Haneef & Akıntuğ, 2016

Volume 2 Issue 1, pp. 135-149

Date of Publication: 23rd November, 2016

DOI- https://dx.doi.org/10.20319/Mijst.2016.s21.135149

This paper can be cited as: Haneef, F., & Akıntuğ, B. (2016). Quantitative Assessment of Heavy Metals in Coal-Fired Power Plant's Waste Water. MATTER: International Journal of Science and Technology, 2(1), 135-149.

QUANTITATIVE ASSESSMENT OF HEAVY METALS IN COAL-FIRED POWER PLANT'S WASTE WATER

Fahad Haneef
Sustainable Environment and Energy Systems (SEES)
Middle East Technical University Northern Cyprus Campus (METU NCC), Kalkanli, Guzelyurt, Mersin 10, Turkey
fahad.haneef@metu.edu.tr

Bertuğ Akıntuğ
Middle East Technical University Northern Cyprus Campus (METU NCC), Kalkanli, Guzelyurt, Mersin 10, Turkey
bertug@metu.edu.tr

Abstract

Coal-fired power plants are water intensive sources of energy generation. Waste water dumped by these coal-fired power plants is significant threat to our environment and human health. The electric power sector is the major source of toxic wastes in Pakistan, due to coal ash and coal waste, which contain toxic heavy metals such as Cr, Co, Cu, Pb, Mn, Ni, Zn, Hg, Ag, and As. Different Environmental report shows nearly all power plants in Pakistan discharge toxic coal ash or wastewater into public water. This paper provides a brief overview about how badly Coal Industry is poisoning water and later on the characteristics of wastewater discharge from coal based thermal plants are discussed. The study presented in this paper quantitavely evaluates the heavy metals like Cr, Ni, Hg, As, Cd, Pb, Mn and Co emissions in coal ash or waste water of a coal power plant. 1 MW capacity plant was selected for the study and the results showed such a *plant will produce Cr 33.7g/kWh, Pb 44.9g/kWh, As 44.9g/kWh and Hg 0.6g/kWh respectively. At the end, some plausible recommendations are suggested for government of Pakistan to mitigate the effects of these power plants.*

Keywords

Coal, Coal Fired Power Plant, Waste Water, Heavy Metals, Coal Ash, Pakistan. Water Pollution

1. Introduction

'Coal-Utter Disregard for the Environment', from the demolition of mountain peaks to the polluting of our water resources, coal is dangerous and dirty for our environment and health. Apart from its devastating effects, undeniable fact is that coal still plays a vital role in the world power generation; it's the second primary source of world energy needs. From the beginning of 21st century, it has been the rapidly-growing power and energy source. . Global coal demand will keep on increasing over the next five years, reaching the 9 billion ton level by 2019 ("Coal," n.d.). Coal provides around 30.1% of global primary energy needs, coal power plants fuel over 40% of the world's electricity. (British Petroleum, 2015)

However, for environmentalists, coal has always been a disaster option because burning coal results insignificant amounts of harmful pollutants into environment, which are very damaging for environment and human health. Coal fired power plants, single dangerous threat to climate today, are the largest source of manmade CO_2 emissions. Over 83% of the CO_2 emission since 1990 was caused by coal power plants (EIA, 2009). Coal Combustion wastes are known as those wastes which are generated after the burning of coal like fly ash, bottom ash, waste of flue gas desulfurization and molten coal ash at the bottom of boiler (known as Boiler slag). Managing and disposing of coal combustion waste (CCW) is always of major concern because of the heavy metals and other toxins which can leach out of the waste water and can contaminate the ground and surface water. This CCW contains various toxic chemicals like Al, Ca, B, As, Mn, Cr and Pb. These wastes are damaging to nervous system and kidneys, also causes cancer and listening problems in children. The large amount of CCW produced every year is either disposed into landfill or into the artificial ponds known as surface impoundments, in which CCW is mixed with water. When it rains, toxic chemicals of CCW in these ponds start dissolving into the water, later on this contaminated water known as leachate can spread widely contaminating the nearby surface water or ground water. Sometimes disposed CCW of ponds is mixed with water on purpose to make a sludge which can then easily be transported through a pipe line to the dumping site from the coal power plant. Hundred acres of landfill may be required for a single mega coal power plant to dispose of its waste, which obviously results in destruction of green areas (Greenpeace, 2010). While other industries' wastes may not be completely toxic but the waste generated by coal plants is 100% toxic. Water pollution caused by coal plants is always on large scale and often irreversible. A typical coal plant uses, 100 of gallons of water a year from a nearby river or lake, for their cooling systems (Macknick, Newmark, Heath, & Hallett, 2012). They are damaging eco system, the fish we eat could also get poisoned because of that, also our water supplies are under great risk of contamination, which could be a threatening factor for the people whose livelihood is dependent on these water systems.

