၂၀၁၈ ခုနှစ်၊ စက်တင်ဘာလ

တီကျစ်ဒေသ

ရေနမူနာ ဆန်းစစ်လေ့လာချက် အစီရင်ခံစာ

Water Quality Assessment Report

ကန်သတ်

အခန်း(၁) အမည်နှင့် အဓိပ္ပါယ်ဖော်ပြချက် ၂ (ဇ)

ပတ်ဝန်းကျင်အပေါ် သက်ရောက်မှုဆိုသည်မှာ အဆိုပြုထားသည့်စီမံကိန်း သို့မဟုတ် စီးပွားရေးလုပ်ငန်း သို့မဟုတ် လုပ်ဆောင်မှု သို့မဟုတ် တာဝန်ယူဆောင်ရွက်မှုများကြောင့် သဘာဝပတ်ဝန်းကျင်၊ တည်ဆောက်ထားသောပတ်ဝန်းကျင်၊ အများပြည်သူနှင့် လူမှုအဖွဲ့အစည်းအပေါ် ဖြစ်ပေါ်နိုင်သည့် အကျိုးသက်ရောက်မှု သို့မဟုတ် အကျိုးဆက်ကို ဆိုသည်။ ယင်းစကားရပ်တွင် လုပ်ငန်းခွင်ဆိုင်ရာ၊ လူမှုအဖွဲ့အစည်း၏ လူမှုရေး၊ စီးပွားရေး၊ ယဉ်ကျေးမှု၊ အများပြည်သူနှင့် လူမှုအဖွဲ့အစည်း၏ ကျန်းမာရေးနှင့် ဘေးအန္တရာယ်ကင်းရှင်းရေးဆိုင်ရာ ကိစ္စရပ်များ အပေါ် တိုက်ရိုက်သော်လည်းကောင်း။ ကောင်းကျိုးသော်လည်းကောင်း၊ ဆိုးကျိုးသော်လည်းကောင်း၊ နှစ်မျိုးလုံးသော်လည်းကောင်း ဖြစ်ပေါ်နိုင်သည့် သက်ရောက်မှု များအပြင် ဆန္ဒမပါသောနေရာရွှေ့ပြောင်းမှု သို့မဟုတ် တိုင်းရင်းသားမျိုးနွယ်စုနှင့်သက်ဆိုင်သည့် လူမှုရေးဆိုင်ရာ သက်ရောက်မှုများလည်း ပါဝင်သည်။

ကျေးဇူးတင်လွှာ

ဤအစီရင်ခံလွှာဖြစ်မြောက်ရေးအတွက် အဖက်ဖက်မှ အင်အားစိုက်ထုတ်
အကူအညီပေးခဲ့ကြသော ၁။ **စိမ်းလန်းအမိမြေ ဖွံ့ဖြိုးတိုးတက်ရေးအသင်း ALARM**၊

၂။ Earth Rights International (ERI)

၃။ Mr. Lauri Myllyvirta (Green Peace)

၄။ Mr. Paul Winn (Water keeper Alliance)

၅။ ပေါင်းကူး (Paung Ku)

စသည့် တို့ နှင့် တကွ အခြား ပူးပေါင်းပါဝင်ခဲ့ကြသော အဖွဲ့အစည်းများနှင့် လူပုဂ္ဂိုလ် တစ်ဦးချင်း
စီတို့အား လှိုက်လှဲစွာ ကျေးဇူးတင်ရှိပါကြောင်း။

မြန်မာနိုင်ငံ ပွင့်လင်းမြင်သာမှုနှင့် တာဝန်ယူမှု၊ တာဝန်ခံမှုဆိုင်ရာ အရပ်ဖက် မဟာမိတ်အဖွဲ့ MATA

Pollution impact assessment of Thi Kyit, Myanmar

27 August 2018

Paul Winn, International Energy Campaigner, Waterkeeper Alliance – pwinn@waterkeeper.org

Contents

Introduction

Waterkeeper Alliance (WKA) has been provided with a *Laboratory Analysis Report* by Advancing Life and Regenerating Motherland (ALARM) dated 6 April 2018, and an *Analysis Report* by the Analysis Department of the Government of the Republic of Myanmar (GRM) dated 5 April 2018 (72 pages in total) of water and soil samples collected in and around the Village of Thi Kyit in Shan State, Myanmar. Our analysis of likely sources and environmental and human health impacts based on these reports is presented below.

The Laboratory Reports provide results of water analysis for 12 heavy metals and major cations, as well as faecal coliform, oil and grease, TSS, BOD, COD, ammonia, chorine, cyanide, nitrate, nitrite, phosphorous, phenol and dissolved oxygen. Analyses of soil samples were provided to WKA, but appear to be within known background concentrations. A page titled "Analytical Data for Water Samples" was also provided to WKA for mercury concentrations in parts per billion (ppb) of the 11 water samples, which were also within known background levels elsewhere.

Map 1: Location of Thi Kyit Village, Myanmar

The coordinates of the sites from which the water samples were taken were also provided and have been plotted with the corresponding sample identification numbers of the analysis reports and imported into Google Earth represented in Map 2.

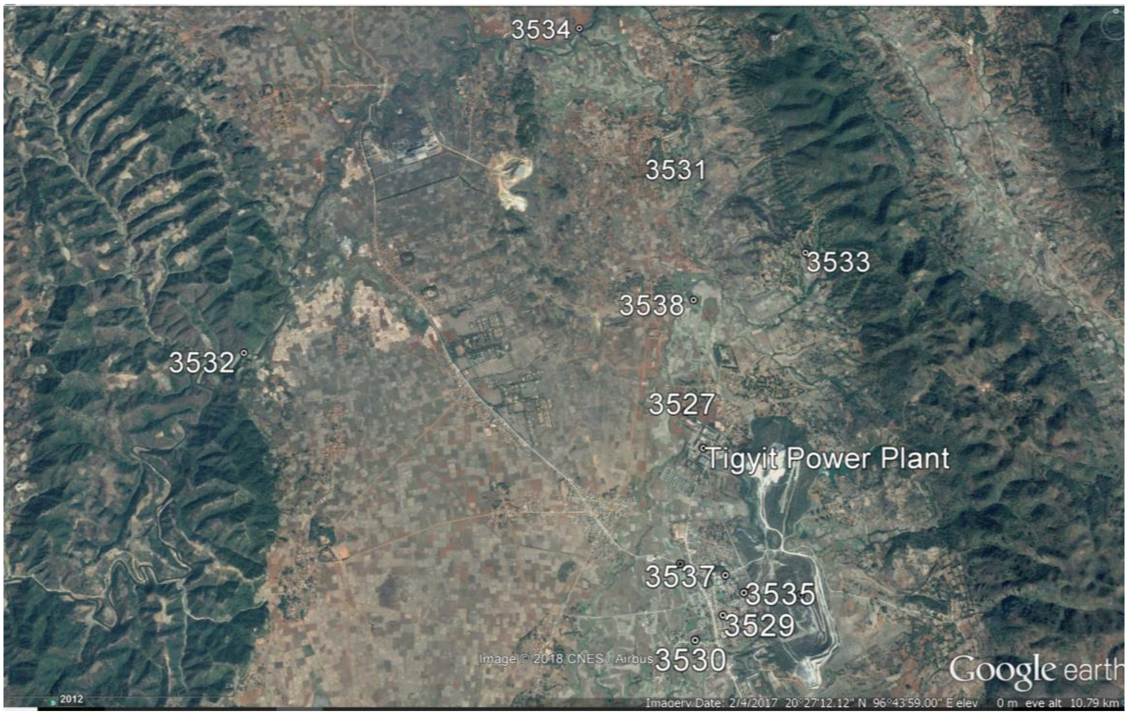
This assessment focuses on the results of pollutants set out in table 1.

