Trace Elements in Tailings: Understanding Their Implications When Used as a Construction Material and as a Re-Usable Agricultural Land

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Abstract

Exposure to harmful elements and consuming food produce from soils deficient of essential elements impact on human development and affect health of living things. Utilizing mine tailings for construction and/or using the tailings for agricultural activities require the understanding of the contained elements in terms of their concentrations and distributions in space. In this study, 40 tailings samples were sampled for the contained elements distributions and concentrations. The collected samples were analysed using ICP-OES analytical method. 11 elements including As, Hg, Mo, Cd, Cr, Ni, Cu, CN, Co, Pb and Zn were studied. The concentration levels of these 11 elements were compared with the global background values in soils. All elements except Mo showed an enrichment factor of 49.178, in excess of about 83%. The calculated geo-accumulation index (Igeo) of the selected elements confirmed Mo to be the only element in the tailings to suggest moderate pollution with Muller's value of 1.1876. Tomlinson's (1980) assessment of the Pollution Load Indices (PLI) was in agreement to Igeo value. Apart from the sample that was collected at CHR006 with PLI>1(calculated PLI=1.5191), all sample locations had PLI < 1 with values between 0.0007 and 0.0724. The polluted element identified by Igeo and PLI (Mo) has no known detrimental effects on humans and therefore the tailings could be used for all sorts of construction works and the materials can be re-used for agricultural work.

Keywords – *Tailings, Re-used, Elements, Geo-accumulation, Pollution, Chirano.*

I. Introduction

Sand size materials constitute the waste materials left after mineral extraction from mineralized ore-bodies in mining areas. Records of mine tailings (MT) being used as construction materials, especially in hollow blocks and in bricks production and as masonry mortar is long known. MT can be re-used for various purposes including construction and agricultural works. The essentiality of this study is hinged on the fact that elements such as Pb, Cu, Zn, Co and Cd were found in tailings in an investigation by British Geological Survey (BGS) in Argentina and Brazil [7]. Similarly at AngloGold Ashanti, Obuasi mines, elevated levels of As were recorded in tailings and the nearby streams [1]. Antwi-Agyei et al. [1] further reported of the presence of high concentration levels of Cu, Pb and Zn in active and decommissioned tailings dams. These elements depending on the rate of exposure, concentration levels and pathways may have health implications and as such may not be good to be used as indoor building materials or other such purposes as farming.

Kinross Gold Mine at Chirano has three huge tailings dams but the contained elements and their concentrations have not yet been determined. Considering the estimated housing units deficit of 70,000 to 120,000 put up by the statistical service [3], the accumulated mine tailings material dumped in the dam over 10 years could make a very good contribution in Ghana's real estate development with the slightest value addition. Good quality and easy to afford cheap blocks as well as plastering sand and other building materials can be obtained from the tailings but this has to be done to avoid human exposure to potentially harmful elements that will result in adverse health effects from the contained elements in the tailings. It is on the basis of these that risk assessment of their use as a construction material was carried out by establishing the composition and concentration levels of elements in the tailings. This assessment was to evaluate the environmental suitability of using the tailings as construction materials.

II. Location, Physiographic and Geological Settings

A. Location

The area is located in southwestern Ghana, approximately 100 kilometers southwest of Kumasi, which is the second biggest city in Ghana (Fig 1). The township of Bibiani in the Sefwi Bekwai District of the Western region lies about 15 kilometers north-northeast of the mine area (37 kilometers by road). The mine can be accessed through a sealed highway to Kumasi from Accra and then through a sealed highway running southwest towards Bibiani and onwards to Sefwi Bekwai [8]. The final access route to the area is either by a 22 kilometer gravel road from Tanoso Junction, which is 15 kilometers south of Bibiani or by a 13 kilometer gravel road whose junction is approximately 9 kilometers beyond Sefwi Bekwai [6].

