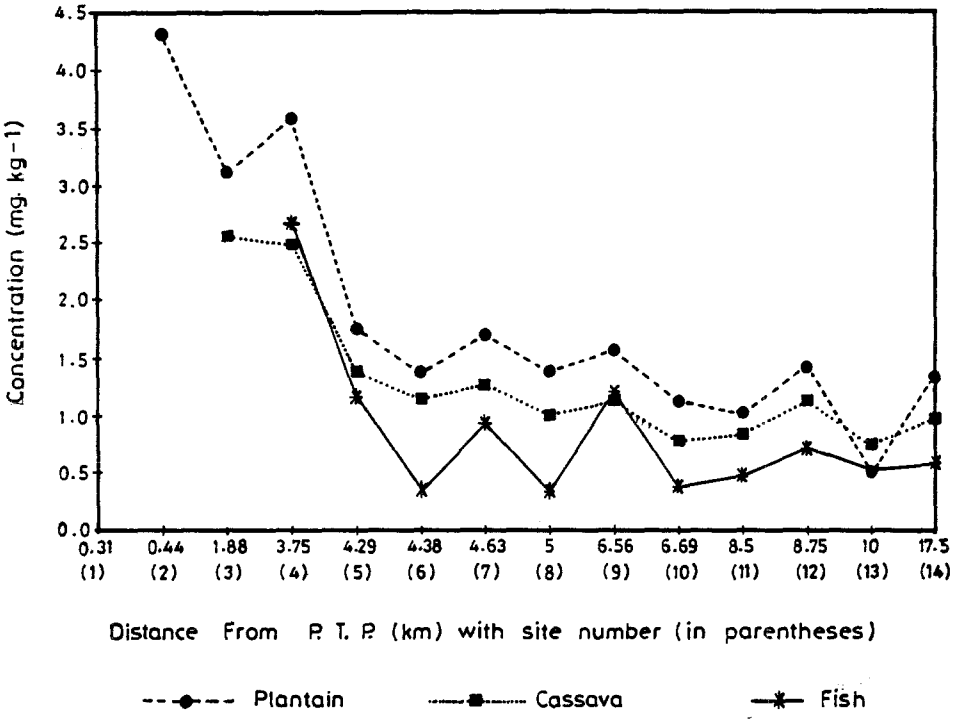

Figure 3. Variation of total arsenic concentration with distance from the Pompora Treatment Plant.

Table III

Concentration of mercury (mg kg^{-1} dry weight) in samples from Obuasi and its environs[a]

Location	Plantain	Fern	Elephant grass	Cassava	Top soil	Mud fish
Kwabrafoso	–	2.4±0.4	–	–	0.7±0.1	–
Wawaase	1.5±0.3	2.6±0.4	–	–	0.6±0.2	–
Kokoteasua	0.7±0.1	2.6±0.2	3.2±0.2	1.1±0.2	0.4±0.1	–
Nyamso	1.4±0.3	9.7±0.8	6.2±0.7	1.8±0.4	1.1±0.2	2.0±0.5
Dadwen	0.1±0.04	3.6±0.3	0.2±0.1	0.2±0.1	0.3±0.1	0.2±0.1
Pomposo	0.2±0.1	2.1±0.4	2.6±0.6	0.2±0.05	1.4±0.2	1.3±0.2
Diewuoso	0.9±0.2	4.4±0.5	–	0.5±0.1	1.2±0.3	0.8±0.2
Odumase	0.3±0.2	1.8±0.6	1.1±0.4	0.3±0.1	0.6±0.1	0.2±0.1
Hia	0.7±0.3	2.1±0.5	1.9±0.6	0.8±0.3	2.5±1.1	0.6±0.4
Ayease	0.2±0.1	1.3±0.5	1.0±0.4	0.5±0.2	1.3±0.2	0.2±0.1
Domeabra	0.1±0.04	1.2±0.5	1.0±0.5	0.2±0.1	0.6±0.3	0.4±0.2
Akrofuom	0.4±0.2	4.1±0.6	3.3±0.6	0.2±0.1	0.6±0.1	0.2±0.1
Suhyenso	0.3±0.1	2.0±0.2	–	0.2±0.1	0.4±0.1	0.4±0.1
Ampunyase	2.1±0.4	8.0±0.6	5.3±0.6	2.5±0.4	1.2±0.2	0.9±0.5

[a] Based on three samples/site.