Table 1: Major pollutants and parameters identified in Thi Kyit Laboratory Reports

Sample #	3527	3528	3529	3530	3531	3532	3533	3534	3535	3536	3537	3538	3539	USEPA National Primary Drinking Water Regulations	WHO Guidelines for drinking-water quality, 4th edition.	Myanmar National Environmental Quality (Emissions) Guidelines (NEQG)	Comment
matrix	WW	DW	DW	DW	DW	DW	DW	WW	DW	WW	DW	DW	WW	DW	DW	WW	
pH	8.2	7.2	7.9	7.5	7.8	7.9	7.1	7.9	8	8	7.7	7.2	8			6 TO 9	
mg/l																	
TSS	5	3	10	3	6	6	2	1		**265**	3	2	32			**50**	Max. 5.3 x NEQG
BOD	8.5	*	*	*	*	*	*	7.1	*	6.4	*	*	5.1			50	
COD		*	*	*	*	*	*		*	21	*	*				250	
disolved oxygen	6.5	5.9	6.5	7.1	6.8	6.8	5.6	6.5	7.4	5.9	7.4	6.8	*				
oil and grease	**21**	*	*	*	*	*	*	**15**	*	**12**	*	*	**15**			**10**	Max. 2 x NEQG
amonia - nitrogen	0.05	0.03	0.21	0.15	0.33	0.23	0..46	0.19	0.08		0.14	**0.55**				10	
hardness	*	220	280	180	140	200	280	*	160	*	190	190	*				
chlorine	0.04	0.06		0.09										4	5	0.2	
free cyanide																0.1	
nitrate-nitrogen	1.1	0.6		5.8	1.8	0.5	1	1.2	8	1.9	0.7	2.5	1.5	10	50		
nitrite		0.03												1	3		
phosphorous	0.2	0.11	0.07	0.07	0.13		0.03	0.04	0.03				0.09			2	
phenol	0.11		0.15				0.15	0.26			0.22			6	2	0.5	
sulfide										0.16						1	
arsenic				0.05					0.05	0.01	0.01			0.01	0.01	0.1	Max. 5 x WHO
cadmium											0.01	0.01	0.01	0.005	0.003	0.1	Max. 3.3 x WHO
chromium (total)	*							*		*			*	0.1	0.05	0.2	
cobalt	0.004	0.005	0.003	0.003	0.003	0.003	0.006	0.004	0.004	0.005	0.005	0.004	0.005				
copper														1.3	2	0.5	
fluoride	0.12	0.07	0.08	0.1	0.17	0.06	0.11	0.05	0.07	0.09	0.08	0.15	0.13	4	1.5	20	Max. above WHO
iron																3.5	
lead											**0.14**	**0.27**	**0.22**	0.015	0.01	**0.1**	Max. 27 x WHO and 2.7 x NEQG
manganese	0.23															2	
nickel				0.2		0.3	0.2	**0.6**	0.2						0.07	**0.5**	8.6 x WHO and above NEQG
selenium	*	**0.109**	0.086	0.074	0.078	0.06	**0.125**	*	**0.137**	*	**0.17**	**0.11**	*	0.05	0.04	**0.1**	Max. 4.25 x WHO and above NEQG
zinc	0.3	0.19	0.34	0.25	0.24	0.41	0.43	0.23	0.3	0.14	0.47	0.33	0.12			2	

*- not analysed; WW - waste water; DW - assumed to be drinking water; USEPA[1] and WHO[2] - drinking water guidelines; Concentrations in red - exceed WHO guidelines, and in bold- exceed NEQG for effluent concentrations ; Blank - below laboratory detection limits.

[1] U.S. EPA, 2018.
[2] WHO, 2011.



Map 2: Water sample sites surrounding the Thi Kyit Power Plant

Water sample sites, pollution and potential impacts

The laboratory analyses of water samples taken from waterways near to the village of Thi Kyit, Myanmar shows heavy metal concentrations significantly above World Health Organisation (WHO) drinking water guidelines in 12 of the 13 water samples and nine water samples exceed maximum concentrations of one or more parameter under the Myanmar Environmental Quality (Emissions) Guidelines.

Four water samples (3530, 3535, 3537, and 3538) contained concentrations of three heavy metals that exceeded WHO drinking water guidelines and two sample (3537 and 3538) exceeded the Myanmar or Environmental Quality (Emissions) Guidelines for 2 heavy metals.

For example;

- sample 3537 contained selenium 4.25 times, cadmium 3.3 times and lead 14 times WHO guidelines;
- sample 3538 contained concentrations of lead 27 times and cadmium 3.3 times the WHO guidelines; and
- samples 3530 and 3535 contained arsenic concentrations 5 times the WHO guidelines for safe drinking water.

An indicator of poor water quality is Total Suspended Solids (TSS)[3] for which one water sample (3536) exceeded the maximum under the Myanmar Environmental Quality (Emissions) Guidelines for effluent water by more than five times.

Other pollutants found was oil and grease. All four water samples analyzed for oil and grease (3532, 3534, 3536, and 3539) exceeded the Myanmar Environmental Quality (Emissions) Guidelines for effluent containing this pollutant. The presence of oil and grease in water bodies leads to the formation of oil layer, which causes significant pollution problem such as reduction of light penetration and photosynthesis. It further hinders oxygen transfer from atmosphere to water medium and this leads to decreased amount of dissolved oxygen at the bottom of the water and this adversely affects survival of aquatic life in water.[4]

Pollutants of significant health concerns

Heavy metals are significant environmental pollutants, and their toxicity is a problem of increasing significance for human health and the environment. Because of their high solubility in water, heavy metals can be absorbed by living organisms. Once they enter the food chain, concentrations of heavy metals can magnify as they accumulate in organisms and ecosystems. If the metals are ingested beyond recommended maximum concentration, they can cause serious health disorders.

Lead

Very high concentrations of lead were found in three water samples. The World Health Organisation (WHO) guidelines for maximum lead in drinking water is 0.01 mg/l. Three water samples exceeded WHO maximum safe levels of lead;

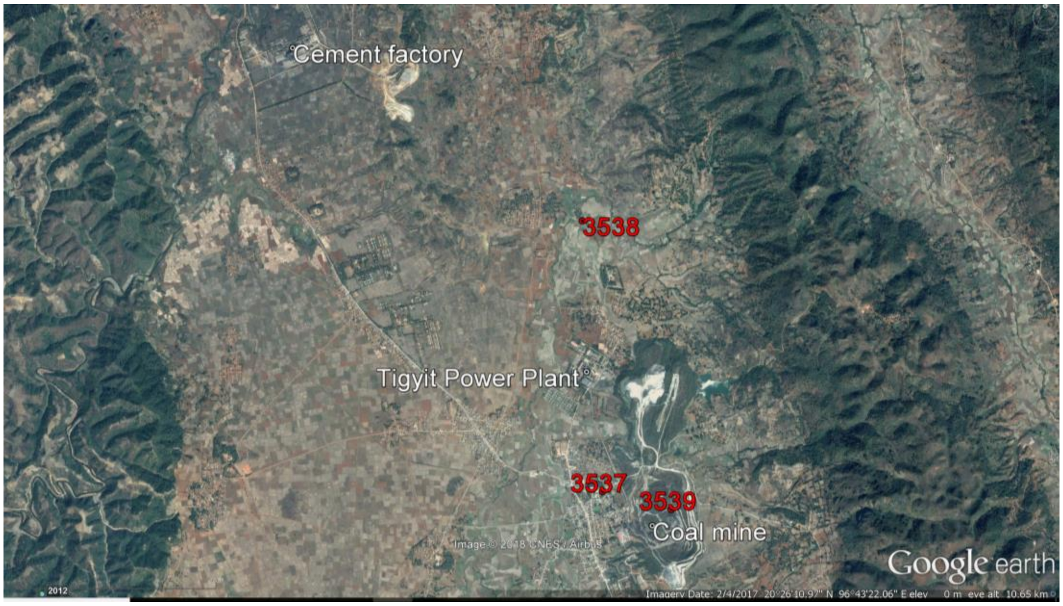
- 3538 (0.27mg/l) 27 times:
- 3539 (0.22 mg/l) 22 times; and
- 3537 (0.14 mg/l) 14 times the WHO guideline.