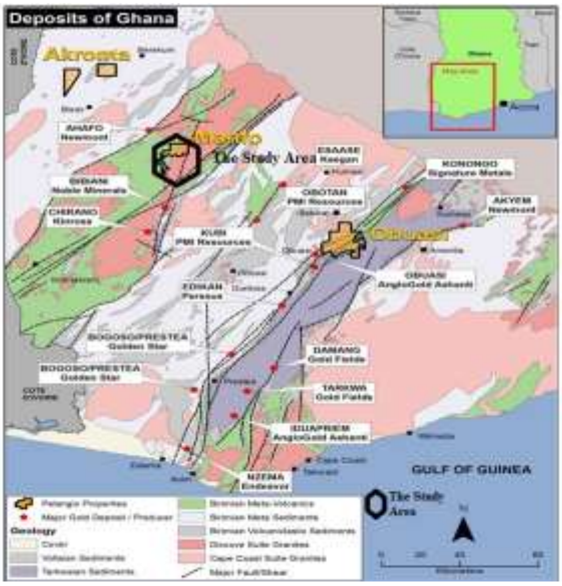

Fig 1: Geology and study area location

B. Physiographic Settings

The area is characterized by humid tropical climate, with dry seasons ranging from November to February whilst the humid season between March and April. The humid season is followed by wet season which extends from May to October with peaks between May and June. The annual rainfall is estimated at about 1,420 mm [6]. In terms of vegetation about 42% of the Kinross Chirano concession lies in a forest reserves. The vegetation in the area comprises perennial trees and shrubs of which some are logged for commercial timber production. The main rivers draining the area are Ankobra and Suraw River and their tributaries [8].

C. Local Geological Settings

Underlying the area is Paleoproterozoic rocks of the Sefwi belt. The rocks consist of metavolcanic, metasedimentary and Tarkwaian suites of rocks intruded at places by Belt and Basin granitoids in the metavolcanic and metasedimentary units. Mafic metavolcanics comprising basalt, andesite, dacite, dolerite and associated gabbro characterize the volcanic units. The metasedimentary units occupying the eastern areas principally are made up of phyllite, schist, tuff, and some greywackes other rock units exhibiting argillaceous facies [2]. The Tarkwaian consists of sandstones, siltstones, Kawere and Banket conglomerates.

III. Methodology

The materials used in assessing the suitability of the tailings for future economic use such as in construction and agricultural works include field and laboratory works. The fieldwork involved the collection of soil samples from Tailings Storage Facility (TSF) called the tailings dam. The sites for sampling were located at the TSF using the GPS device. Sampling interval at a distance of 50 meters was designed to be the separation between samples along a cross line defined by east-west grid. The top 5 cm uppermost veneer of the tailing material was scrapped off to avoid external contamination due to long exposure to the atmosphere. The samples were shoveled after scrapping off the top 5 cm material at an angle to help give a composite sample and representative samples at a site. Total of 40 samples were taken for geochemical analysis and these included three duplicate samples. No major sample preparation works was done on the collected samples except five samples that were wet. Apart from the five samples all the samples were generally dry and of uniform fine matrix, which did not require sieving. The five (5) wet samples were sun dried for about twelve hours after which 1 kg weight of all the dried samples were labeled with unique identification numbers. The labeled samples were readied for chemical analysis at SGS Geochemical Laboratory at Tarkwa using Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES) analytical technique for trace elements and major oxides analysis.

A. The Laboratory Sample Preparation and Analysis

The samples were digested using Aqua Regia. The Aqua Regia method used nitric acid and hydrochloric acid in the ratio of 1:3. The combined acids help to release most elements in the samples. After the digestion, the samples were placed in the plasma chamber where the plasma excites the atoms and ions that travel through it. The electrons of the excited atoms or ions jump from a lower to higher energy level. Upon easing of these electrons from the excited energy state to their initial 'ground' state, energy is emitted in the form of photons. The emitted photons possess wavelengths that are characteristic of their respective elements. These were then measured to represent the concentration levels of elements in the respective sample. Also in order to ensure analytical quality of the results duplicate samples were taken on every tenth (10th) sample. Three duplicates samples namely CHR11, CHR22 and CHR33 were collected.

The assessments of the pollution indices were obtained calculating the contamination factors of the elements in soil samples at a place. This was calculated by dividing the measured concentration averages by the global averages or background values in the samples.

$$CF = \frac{Cn}{Bn}$$

Where Cn is the measured concentration level of elements in the sample and Bn is the background value of element in soils.

The elements contamination levels in the entire tailings were calculated using Muller [5] proposed Geo-accumulation Index. This was calculated using the formula:

$$Igeo = \log 2[\frac{Cn}{1.5Bn}]$$

Where Cn is the measured value and Bn is the background value.