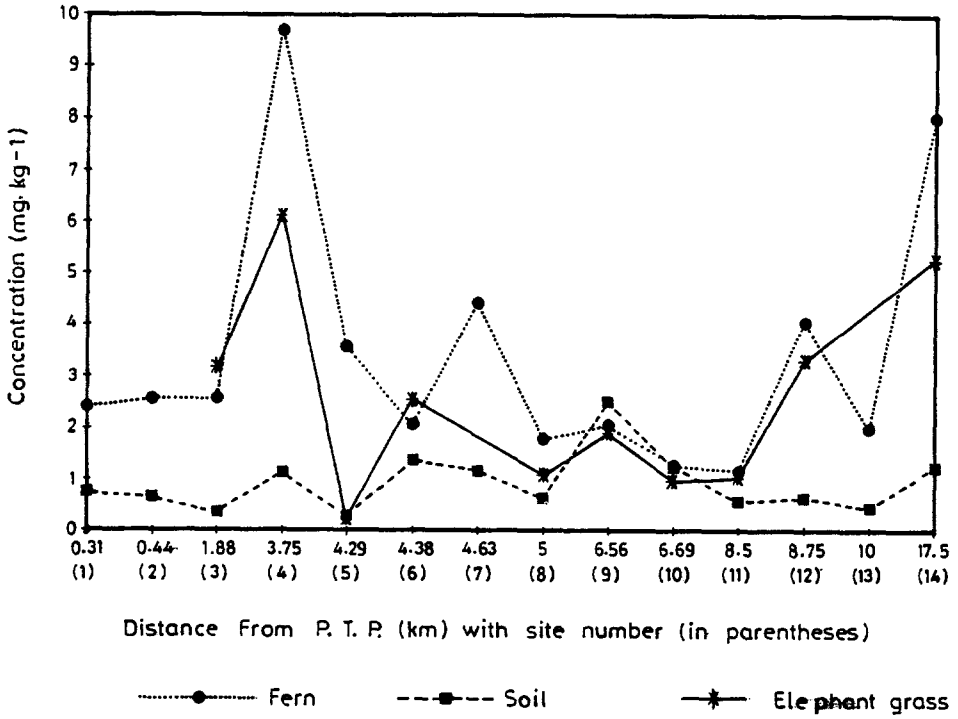

Figure 4. Variation of total mercury concentration with distance from the Pompora Treatment Plant.

Table IV
Plant/soil ratios calculated from concentration values of arsenic

Location	Plantain	Fern	Elephant grass	Cassava
	Soil			
Kwabrafoso	–	1.61	–	–
Wawaase	0.09	1.61	–	–
Kokoteasua	0.13	0.97	0.64	0.11
Nyamso	0.12	1.63	0.89	0.08
Dadwen	0.48	1.69	0.54	0.38
Pomposo	0.48	1.12	1.12	0.40
Diewuoso	0.45	8.11	–	0.34
Odumase	0.51	1.17	0.55	0.37
Hia	0.44	1.26	0.43	0.31
Ayease	0.47	1.20	0.56	0.32
Domeabra	0.43	1.20	0.58	0.36
Akrofuom	0.43	8.44	2.19	0.34
Suhyenso	0.23	0.99	–	0.35
Ampunyase	0.50	9.21	2.44	0.36