All three water samples also exceeded the Myanmar Environmental Quality (Emissions) Guidelines for for lead (see table 1).

---

[3] Turbidity and TSS are the most visible indicators of water quality. These suspended particles can come from soil erosion, runoff, discharges, stirred bottom sediments or algal blooms. While it is possible for some streams to have naturally high levels of suspended solids, clear water is usually considered an indicator of healthy water. Excessive suspended sediment can impair water quality for aquatic and human life, impede navigation and increase flooding risks. See https://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/

[4] T. Mohammadi, and A. Esmaelifar, 2005.



Map 3: Thi Kyit sites and sample numbers of water sample with high lead levels in relation to likely industrial sources.

The WHO states in its Drinking Water Guidelines[5] that exposure to lead is associated with a wide range of effects, including various neurodevelopmental effects, mortality (mainly due to cardiovascular diseases from increased blood pressure.), impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes.

Impaired neurodevelopment in children is generally associated with lower blood lead concentrations than the other effects. Infants and children are considered to be the most sensitive subgroups of the population. [6] The *Toxicological Profile for Lead* by the US Agency for Toxic Substances and Disease Control[7] warns that, in general, if adults and children swallow the same amount of lead, a bigger proportion of the amount swallowed will enter the blood in children than in adults with children absorb about 50% of ingested lead and that no safe blood lead level in children has been determined. Based on the dose-response analyses, 0.025mg/l of lead to 1kg body weight is associated with a decrease of at least 3 intelligence quotient (IQ) points in children and an increase in systolic blood pressure of approximately 3 mmHg (0.4 kPa) in adults.[8]

Lead exposure may also cause weakness in fingers, wrists, or ankles and may also cause anemia. [9] The US ATSDR warn that; "At high levels of exposure, lead can severely damage the brain and kidneys in adults and children and ultimately cause death. In pregnant women, high levels of exposure to lead may cause miscarriage. High level exposure in men can damage the organs responsible for sperm production".[10] Lead can be transferred from the mother to the fetus and also from the mother to infants via maternal milk.[11]

---

[5] WHO, 2011. p 384.
[6] *Ibid*
[7] ATSDR, 2007a. p 10.
[8] WHO, 2011. p 384.
[9] ATSDR, 2007a. p 8.
[10] ATSDR, 2007a pp 8-9.
[11] ATSDR, 2007. pp 156.

Lead is toxic to all aquatic biota, and organisms higher up in the food chain may experience lead poisoning as a result of eating lead-contaminated food.[12] Older organisms tend to contain the greatest body burdens with lead concentrations usually highest in benthic organisms and algae, and lowest in upper trophic level predators (e.g., carnivorous fish).[13] Bio-concentration factors for aquatic biota are: 42 for fish, 536 for oysters, 500 for insects, 725 for algae, and 2,570 for mussels. [14]The European Inland Fisheries Advisory Commission set a maximum admissible lead concentration in water of 0.004 to 0.008 mg per liter for salmonids and 0.07 mg per liter for cyprinids.[15]The US EPA National Recommended Aquatic Life Criteria for freshwater are 0.065 mg/l (acute) and 0.0025 ug/l (chronic).[16]

Excess lead causes a number of toxicity symptoms in plants e.g. stunted growth, chlorosis and blackening of root system and inhibits photosynthesis, upsets mineral nutrition and water balance, changes hormonal status and affects membrane structure and permeability.[17]

An advisory warning should be made that the waters from which these samples were taken should not be used for any domestic purpose. People living near to these waters, particularly the children, and those who consume fish from these waters should have blood samples taken to determine blood lead levels and whether therapy is required.

Fish taken from these waters should be tested for lead content before being consumed.

Arsenic

The WHO Drinking Water Guidelines and US EPA Drinking Water Standards for maximum arsenic concentration is 0.01 mg/l. Water samples 3530 and 3535 was found to have five times (0.05mg/l) the WHO guidelines for safe drinking water. Two other samples, 3536 and 3537, were found to have 0.01mg/l, which is at the maximum recommended concentration for safe drinking water.

[12] ATSDR, 2007a. p 322.
[13] ATSDR, 2007a. p 321.
[14] *ibid*
[15] Svobodová et al, 1993.
[16] US EPA, 2011.
[17] Sharma & Dubey, 2005.

Map 4: Thi Kyit sites and sample numbers of water sample with high arsenic levels in relation to likely industrial source

Chronic exposure of humans to inorganic arsenic in the drinking water has been associated with excess incidence of miscarriages, stillbirths, preterm births, and infants with low birth weights. [18]

Inorganic arsenic compounds are classified by International Agency for Research on Cancer (IARC) as a Group 1 carcinogen (carcinogenic to humans).[19] The International Programme on Chemical Safety (IPCS) concluded that long-term exposure to arsenic in drinking-water is causally related to increased risks of cancer in the skin, lungs, bladder and kidney, as well as skin changes, such as hyperkeratosis and pigmentation changes.[20] Increased risks of lung and bladder cancer and of arsenic-associated skin lesions have been reported to be associated with ingestion of drinking-water at concentrations below 0.05 mg/l.[21] It has been estimated that the lifetime risk of dying from cancer of the liver, lung, kidney, or bladder from drinking water with a concentration of at 0.05mg/l arsenic a day could be as high as 13 per 1,000 persons.[22]The US EPA declared in 1986[23] that "For the maximum protection of human health from the potential carcinogenic effects due to exposure of arsenic through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non- threshold assumption for this chemical."

Continuous exposure of freshwater organisms including fish to low concentrations of arsenic results in bioaccumulation, notably in liver and kidney. Arsenic induces hyperglycemia, depletion of enzymatic activities, various acute and chronic toxicity, and immune system dysfunction.[24] The bioconcentration

---

[18] ATSDR, 2007b. p 18.
[19] IARC, 2018.
[20] WHO, 1981.
[21] WHO, 2011. p 317.
[22] Smith et al, 1992.
[23] US EPA, 1986.
[24] Kumari et al, 2017.

factors (BCFs) have been determined at 8,700 for bryophytes, 1,900–2,200 for invertebrates, and 200–800 for fish (livers).[25]The US EPA sets 0.340mg/l for acute and 0.150mg/l for chromic concentrations respectively for healthy freshwater aquatic life.[26]

Inorganic arsenic disrupt plant metabolism through disrupting phosphate metabolism and transport proteins, leading to imbalances in phosphate supply. [27]

An advisory warning should be made that the waters from which these samples were taken should not be used for any domestic purpose. People living near to these waters should have blood samples taken to determine blood arsenic levels and whether therapy is required.