The geochemical variability of elements concentrations and distributions across the landscape made it necessary to assess the pollution conditions at each of the sampling station using Tomlimson's et al. [9] method. The formula used is:

$$PLI = \sqrt[n]{(CF1).(CF2).(CF3)\ldots(CFn)}$$

IV. Results

The results obtained for samples collected at the Tailings Storage Facility and the inserted control samples are presented in Table 1. Table 1 contains the sample coordinates and the geochemical results of eleven elements comprising essential and potentially toxic elements. The descriptive statistics of elements in the samples is presented in Table 2. This table makes it easy to compare measured elements average concentration values with the accepted global values for the determination of risky areas due to elements excesses and deficiencies. Contamination or enrichment factors were derived for the elements from Table 2 and presented in Fig. 2.

The pollution status in terms of the contained elements concentration levels were calculated using geo-accumulation and pollution load indices (Table 3) and evaluated using Table 4 that explains the degree of pollution in the tailings dump site. The geo-accumulation index only provides the relative pollution levels for the entire TSF and unable to determine the pollution levels at the respective stations where samples were collected. Since metal migrations in surface environment have many controls on their distributions and concentrations; possibilities of some elements pollutions being higher and lower in the same TSF was assessed using Pollution Load Index that calculates the pollution situation at a sample point. Results of PLI at the TSF in this study are also presented in Table 3. The confidence in the analytical data were demonstrated by closeness of the certified reference materials certificate values comparison with the resultant values obtained for analyzed CRM values as shown in Figs. 3 – 5.

TABLE I
Concentration Levels of Elements

Sample ID	West (x◦)	North (y◦)	As	Pb	Co	Cr	Hg	Ni	Zn	Cu	Cd	Mo	Total CN (mg/kg)
CHR 01	2.36975	6.30917	1	15	24	16	0.1	39	37	35	0	58	0.4
CHR 02	2.3702	6.30907	1	11	21	20	0.1	41	55	38	0	52	0.6
CHR 03	2.37063	6.30895	1	12	23	17	0.1	44	48	41	0	81	0.6
CHR 04	2.37106	6.3088	1	10	22	17	0.1	44	57	36	0	38	0.4
CHR 05	2.37142	6.30872	1	10	16	16	0.1	32	38	28	0	58	0.4
CHR 06	2.37118	6.3083	2	9	19	13	0.1	37	46	32	0	29	0.6
CHR 07	2.37073	6.30837	1	12	21	15	0.1	41	47	35	0	62	0.7
CHR 08	2.3703	6.3085	1	11	25	17	0.1	48	56	42	0	46	0.6
CHR 09	2.36988	6.30862	1	11	21	17	0.1	44	59	36	0	53	0.3
CHR 10	2.36945	6.30879	1	10	18	16	0.1	33	37	34	0	85	0.4
CHR 11	2.36945	6.30879	1	11	19	17	0.1	34	40	33	0	85	0.4
CHR 12	2.36919	6.30844	1	14	31	17	0.1	43	37	31	0	28	0.7
CHR 13	2.36936	6.30832	1	12	17	16	0.1	31	43	25	0	38	0.6
CHR 14	2.36979	6.30816	1	11	21	18	0.1	45	61	36	0	45	0.5
CHR 15	2.37026	6.30808	1	11	20	16	0.1	41	50	36	0	52	0.4
CHR 16	2.37069	6.30799	1	13	22	19	0.1	49	64	41	0	58	0.4
CHR 17	2.37113	6.30791	1	7	18	12	0.1	36	42	35	0	45	0.4
CHR 18	2.37138	6.30744	1	9	19	14	0.1	32	37	35	0	58	0.3
CHR 19	2.37093	6.30741	1	9	21	14	0.1	40	49	41	0	38	0.5
CHR 20	2.3705	6.30752	1	13	24	18	0.1	48	53	43	0.7	68	0.7
CHR 21	2.37006	6.30757	1	14	19	23	0.1	46	66	36	0	86	0.3
CHR 22	2.37006	6.30757	1	15	18	22	0.1	45	63	35	0	75	0
CHR 23	2.36962	6.30768	1	12	20	18	0.1	34	43	38	0	72	0.2
CHR 24	2.3692	6.3078	1	11	16	16	0.1	36	50	29	0	47	0.2