According to 1983 emission data from the US, Canada, and European Union, Nriagu and Pacyna (Nriagu, 1989) made an estimation of trace metals emission worldwide by various sources. They came up with a conclusion that anthropogenic sources accounted for 40-85% of the total emission for every single one of these elements, and Coal combustion for electricity market constituted 2-6%, 2-3%, 14-17%, 9-17%, 6-13% emissions of arsenic, cadmium, chromium, mercury and selenium, respectively (Nriagu & Pacyna, 1988). In a report published by U.S Environment Protection Agency (US EPA, 2015), the fact that "Coal-fired power plants are the largest source of mercury pollution in the U.S." , responsible for 33% of mercury emissions. The main reason of mercury exposure is consuming contaminated fishes and seafood. Trace amounts of mercury present in coal, when dumped into the lake/river in the form of coal wastes, settles in the water and transform into an organic form called methyl mercury. It contaminates fish and bio accumulates through the food chain, so at the end, we humans become contaminated by eating the fish. (US EPA, 2008) (Lockwood, & Hood, 2009)

Pollutants from coal have very harmful effects on major organ systems of human body and are primary sources of four to five causes of death in the US (Greenpeace, 2015). From mining coal to transporting it and from its combustion to disposal of coal wastes, at every single stage, coal development is putting human and environmental health into danger. The United State Environment Protection Agency indicated that drinking contaminated water exposed to arsenic, which leads to the maximum risk of cancer in 1/50 people living around coal ash impoundments. According to the American Lung Association, every year 24,000 people die impulsively because of coal fired power plants pollution. 38,000 cases of heart attack and in addition to this, 550,000 asthma attacks resulted by coal power plant pollution. (Greenpeace, 2015)

A significant amount of data is present in literature, discussing significant impacts of coal-fired power plants and wastes produced by them, on the environment and human health. Sushil and Batra (Sushil & Batra, 2006) analyzed the fly ash heavy metal content and disposal of three Indian thermal power plants. Analysis of the ashes for the presence of Cr, Zn, Mn, Cu, Pb, Co and Ni and they concluded that threatening levels of these metals were found in fly and bottom ash, especially Cr and Zn concentrations were highest while Co concentration was low. Similarly, Deng et al., (Deng et al., 2014) performed an intensive field study to analyze Cadmium (Cd), Manganese (Mn) and Lead (Pb) emissions from combusting coal at six different coal fired power plants in China. Results showed that Pb has the highest fraction among the released trace metals. Major segment of these metals gets mixed with bottom and fly ash during the combustion process. Dai et al., (Dai et al., 2012) discussed the geochemistry of trace elements in Chinese coals, coal waste impacts on human health, and industrial utilization. They found out that comparing to world coals trace elements concentration, Chinese coals have typical values for most trace elements, with the exception of higher Li (31.8 μg/g), Zr (89.5 μg/g), Nb (9.44 μg/g), Ta (0.62 μg/g), Hf (3.71 μg/g), Th (5.84 μg/g), and rare earth elements (ΣLa-Lu+Y, 136 μg/g) and toxic elements of Hg (0.163 μg/g), As (3.79 μg/g), and F (130 μg/g). Baba et al., (Baba & Kaya, 2004) in their study stated that lignite use in power generation has led to increase in environmental related problems. These problems occurred not only because of flu gas emissions but also due to residual ash disposal, which has toxic heavy metal contents including leaching characteristics of coal wastes from thermal power plants of western Turkey. A study on As, Cd, Co, Cr, Cu, Hg, Fe, Mn, Ni, Pb, Se, and Zn emissions from a 220MW coal-fired power plant and 6MW oil fired-power plant in India was carried out by Reddy et al., (Reddy, Basha, Joshi, & Jha, 2005) after different toxicity tests, the results indicated that trace metals emissions were high in coal-based power plant than the fuel oil-fired power plant.