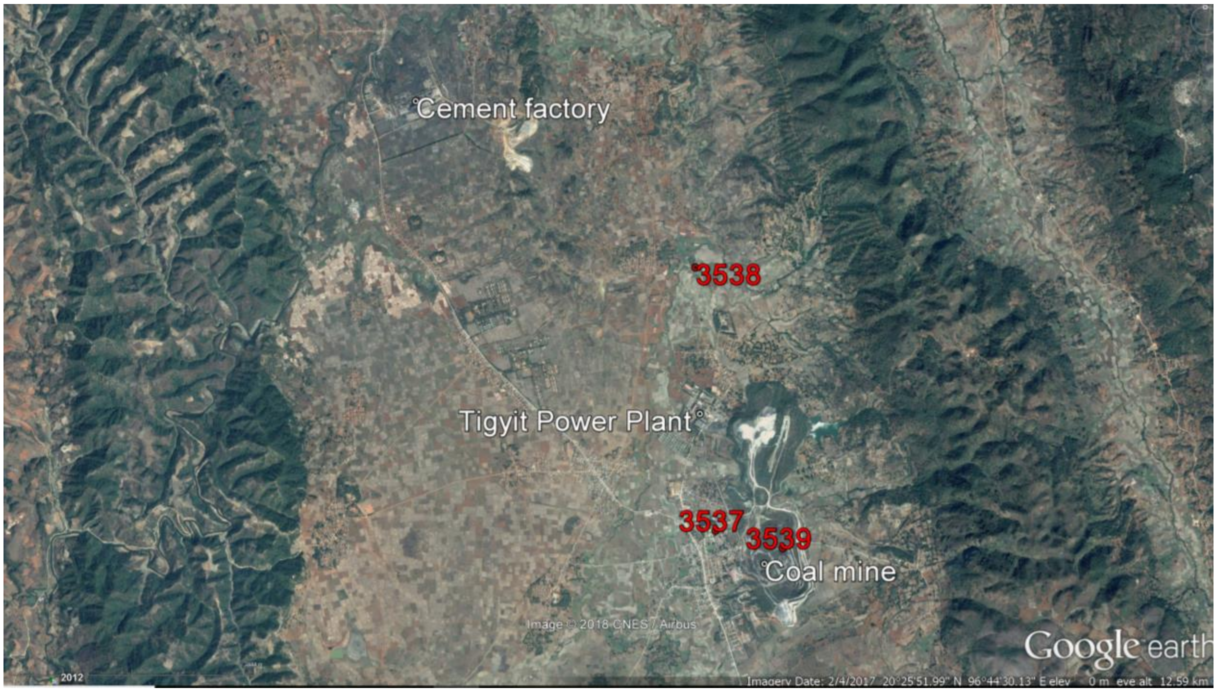
Cadmium

The WHO guidelines for cadmium concentration in drinking water is 0.003mg/l. Three water samples exceeded this concentration:

- 3537, 3538, and 3539 (all 0.01 mg/l) which is 3.3 times the WHO recommended concentration of cadmium for safe drinking water and at the limit of the Myanmar Environmental Quality (Emissions) Guidelines for effluent.

The WHO identifies that cadmium accumulates primarily in the kidneys and has a long biological half-life in humans of 10–35 years. [28] There is evidence that cadmium is carcinogenic by the inhalation route, and IARC has classified cadmium and cadmium compounds in Group 2A (probably carcinogenic to humans). However, there is no evidence of carcinogenicity by the oral route and no clear evidence for the genotoxicity of cadmium.[29]

[25] Lithner et al, 1995.
[26] US EPA, 2017.
[27] Finnegan et al, 2012.
[28] WHO, 2011. p 327
[29] *ibid*



Map 5: Thi Kyit sites and sample numbers of water sample with high cadmium levels in relation to likely industrial source

Eating food or drinking water with very high cadmium levels severely irritates the stomach, leading to vomiting and diarrhea, and sometimes death. [30] Eating lower levels of cadmium over a long period of time can lead to a build-up of cadmium in the kidneys. If the build-up of cadmium is high enough, it will damage the kidneys. Exposure to lower levels of cadmium for a long time can also cause bones to become fragile and break easily. [31] Cadmium is found in breast milk and a small amount will enter the infant's body through breastfeeding. The amount of cadmium that can pass to the infant depends on how much exposure the mother may have had. [32] Similarly, consuming milk of animals that drink cadmium contaminated water, will similarly pass on cadmium.

Cadmium concentrates in freshwater and marine animals hundreds to thousands of times higher than in the water. Reported bio concentration factors (BCFs) range from <200 to 18,000 for invertebrates,[33] and from 3 to 4,190 for fresh water aquatic organisms,[34] People who regularly consume shellfish and fish, particularly organ meats (liver and kidney), may be expected to have increased cadmium exposure.[35]

The *Water Quality and Fish Health* Technical Paper by the European Inland Fisheries Advisory Commission state that: "…very small concentrations of cadmium may produce specific effects after a long exposure period. Chief among these specific effects are those exerted on the reproductive organs. An adverse influence of long exposure to cadmium upon the maturation, hatchability and development of larvae in rainbow trout was recorded at concentrations as low as 0.002 mg l^{1}….For salmonids, the

---

[30] ATSDR, 2012. p 5.
[31] ibid
[32] Ibid. p 3.
[33] van Hattum et al, 1989.
[34] US EPA, 1995.
[35] ATSDR, 2012. p 280-281.

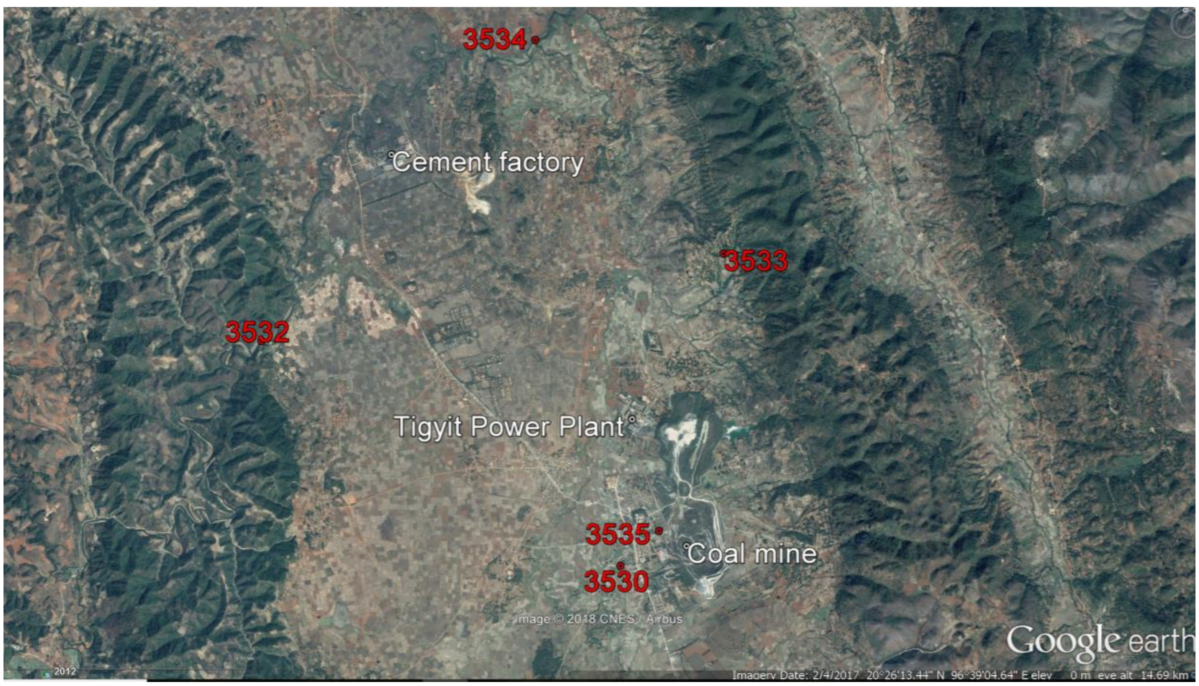
maximum admissible cadmium concentration in water is 0.0002 mg per litre, and for cyprinids 0.001 mg per litre. [36]The US EPA recommends 0.0018 mg/l acute and 0.00072mg/l chromic criteria for healthy freshwater aquatic life. [37]

Cadmium negatively affects plant growth and development. Stomatal opening, transpiration and photosynthesis has been reported to be affected by cadmium, as has iron, nitrate and phosphorous deficiencies.[38]Chlorosis, leaf roll and stunting are the main visible symptoms of cadmium toxicity in plants.[39]

Nickel

The WHO guidelines for Nickel in drinking water is 0.07mg/l. Concentration significantly exceeded these guideline in four water samples:

- 3534 (0.6 mg/l) 8.57 times the concentration recommended by the WHO as a safe level for drinking water, and exceeds the Myanmar Environmental Quality (Emissions) Guidelines for effluent.
- 3532 (0.3 mg/l) 4.3 times the WHO guidelines.
- 3533 and 3535 (0.2mg/l) almost 3 times recommended by the WHO.