CHR 25	2.36879	6.30801	1	16	14	14	0.1	31	45	27	0	72	0.2
CHR 26	2.36844	6.30776	1	10	15	17	0.1	30	39	25	0	42	0.3
CHR 27	2.36884	6.30753	1	10	16	16	0.1	30	36	24	0	46	0.6
CHR 28	2.36926	6.3074	1	17	17	100	0.1	77	53	34	0	85	0.6
CHR 29	2.3697	6.30731	1	10	16	16	0.1	30	38	31	0	54	0.4
CHR 30	2.37017	6.30729	1	14	18	22	0.1	44	65	34	0	100	0.3
CHR 31	2.37057	6.30724	1	10	23	18	0.1	49	67	43	0	46	0.5
CHR 32	2.37103	6.30713	1	9	20	15	0.1	43	54	45	0	55	0.3
CHR 33	2.37103	6.30713	1	9	21	14	0.1	43	52	43	0	49	0.4
CHR 34	2.37146	6.30706	1	8	16	12	0.1	30	38	32	0	43	0.7
CHR 35	2.37084	6.30691	1	9	17	12	0.1	30	36	36	0	39	0
CHR 36	2.3704	6.3089	1	14	19	19	0.1	41	55	37	0.3	100	0.2
CHR 37	2.36987	6.30695	1	14	17	16	0.1	31	41	30	0	62	0.2
CHR 38	2.36943	6.30696	1	11	20	16	0.1	35	40	37	0	74	0.4
CHR 39	2.36897	6.30699	1	14	21	16	0.1	35	38	35	0	65	0.2
CHR 40	2.3685	6.30695	1	13	20	14	0.1	33	38	27	0	78	0.5

TABLE II
Descriptive Statistics of the selected Elements

Element	Min	Max	Mean	Median	Standard Deviation	Accepted values in soils (mg/kg)	Reference
As	1	2	1.03	1	0.156	10	
Pb	7	17	11.52	11	2.28	14	
Cr	12	100	18.52	16	13.283	25	
Hg	0.1	0.1	0.1	0.1	4.16E-17	1	
Ni	30	77	39.37	39.5	8.599	70	ICRCL 59/83
Zn	36	67	47.82	46.5	9.654	71	
Cu	0	45	34.78	35	5.232	25	
Cd	0	0.7	0.02	0	0.118	3	
CN	0	0.7	0.41	0.4	0.18	250	
Co	14	31	19.62	19.5	3.176	20	New Dutchlist
Mo	28	100	59.178	56.5	18.281	10	

TABLE III
Enrichment Factor and Geo-accumulation Index

Element	Measured Value (Cn)	Background Value (Bn)	E.F	Igeo
As	1.03	10	-8.97	0.0206
Pb	11.52	500	-488.48	0.0046
Cr	18.52	25	-6.48	0.1487
Hg	0.1	1	-0.9	0.0201
Ni	39.37	70	-30.63	0.1129
Zn	47.82	300	-252.18	0.0320
Cu	34.78	130	-95.22	0.0537
Cd	0.02	3	-2.98	0.0013
CN	0.41	250	-249.59	0.0003
Co	19.62	20	-0.38	0.1969
Mo	59.178	10	49.178	1.1876

TABLE IV
Pollution Status Classifications and Descriptions

Igeo values	Igeo Class	Pollution Intensity
> 5	6	Extremely polluted
4–5	5	Strongly to extremely polluted
3–4	4	Strongly polluted
2–3	3	Moderately to strongly polluted
1–2	2	Moderately polluted
0–1	1	Unpolluted to moderately polluted
0	0	Unpolluted