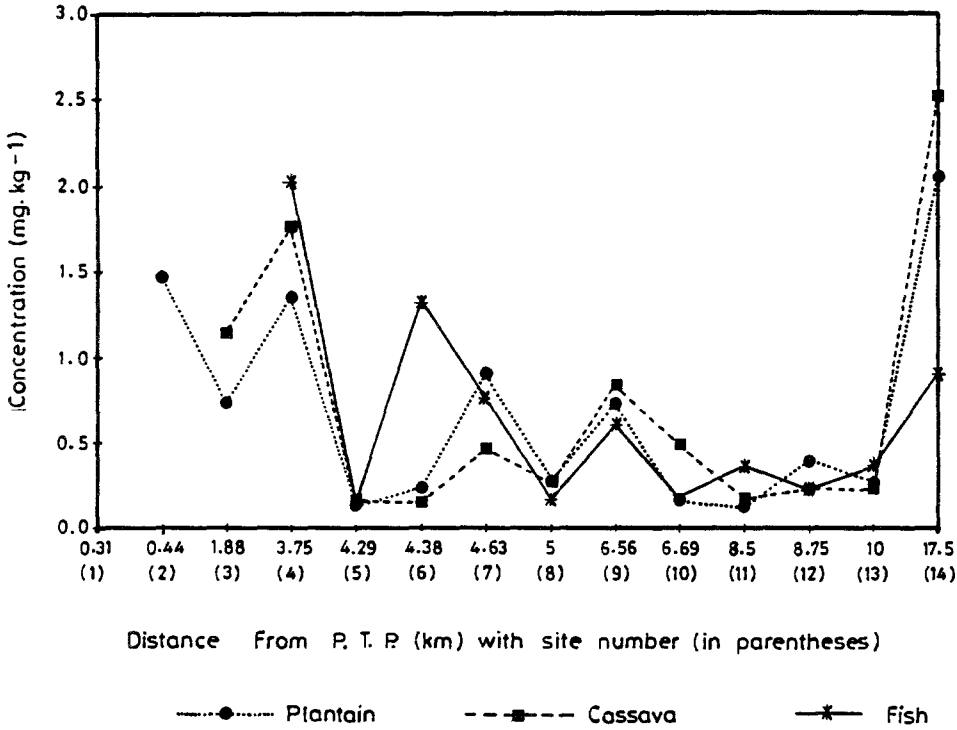

Figure 5. Variation of total mercury concentration with distance from the Pompora Treatment Plant.

Table V
Plant/soil ratios calculated from concentration values of mercury

Location	Plantain	Fern	Elephant grass	Cassava
	Soil			
Kwabrafoso	–	3.27	–	–
Wawaase	2.31	4.05	–	–
Kokoteasua	2.11	7.37	9.09	3.26
Nyamso	1.20	0.57	5.45	1.57
Dadwen	0.45	12.41	0.79	0.55
Pomposo	0.17	1.50	1.86	0.11
Diewuoso	0.78	3.79	–	0.40
Odumase	0.48	2.82	1.71	0.41
Hia	0.29	0.81	0.76	0.33
Ayease	0.13	1.01	0.78	0.39
Domeabra	0.21	2.05	1.81	0.30
Akrofuom	0.64	6.46	5.29	0.37
Suhyenso	0.61	4.50	–	0.52
Ampunyase	1.66	6.45	4.27	2.03

recorded around the geothermal plant were attributed to the geochemical features of the soil which is low in organic matter and rich in carbonate content.

The results of "plant/soil" ratios calculated for arsenic and mercury are shown in Tables IV and V, respectively. There are many factors that will influence the mobilization of mercury and other heavy metals from soils. Mercury and other heavy metals present in soils are often associated with organic matter and the concentration of these metals in the soil is correlated with the amount of organic matter present and the soil type. Soil analysis of samples from the sites revealed differences in texture and organic matter. Organic matter ranged from 1.2% to 4.3%.

From the data plantain and cassava appear to be an "excluder" of arsenic and mercury and therefore both foodstuffs would not be a good indicator of pollution. Conversely the fern and elephant grass have high bioaccumulation ratios for mercury, indicating possible pollution status of soil and air. The assumption is substantiated by the high bioaccumulation ratios for arsenic with respect to fern. Sites 7, 12 and 14 have bioaccumulation ratios of 8.11, 8.44 and 9.21, respectively for arsenic. These three sites could be termed low organic soil areas with organic matter of about 1.4%. Consequently plants in these areas are able to bioaccumulate metals better than the other areas with elevated organic matter levels.

The variability of the bioaccumulation ratios for fern and elephant grass probably resulted in part from differences in the organic matter, silt and clay content of soil in the sampling sites. Nevertheless, the elevated bioaccumulation ratios for fern and elephant grass clearly show that mercury and arsenic are accumulated in the environs of Obuasi. Furthermore, the data have established a large variability of arsenic and mercury distribution in the samples analyzed and that there exists metal concentration gradient in the area under investigation.

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