Map 6: Thi Kyit sites and sample numbers of water sample with high nickel levels in relation to likely industrial source

[36] Svobodová, et al, 1993.
[37] US EPA, 2017.
[38] Benavides et al, 2005.
[39] *ibid*

The most common harmful health effect of nickel in humans is an allergic skin reaction. A person can become sensitive to nickel when nickel is in direct and prolonged contact with the skin.[40]

Nickel is highly toxic to fish and other aquatic species at concentrations as low as 0.01mg/l.[41] The US EPA recommend a maximum of 0.47mg/l for acute and 0.052mg/l for chronic concentrations for healthy freshwater aquatic life.[42]

Nickel does not appear to concentrate in fish.[43] However, to protect fresh water fish species, the FAO (1984) suggested an average concentration of nickel should not exceed 0.01 mg/l and the 95 percentile should not exceed 0.03 mg/l in soft water (20 mg/l as $CaCO_3$). In hard water (320 mg/l as $CaCO_3$), the corresponding concentrations of nickel should be 0.04 and 0.12 mg/L respectively.[44] Despite all the water samples analyzed for hardness showing very hard water (140-280mg/l), with water sample 3533 showing a hardness of 280 mg/l (4.7 times the maximum concentration for drinking water under the GoRM regulations), the nickel concentrations found in these water samples would be expected to be highly toxic to freshwater ecosystems and fish populations.

Studies show that some plants can take up and accumulate nickel. [45]As with other heavy metals, excess concentrations of Ni in plants cause chlorosis and necrosis, due to disruption of Fe uptake and metabolism.[46] Elevated concentrations of Ni can inhibit cell division at root meristems in non-tolerant plants and decrease plant growth.[47]

Selenium

The WHO sets a guideline of 0.04 mg/l for selenium concentrations in drinking water. All water samples analysed for selenium exceeded this concentration.

- 3537 (0.17 mg/l) 4.25 time WHO;
- 3535 (0.137 mg/l) 3.4 times WHO;
- 3533 (0.125 mg/l) 3.1 times WHO;
- 3538 (0.11 mg/l) 2.75 times WHO:
- 3528 (0.109 mg/l) 2.7 times WHO;
- 3529 (0.,086 mg/l) 2.15 times WHO;
- 3531 (0.078 mg/l) 1.95 times WHO;
- 3530 (0.074 mg/l) 1.85 times WHO;
- 3532 (0.60mg/l) 1.5 times WHO guidelines.

Five of these water samples (3528, 3533, 3535, 3537, and 3538) also exceed the Myanmar Environmental Quality (Emissions) Guidelines for selenium in effluent .

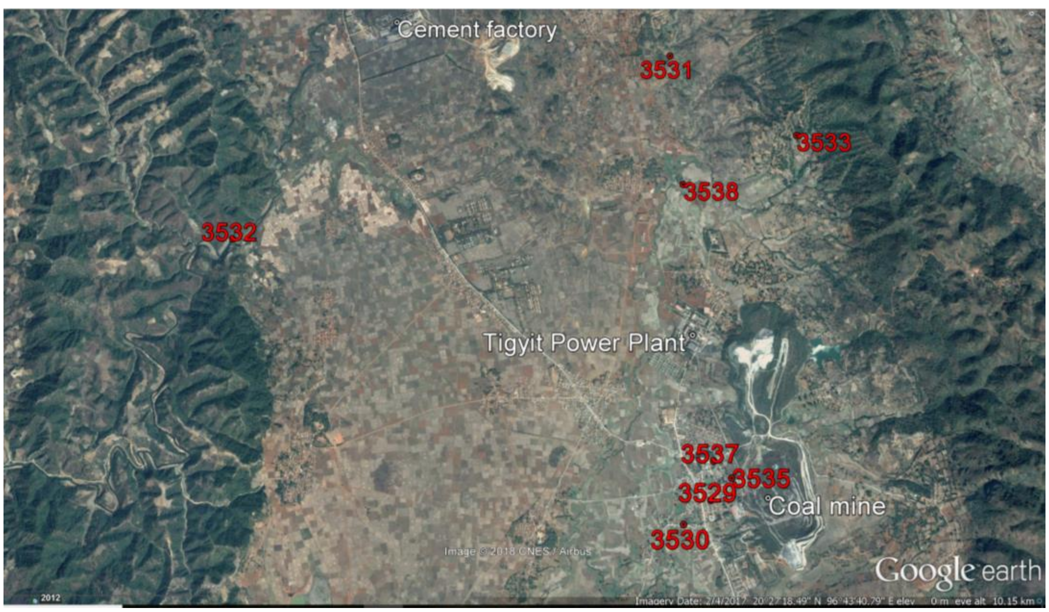
---

[40] ATSDR, 2005. p 6.
[41] Grimwood & Dixon, 1997.
[42] US EPA, 2017.
[43] ATSDR, 2005. p 227
[44] FOA, 1984. p 15.
[45] ATSDR, 2005. p 3.
[46] De kock, 1956.
[47] Satish et al, 2015.

Selenium is an essential trace element, and foodstuffs such as cereals, meat and fish are the principal source of selenium for the general population. Levels in food also vary greatly according to geographical area of production. However, even in high selenium areas, the relative contribution of selenium from drinking-water is likely to be small in comparison with that from locally produced food.[48]

Chronic oral intake of very high levels of selenium (10–20 times more than normal[49]) can produce selenosis in humans, the major effects of which are dermal and neurological and causes diseased nails, skin and hair loss, as well neurological problems, including unsteady gait and paralysis.[50]
The primary adverse effects in laboratory animals exposed to selenium are cardiovascular, gastrointestinal, hematological, hepatic, dermal, immunological, neurological, and reproductive, although doses causing these effects are generally at least 5 times higher than normal daily selenium intake. A condition (syndrome) referred to as “blind staggers” has been repeatedly observed in cattle feeding off vegetation in areas with high selenium content in the soil. [51]

Selenium can also cause developmental abnormalities and reproductive failure in fish and wildlife.[52] Waterborne concentration of selenium of 0.0027 mg/l has been found to result in 20-30% total fish population mortality a year for of two species.[53] In 2016, the US EPA introduced a recommended a 30 day chronic concentration of between 0.0015 mg/l and 0.0031mg/l for healthy freshwater organisms. [54]



Map 7: Thi Kyit sites and sample numbers of water sample with high selenium levels in relation to likely industrial source

[48] WHO, 2011. p 413.
[49] In the USA the average daily intake without supplements is 108 ug per day see U.S. DAARS, 2012.
[50] ATSDR, 2003. p 15.
[51] Ibid. p 16.
[52] Lemly, 2002.
[53] Lemly, 2013.
[54] US EPA, 2016.

Source of pollution

The above identified heavy metal concentrations are significantly above known natural background levels. Therefore, the source of these pollutants is most likely industrial in nature. There are three major industrial facilities in the Thi Kyit area from where these water samples were collected:

- power plant and ash dump;
- coal mine; and
- cement factory.

Power plant and coal ash dump

The 120 megawatt (MW) Thi Kyit Power Plant operations began in 2005, is the only operating coal-fired power station in Myanmar. Operations were suspended at the plant in 2014 due to residents' complaints over air pollution.