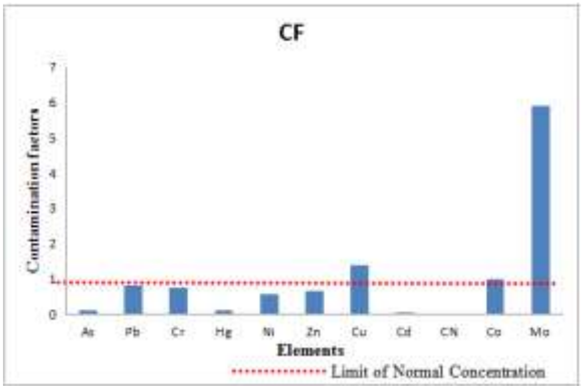

Fig 2: Contamination factors

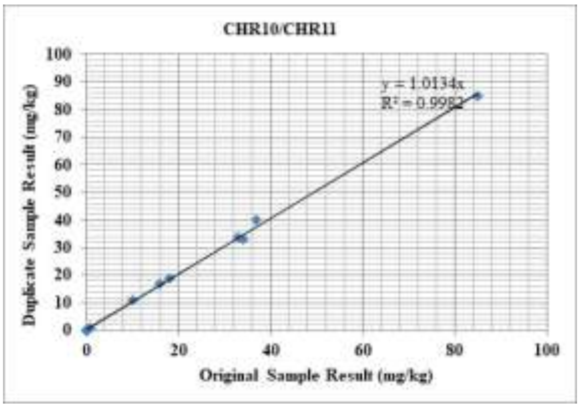

Fig 3: QAQC Analysis for samples CHR10 and CHR11

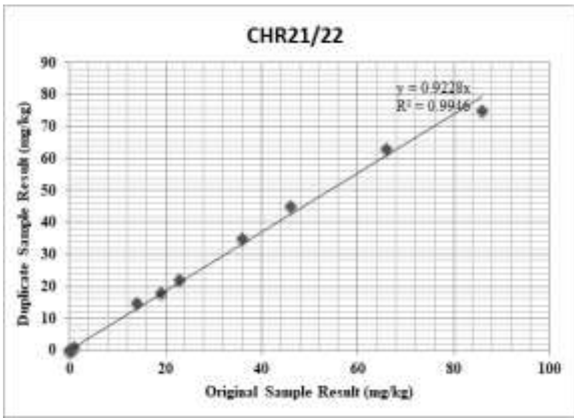

Fig 4: QAQC Analysis for samples CHR 21 and CHR22

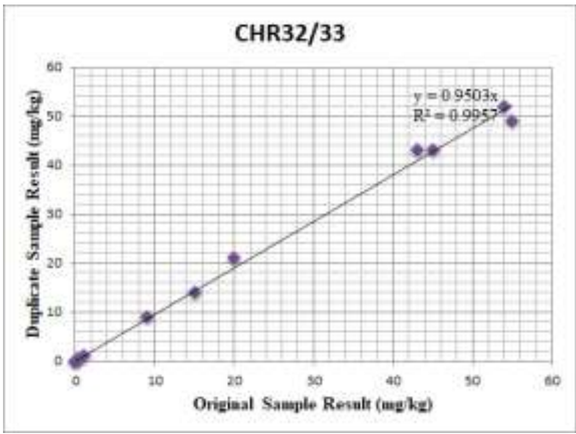

Fig 5: QAQC Analysis for samples CHR32 and CHR33

V. Discussion

Figures 3-5 showed good correlations between most elements in the original and duplicate samples except Molybdenum that demonstrates inconsistent variations between duplicate pairs in samples CHR21/22 and CHR32/33. As seen in Figs. 3-5, the quality of the analytical data was considered good and acceptable because most of the elements in the duplicate pairs correlated well with each other. The results shown in Table 1 confirm the general notion of variable geochemical variations across the landscape. The gold deposit mined at Kinross comes from different mine pits underlain by different geology with contrasting geological and geochemical processes hence the variable elemental concentrations and distribution. The waste slimes of these materials from different sites are dump into a tailings storage facility with no considerations to the source of the waste materials. There is further redistribution of elements controlled by the surface process in the TSF. These and many factors such as pH, conductivity and CEC of the tailings that this study did not investigate contributed to the geochemical variability as displayed in Table 1. The descriptive statistics of elements in samples shown in Table 2 provided insights of elements that have average concentration levels greater or lower than the globally accepted values in soils. From Table 2 the element that is in excess of the globally accepted value is Mo. The measured average value of Mo is 59.1 ppm as against globally accepted value of 10 ppm; percentage increase of 83%. Molybdenum is a trace mineral that provides a number of health benefits. Research had shown that Mo in humans fight anemia prevent cancer as well as asthma. It controls also dental cavity including certain mouth and gum disorders and above all contribute in preventing sexual impotence [4]. The high concentrations of Mo in the tailings suggest that on mine decommissioning these areas can be re-used for agricultural purposes. All other elements analyzed including toxic and essential elements plus cyanide used in gold extraction were below the accepted global concentration limits in soils. A situation that makes tailings materials at Kinross harmless and could be used for farming and construction works.