An enormous body of evidence exists in the scientific literature showing that effluents generated from leaching of coal ash typically has high concentrations of toxic elements, particularly heavy metals, and that these effluents have the potential to contaminate surrounding waterways and soils.[55] Depending on where the coal was mined, coal ash typically contains arsenic, lead, mercury, cadmium, chromium, selenium, aluminum, antimony, barium, beryllium, boron, chlorine, cobalt, manganese, molybdenum, nickel, thallium, vanadium, and zinc,[56] copper, antimony,[57] strontium , yttrium,[58] and radioelements including uranium, thorium, and potassium,[59] and their numerous decay products, including radium and radon.[60] In the presence of water, these elements can move into the environment in the form of leachates and be consumed or absorbed by people and organisms, where they can bio-accumulate and cause severe toxicological effects.[61]

The amount of heavy metals released from coal ash such as fly ash and bottom ash stock piles depends largely on the pH, bonding between the element and the ash, its chemical form, and physicochemical properties of water.[62]

If eaten, drunk or inhaled, these toxicants can cause cancer and nervous system impacts such as cognitive deficits, developmental delays and behavioral problems. They can also cause heart damage, lung disease, respiratory distress, kidney disease, reproductive problems, gastrointestinal illness, birth defects, and impaired bone growth in children.[63]

---

[55] See for example: US EPA, 2009. Adriano et al 1980. Jankowski et al, 2006; Querol et al, 1996.; Feng & Hong, 1999; Fytianos et al, 1998; Pires & Querol, 2004; Choi et al, 2002; Llorens et al, 2001; Maiti & Jaiswal, 2008.
[56] U.S. EPA, 2010 pp 2-4.
[57] Wadge & Hutton, 1987
[58] Querol et al, 1996.
[59] Baba, 2002.
[60] Zielinski & Finkelman, 1997.
[61] Bryan & Langston, 1992.
[62] Fulekar & Dave, 1991; Pandey, 2014.
[63] U.S. EPA, 2010.

Many are listed carcinogens. For example, the US Environmental Protection Agency (EPA) has found that people living near an unlined wet ash dump that drink water from a well, may have as much as a 1 in 50 chance of getting cancer from arsenic-contaminated water.[64]

A number of studies have showed also decreased survival and metamorphic success in aquatic organisms exposed to coal ash contaminated sediments.[65] The discharge of metals from coal ash dumps has been linked to a number of lethal and sublethal effects on fish species. Populations of fish have decreased in lakes,[66] and growth, male condition factor, and lipid storage have been found to decrease in fish exposed to coal ash contaminated sediments.[67] A number of coal ash trace elements have been found to result in lethal and sublethal decreased growth and condition factors,[68] fish population and community changes, such as decreased population density, reproductive success, and adult biomass, [69] hispathological abnormalities in somatic and reproductive tissues in fish,[70] and the reduction in fish population fitness through increased susceptibility to disease, predation, and decreased reproductive capacity.[71] Heavy metal toxicity is also one of the major non-biological stresses affecting plants and crops.[72]

Coal mine

A major impact of coal mining is its pollution of available freshwater with acid mine drainage (AMD). Contamination of waterways by coal mining is well documented and heavy metals release leading to the formation of AMD has been extensively reported,[73] as has the development of AMD from coal mining.[74] Acid mine drainage is one of the most serious localized environmental problems that the coal mining industry faces.[75] AMD causes acidification and metal contamination of surface and ground water bodies and requires high-cost, long-term remediation and treatment measures to mitigate its impact.

When mine materials and overburden-containing metal sulfides are exposed to air and water, the sulfide bearing rocks oxidize to produce sulfates and acid. Under such acidic conditions a wide range of metals become more soluble. In coal mining operations, AMD is predominantly caused when sulfide minerals that are present in coal beds or in strata overlying and underlying the coal are exposed to oxidation.[76]

Some of the effects of AMD include fish kills and the loss of other aquatic species, and impacts on vegetation such as killing crops or reduced or impaired yields.[77] The formation of AMD can be a long-term source of water contamination. Once a mining operation has ceased, poor water quality may continue to impact on the environment, human health and livelihood for decades or even centuries. A

---

[64] *ibid*
[65] Snodgrass, et al, 2004.
[66] See for example Cumbie & VanHorn, 1978; Olmsted et al, 1986; Lemly, 1997.
[67] Rowe, 2003.
[68] Hopkins, 2001.
[69] Garrett & Inman, 1984.
[70] Sorensen, 1988.
[71] Hatcher et al, 1992.
[72] Hossain et al, 2012.
[73] See for example Jambor and Blowes, 1998; Parker, 1999.
[74] See for example Banks, Burke and Gray, 1997: Brady, Smith and Schueck, 1998.
[75] Saria, Shimaoka and Miyawaki, 2006.
[76] Jennings et al, 2000; Montero et al, 2005; Lottermoser, 2007.
[77] Kargbo et al, 1993; Bell et al, 2001; Nordstrom and Alpers 1999.

well-known mine site in the Iberian Pyrite Belt in Spain, for example, has been generating AMD for well over 2000 years.[78]

Due to acid mine drainage, accumulated overburden and wastewater created by coal mining, a range of heavy metals are released. Significant concentrations of aluminum, iron, manganese and other metals are commonly discharged. These heavy metals can have a negative impacts on human health, aquatic life and crops.

Cement factory

Cement manufacture has been found to impact waterways through the release of heavy metals in effluent.[79]The cement plant apparently used local lignite (brown coal) and reuses the coal ash in the cement in produces.

Conclusion

The Thi Kyit power plant and particularly the coal ash dump and any coal ash storage areas are most likely the major source of the majority of the high heavy metal concentrations and other pollutants identified in the water samples analysed. However, the coal mine and the cement factory may be contributing to these pollutant loads.

Water drains from the south to the north with the cement factory about 5km northwest of the power station and the coal mine immediately to the south of the power plant and coal ash dump. Without a detailed drainage map of the area, we cannot definitively distinguish between the point sources of the power plant and the coal mine. However, from experience with water sampling of other coal mines around the world, AMD from mines generally does not contain such high lead concentrations.

The cement factory can possible to be contributing to the high nickel levels in sample 3534, as the sample was taken downstream of the factory, and the concentration of nickel is significantly higher that sample 3532, which was taken upstream of the factory (see map 6). However, as the general direction of drainage to both 3534 and 3532 is also from the power plant and the coal mine and these sources may also possibly be the source of the high nickel concentrations.

An advisory warning should be made that the waters from which the samples with high lead, arsenic, cadmium, nickel, and selenium were taken should not be used for any domestic purpose until the source of the pollution has been identified, the pollution ceases, and the water has returned to background concentrations. Children living near to these waters should have blood samples taken to determine blood lead levels and whether therapy is required. Fish taken from these waters, especially shellfish and large fish, should be tested for these heavy metals content before being consumed.

References

Adriano, D. C.; Page, A. L.; Elseewi, A. A.; Chang, A. C.; Straughan, I. (1980) Utilization and disposal of fly-ash and other coal residues in terrestrial ecosystems A review. *J. Environ. Qual*., 9, 333−344;

[78] Tornos, F., López Pamo, E. Sánchez España,

[79] Ipeaiyeda et al, 2017.

ATSDR - Agency for Toxic Substances and Disease Registry, 2003. Toxicological Profile for Selenium. https://www.atsdr.cdc.gov/ToxProfiles/tp92.pdf

ATSDR - Agency for Toxic Substances and Disease Registry, 2005. Toxicological Profile for Nickel. Washington DC. https://www.atsdr.cdc.gov/toxprofiles/tp15.pdf

ATSDR - Agency for Toxic Substances and Disease Registry, 2007a. *Toxicological Profile for Lead.* https://www.atsdr.cdc.gov/toxprofiles/tp13.pdf

ATSDR - Agency for Toxic Substances and Disease Registry, 2007b. *Toxicological Profile for Arsenic.* https://www.atsdr.cdc.gov/ToxProfiles/tp2.pdf

ATSDR - Agency for Toxic Substances and Disease Registry, 2008. *Toxicological Profile for Phenol* U.S. Department Of Health And Human Services. Washington DC. https://www.atsdr.cdc.gov/toxprofiles/tp115.pdf.

ATSDR - Agency for Toxic Substances and Disease Registry, 2012. *Toxicological Profile for Cadmium.* https://www.atsdr.cdc.gov/toxprofiles/tp5.pdf

Baba, A., 2002. Assessment of radioactive contaminants in by-products from Yatagan (Mugla, Turkey) coal-fired power plant *Env Geol* 41: 916.

Banks, D., Burke, S.P., Gray, C.G., 1997. Hydrogeochemistry of coal mine drainage and other ferruginous waters in north Derbyshire and south Yorkshire, UK. *Quart. J. Eng. Geol*. 30, 257–280;

Bell FG, Bullock SET, Hälbich TFJ, Londsay P, 2001. Environmental impacts associated with an abandoned mine in the Witbank Coalfield, South Africa. *Int J Coal Geol* 45:195–216;

Benavides M.P., Gallego S.M. & Tomaro M.L., 2005. Cadmium toxicity in plants. *Brazilian Journal of Plant Physiology* 17, 21–34. http://www.scielo.br/pdf/bjpp/v17n1/a03v17n1

Bhalerao, S.A, Amit S. Sharma and Anukthi C. Poojari. 2015. Toxicity of Nickel in Plants. *Int. J. Pure App. Biosci*. 3 (2): 345-355 (2015).

Brady, K.B.C., Smith, M.W., Schueck, J., 1998. *Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania*. Department of Environmental Protection, Harrisburg, PA.

Bryan, G. W., & Langston, W. J., 1992. Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review. *Environmental pollution*, *76*(2), 89-131.

Choi, S. K., Lee, S., Song, Y. K., & Moon, H. S., 2002. Leaching characteristics of selected Korean fly ashes and its implications for the groundwater composition near the ash disposal mound. *Fuel*, *81*(8), 1083-1090;

Crooke W.M., 1958. Effect of heavy metal toxicity on the cation exchange capacity of plant roots. *Soil Sci*. 86: 231–241

Cumbie PM, VanHorn SL, 1978. *Belews Lake environmental study report: selenium and arsenic accumulation*. Tech. Report 78–04. Duke Power Co., Charlotte, NC.

De kock P.C., 1956. Heavy metal toxicity and iron chlorosis. *Ann Bot*.20: 133–141.

FOA – Food and Agriculture Organization of the United Nations, 1984. *Water quality criteria for European freshwater fish. Report on Nickel and freshwater fish*. European Inland Fisheries Advisory Commission. http://www.fao.org/docrep/017/ap673e/ap673e.pdf (accessed 30/5/18)

Finnegan, P. M., & Chen, W., 2012. Arsenic Toxicity: The Effects on Plant Metabolism. *Frontiers in Physiology*, *3*, 182. http://doi.org/10.3389/fphys.2012.00182 (accessed 30/5/18)

Feng, X., & Hong, Y., 1999. Modes of occurrence of mercury in coals from Guizhou, People's Republic of China. *Fuel*, *78*(10), 1181-1188.

Fulekar, M. H., & Dave, J. M., 1991. Release and behaviour of Cr, Mn, Ni and Pb in a fly-ash/soil/water environment: Column experiment. *International Journal of Environmental Studies, 38*, 281–296

Fytianos, K., Tsaniklidi, B., & Voudrias, E., 1998. Leachability of heavy metals in Greek fly ash from coal combustion. *Environment International*, *24*(4), 477-486.

Garrett GP, Inman CR, 1984. *Selenium-induced changes in fish populations in a heated reservoi*r. Proc Annu Conf Southeast Assoc Fish Wildl A 38:291–301

Grimwood, M.J. & Dixon, E., 1997. *Assessment of risks posed by List II metals to Sensitive Marine Areas (SMAs) and adequacy of existing environmental quality standards (EQSs) for SMA protection*. Report to English Nature. http://www.scirp.org/(S(351jmbntvnsjt1aadkposzje))/reference/ReferencesPapers.aspx?ReferenceID=1541858 (accessed 30/5/18)

Hatcher CO, Ogawa RE, Poe TP, French JRP, 1992. Trace elements in lake sediment, macrozoobenthos, and fish near a coal ash disposal basin. *J Fresh Ecol* 7(3):257–269

Hopkins WA, 2001. *Effects of coal combustion wastes on survival, physiology, and performance of the benthic-feeding fish, Erimyzon sucetta*, Doctoral dissertation. University of South Carolina, Columbia, SC

Hossain,M.A, Piyatida, P., Teixeira da Silva,J.A, and Fujita,M., 2012. Molecular Mechanism of Heavy Metal Toxicity and Tolerance in Plants: Central Role of Glutathione in Detoxification of Reactive Oxygen Species and Methylglyoxal and in Heavy Metal Chelation, *Journal of Botany*, vol. 2012, Article ID 872875, 37 pages, 2012. <https://doi.org/10.1155/2012/872875> (accessed 30/5/18)

IARC - International Agency for Cancer Research, 2018. AGENTS CLASSIFIED BY THE *IARC MONOGRAPHS*, VOLUMES 1–121. http://monographs.iarc.fr/ENG/Classification/(accessed 30/5/18)

Ipeaiyeda, A.R., Obaje, G.M., & Rein, A, 2017. Impact of cement effluent on water quality of rivers: A case study of Onyi river at Obajana, Nigeria, *Cogent Environmental Science*, 3:1.

Jankowski, J., Ward, C. R., French, D., & Groves, S. (2006). Mobility of trace elements from selected Australian fly ashes and its potential impact on aquatic ecosystems. *Fuel*, *85*(2), 243-256;

Jambor, J.L., Blowes, D.W., 1998. Theory and application of mineralogy in environmental studies of sulfide-bearing mine wastes. In: Cabri, L.J., Vaughan, D.J. (Eds.), *Modern Approaches to Ore and Environmental Mineralogy. Mineralogical Association of Canada*, pp. 367–401 (Chapter 12)

Jennings, Dollhopf and Inskeep, 2000; Montero IC, Brimhall GH, Alpers CN, Swayze GA, 2005. Characterization of waste rock associated with acid drainage at the Penn Mine, California, by ground-based visible to short-wave infrared reflectance spectroscopy assisted by digital mapping. *Chem Geol* 215:452–472;

Kargbo DM, Fanning DS, Inyang HI, Duell RW, 1993. The environmental significance of acid sulfate clays as waste covers. *Environ Geol* 22:218–226;

Kumari, B., Kumar, V., Sinha, A.K. et al, 2017. Toxicology of arsenic in fish and aquatic systems. *Environ Chem Lett* 15: 43.

Lithner G, Holm K, Borg H., 1995. Bioconcentration factors for metals in humic waters at different pH in the Röbbskär area (N. Sweden). *Water, Air and Soil Pollution* 85:785-790.

Lemly AD, 1997. Ecosystem recovery following selenium contamination in a freshwater reservoir. *Ecotoxicol Environ Safe* 36:275–281

Lemly, A.D. 2002a. Symptoms and implications of selenium toxicity in fish: the Belews Lake case example. *Aquatic Toxicology* 57: 39-49.

Lemly, D., 2013. *Biological Assessment to Determine Impacts of Selenium Pollution From Coal Ash Wastewater Discharges on Fish Populations in Lake Sutton, NC*. Report prepared for Southern Environmental Law Center Chapel Hill Office 601 West Rosemary Street, Chapel Hill NC 27516 November 5 2013.

Llorens, J. F., Fernandez-Turiel, J. L., & Querol, X., 2001. The fate of trace elements in a large coal-fired power plant. *Environmental Geology*, *40*(4-5), 409-416;

Lottermoser B, 2007. *Mine wastes characterization, treatment and environmental impa*cts, 2nd edn. Springer Publisher, Heidelberg

Maiti, S. K., & Jaiswal, S., 2008. Bioaccumulation and translocation of metals in the natural vegetation growing on fly ash lagoons: a field study from Santaldih thermal power plant, West Bengal, India. *Environmental monitoring and assessment*, *136* (1-3), 355-370.