However from Table 3, the computed Igeo for all the analyzed elements were < 1 except Mo that was >1. These Igeo values correspond with unpolluted to moderate pollution confirming the harmless nature of the tailing materials for the toxic elements such as As, Pb, Hg, Cr, Cd and CN but might not be good for Cu, Zn and Ni that are essential for humans and animals if their intended use is for farming. The unpolluted nature of tailings with the toxic elements may inhibit the chances of inhabitants farming over the tailings for food crops over adverse health consequences. On the contrary the deficiencies of the essential elements may affect the population access to dietary supplements for their wellbeing. The Igeo factors the elements concentrations in all sample stations and estimate the overall pollution status for the study environment. The calculated Igeo thus provides overview of the pollution situation for the elements in the entire study area and thus serves as a guide to mitigation call for action towards proper environmental management. Conversely, the PLI deals with pollution related to a sample and do not classify the type of element. The usefulness of using both Igeo and PLI provide the clear geographic location and element that needs attention. As seen in Table 3, the moderately polluted element is Mo and the sample linked to the polluted element is CHR 006, identified with a specific geographic location. This area can be defined and outlined for mitigation if element is harmful or be promoted for human gains if element is essential for human health. Time is not a luxury when it comes to issues related to environmental health management therefore expediting action on decision on lack or excess of elements that may have detrimental effect on life require the concurrent applications of Igeo and PLI.

VI. Conclusion

All the elements considered in the study showed depletion of essential elements such as Zn, Cu, and Cr and potentially toxic elements Pb, As, Hg, Cd as well as CN, a compound used in the extractive metallurgy. The only enriched or polluted elements identified on the basis of contamination factor and Igeo calculations are Mo. This was in the excess of 83% compared with the global accepted Mo value. The computed Igeo confirmed the enhanced concentrations of Mo in the tailings dam materials. CN also showed depletion in the analyzed samples suggesting the mining operation is not introducing foreign chemicals into the environment. It was thus concluded that the tailings material is safe for use as a construction material for any sort of construction work and since Mo is useful for human development; the re-use of the tailings for agricultural work can be considered.

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References

[1] Antwi-Agyei, P., Hogarh, J. N. and Foli, G. "*Trace elements contamination of soil around gold mine tailings dams at Obuasi, Ghana*". African Journal of Environmental Science and Technology Vol. 3(11), 353-359, November, 2009

[2] Appiah D. 2015. "*Aeromagnetic and airborne radiometric data interpretation on Chirano area of the Sefwi gold belt"*. A Thesis Submitted to The Department of Physics, Kwame Nkrumah University of Science and Technology in Partial Fulfillment of the Requirements for The Degree of Master of Philosophy (Geophysics).

[3] Ghana Statistical Service. (2014). 2010 "*population and housing census report"*. Ghana Statistical Service.

[4] Michl, R. J. (1993). U.S. Patent No. 5,213,615. Washington, DC: U.S. Patent and Trademark Office.

[5] Muller, G. (1979). "*Schwermetalle in den sedimenten des Rheins-Veranderungen seit 1971*". Umschau, 79, 778-783.

[6] Oppong, K. (2011). *"Impact of Chirano gold mines operations on levels of As, Pb, Hg and Cd in the Suraw River and the possible health implications on downstream communities*". A thesis submitted to the Department of Environmental Science in partial fulfillment of the requirements for the degree of Master of Science.

[7] Rawlins, B. G., Breward, N., Ferpozzi, L., Figueiredo, B. and Borba, R. 1997. *"Preliminary investigation of mining-related arsenic contamination in the provinces of Mendoza and San Juan (Argentina) and Minas Gerais state (Brazil)*". British Geological Survey Technical Report WC/97/60.

[8] Stuart, H. (2009). "*Technical report on the Chirano gold mine"*, Republic of Ghana for Red Back Mining Inc.

[9] Tomlinson, D. L., Wilson, J. G., Harris, C. R., & Jeffrey, D. W. (1980). *"Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index*". *Helgoländer meeresuntersuchungen*, *33*(1), 566-575.