Montero S., Irene C.; Brimhalla, George H.; Alpers, Charles N.; and Swayze, Gregg A., 2005. *Characterization of Waste Rock Associated With Acid Drainage at the Penn Mine, California, by Ground-Based Visible to Short-Wave Infrared Reflectance Spectroscopy Assisted by Digital Mapping* (2005). USGS Staff -- Published Research. 344. http://digitalcommons.unl.edu/usgsstaffpub/344

Mu Mu Than, 2016. Overview of the Water Environment Standards and Effluent Standards and Its Implementation Myanmar. http://wepa-db.net/3rd/jp/meeting/20160728/PDF/S1_Myanmer_MOALI.pdf

Nordstrom DK, Alpers CN, 1999. *Negative pH, efflorescent mineralogy, and consequences for environmental restoration at the Iron Mountain Superfund site, California*. Proc Natl Acad Sci USA 96:3455–3462

Olmsted LL, Degan DJ, Carter JS, Cumbie PM, 1986. Ash basin effluents as a concern of fisheries managers: a case history and perspective. In: G. E. Hall and M. J. Van den Avyle, (eds). *Reservoir Fisheries Management: Strategies for the 80s*. Proceedings of a national symposium on managing reservoir fishery resources. Published by American Fisheries Society. 327p. https://fisheries.org/bookstore/all-titles/afs-unit-publications/x53012xm/ (accessed 30/5/18)

Oram, B, 2014. *Ammonia in Groundwater, Runoff, Surface Water, Lakes and Streams*. https://www.water-research.net/index.php/ammonia-in-groundwater-runoff-and-streams (accessed 30/5/18)

Parker, G., 1999. *A Critical Review of Acid Generation Resulting from Sulfide Oxidation: Processes, Treatment and Control. In: Acid Drainage.* Australian Minerals and Energy Environment Foundation, Melbourne. pp. 1–182.

Pandey, S. K., 2014. Coal fly ash: Some aspects of characterization and environmental impacts. *Journal of Environmental Science, Computer Science and Engineering & Technology, 3*, 921–937.

Pires, M., & Querol, X. (2004). Characterization of Candiota (South Brazil) coal and combustion by-product. *International Journal of Coal Geology*, *60*(1), 57-72;

Querol, X., Juan, R., Lopez-Soler, A., Fernandez-Turiel, J., & Ruiz, C. R., 1996. Mobility of trace elements from coal and combustion wastes. *Fuel*, *75*(7), 821-838.

Rowe CL (2003) Growth responses of an estuarine fish exposed to mixed trace elements in sediments over a full life cycle. *Ecotox Environ Safe* 54(2):229–239

Saria L,T and Miyawaki, K, 2006. Leaching of heavy metals in acid mine drainage. *Waste management & research,* 24(2), pp.134-140.

Sharma, P, Dubey, R.S, 2005. Lead toxicity in plants. *Brazilian Journal of Plant Physiology*, 17 (2005), pp. 35–52. http://scielo.br/pdf/bjpp/v17n1/a04v17n1.pdf (accessed 30/5/18)

Smith AH, Hopenhayn-Rich C, Bates MN, Goeden HM, Hertz-Picciotto I, Duggan HM, Wood R, Kosnett MJ, Smith MT, 1992. Cancer risks from arsenic in drinking water. *Environ Health Perspect*. 1992 Jul; 97:259-67. https://www.ncbi.nlm.nih.gov/pubmed/1396465 (accessed 30/5/18)

Saw Christopher Maung, 2014. Water Quality and Pollution Control. http://www.dwir.gov.mm/images/dwir-data/water_froum2014/WaterQualityPollutionControlfinal.pdf.

Snodgrass JW, Hopkins WA, Broughton J, Gwinn D, Baionno JA, Burger J, 2004. Species specific responses of developing anurans to coal combustion wastes. *Aquat Toxicol* 66:171–182

Sorensen EMB, 1988. Selenium accumulation, reproductive status, and histopathological changes in environmentally exposed redear sunfish. *Arch Toxicol* 61:324–329

Svobodová, Z.; Lloyd, R.; Máchová, J.; Vykusová, B.
Water quality and fish health. EIFAC Technical Paper. No. 54. Rome, FAO. 1993. 59p.http://www.fao.org/docrep/009/t1623e/T1623E03.htm#ch3.2.3.3 (accessed 30/5/18)

T. Mohammadi, and A. Esmaelifar, 2005. Journal of Membrane Science, vol. 254, pp.129 – 137.

Tornos, F., López Pamo, E. Sánchez España, F.J. The Iberian Pyrite Belt. http://www.igme.es/patrimonio/GEOSITES/Chapter_04_SGFG.pdf (accessed 30/5/18)

U.S. DAARS - United States Department of Agriculture, Agricultural Research Service, 2012. What We Eat in America, 2009-2010. https://data.nal.usda.gov/dataset/what-we-eat-america-wweia-database (accessed 30/5/18)

US EPA – United States Environmental Protection Agency, 1986. Quality Criteria for Water. Washington DC. http://nptwaterresources.org/wp-content/uploads/2014/01/1986-goldbook.pdf (accessed 30/5/18)

US EPA - United States Environmental Protection Agency, 1995. ASTER. 1995. ASTER (Assessment Tools for the Evaluation of Risk) ecotoxicity profile. Duluth, MN: U.S. Environmental Protection Agency, Environmental Research Laboratory.

US EPA – United States Environmental Protection Agency, 2007. *Human and Ecological Risk Assessment of Coal Combustion Wastes* (draft). (Released as part of a Notice of Data Availability) Aug. 6, 2007.

US EPA - United States Environmental Protection Agency, 2009. Steam Electric Power Generating Point Source Category: Final Detailed Study Report; U.S. Environmental Protection Agency: Washington, DC, 2009; https://www.epa.gov/sites/production/files/2015-06/documents/steam-electric_detailed_study_report_2009.pdf

US EPA - Environmental Protection Agency, 2010. *Human and Ecological Risk Assessment of Coal Combustion Wastes*. Office of Solid Waste and Emergency Response, Office of Resource Conservation and Recovery. Draft EPA document. April 2010.

US EPA- United States Environmental Protection Agency,2016. Phenol. https://www.epa.gov/sites/production/files/2016-09/documents/phenol.pdf (accessed 30/5/18)

US EPA - United States Environmental Protection Agency, 2016. *Aquatic Life Ambient Water Quality Criterion for Selenium in Freshwater 2016* – Fact Sheet. https://www.epa.gov/sites/production/files/2016-06/documents/se_2016_fact_sheet_final.pdf (accessed 30/5/18)

US EPA - United States Environmental Protection Agency, 2017. *National Recommended Water Quality Criteria - Aquatic Life Criteria Table* https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-t (accessed 30/5/18)

US EPA – *United States Environmental Protection Agency, 2018. 2018 Edition of the Drinking Water Standards and Health Advisorie*s. Washington, DC. https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf (accessed 30/5/18)

van Hattum B, de Voogt P, van den Bosch L, et al. 1989. Bioaccumulation of cadmium by the freshwater isopod Asellus aquaticus (L.) from aqueous and dietary sources. *Environ Pollut* 62:129-152.

Wadge A and Hutton M, 1987. *The leachability and chemical speciation of selected trace elements in fly ash from coal combustion and refuse incineration*. Environ Pollut 48:85–99

WHO – World Health Organization of the United Nations, 1981. IPCS International Programme on Chemical Safety. *Environmental Health Criteria 18 Arsenic*. http://www.inchem.org/documents/ehc/ehc/ehc018.htm (accessed 30/5/18)

WHO - World Health Organization of the United Nations, 1984. *Phenol Health and Safety Guide*. Geneva http://apps.who.int/iris/bitstream/handle/10665/39958/9241510889-eng.pdf?sequence=1

WHO - World Health Organization of the United Nations, 2011. *Guidelines for drinking-water quality: fourth edition incorporating the first addendum*. Geneva. http://apps.who.int/iris/bitstream/handle/10665/254637/9789241549950-eng.pdf;jsessionid=295132D827A1AF49460BC3121BCA2C2F?sequence=1 (accessed 30/5/18)

Zielinski, R., and Finkelman, R., 1997. *Radioactive Elements in Coal and Fly Ash: Abundance, Forms, and Environmental Significance.* U.S. Department of the Interior U.S. Geological Survey Fact Sheet FS-163-97 http://pubs.usgs.gov/fs/1997/fs163-97/FS-163-97.html (accessed 30/5/18)