Another case study of Çan Thermal Power Plant (CTPP) by Baba et al., (Baba, Gurdal, & Sengunalp, 2010) revealed the significant presence of toxic elements in the coal, including As, U and V. Also an instant increase in Sulphur was found corresponding to the increase in As, Cu, Co and Hg contents in coal. The results showed that most important factors affecting the leaching properties were the water temperature, pH and the quality of limestone used. Sandelin et al., (Sandelin & Backman, 2001) focused in their study on forecasting the chance of eight trace elements (As, Ni, Cd, Pb, Hg Se, Zn, and V) in coal fired power stations. They concluded that there is a chance that these element may correlate with the total particle capture of the power plants and As, Pb, Zn, and Ni are likely to get dissolved in the molten ash mostly. The levels of some heavy metals such as; Mn, Cr, Cd, As, Ni, and Pb were analyzed in coal and sediment samples from River Ekulu in Enugu, Coal City of Nigeria by Adaikpohet al., (Adaikpoh, Nwajei, & Ogala, 2005) They found out that mean concentrations of Mn (0.256-0.389mg/kg) and Cr (0.214-0.267 mg/kg) are high relative to concentrations of Cd (0.036-0.043 mg/kg), As (0.016-0.018 mg/kg), Ni, (0.064-0.067 mg/kg) and Pb(0.013-0.017 mg/kg).

Similar to other countries, situation in Pakistan is also not so different. Majority of the population is suffering from several diseases caused by either air pollution or by drinking contaminated water (Newspaper, 2013) (Zaman & Kumar, 2014). Despite remaining the low GHG emitting country, Pakistan is one of the countries, which has suffered intensely by severe climate conditions and global warming. From 1993-2013, Pakistan was number eighth country to be affected by emerging extreme climatic changes, which resulted into deadliest floods, melting glaciers, intensifying monsoon rains, severe droughts, lethal heat waves. Recently, according to World Bank report (*Cleaning Pakistan's Air*, 2014), Pakistan was ranked third in the world with 110,000 deaths in a year caused by air pollution alone. Different studies shows that source of air pollution in the country is mainly the power sector (van der Wall, 2015) (Yousuf, Ghumman, Hashmi, & Kamal, 2014).

Owing to the fact that Pakistan is an under developed country, major segment of the electricity production comes from the coal power plants. Unfortunately most of these coal plants do not follow national environmental quality standards, that is why most of the time, flue gases are exhausted into the air without proper filtration and the waste water is dumped into the lands or nearby canals without any treated (Younos & Grady, 2014). Coal power plants considered to be the major cause of polluting water in the Pakistan, based on their dumping of million tons of toxic wastes into nearby water streams, lakes and rivers every year. These toxic waste and heavy metals in them do not degrade by time but instead they keep on accumulating, which results in increase in their concentration as they move on to food chain and ending up in human bodies. In short, from many decades coal fired power plants coal plants have been dumping into our lakes, streams and rivers, as their own private properties. CCW are very harmful for communities living near these coals fired power plants. As a result of high concentration of metals in effluent water of these power plants, surface water supplies are becoming unsuitable for human consumption needs (Praharaj, Powell, Hart, & Tripathy, 2002). Farooqi et al., (Farooqi, Masuda, & Firdous, 2007) reported that as a result of poor environmental standards in power plants, the underground water is contaminated with high concentration of Arsenic. Concentration of Arsenic in groundwater was found to be 235 μg/l and also fluorine concentration was 11.0 mg/l. In a collaborative research between Public Health Engineering Department of Pakistan and UNICEF (Nickson, McArthur, Shrestha, Kyaw-Myint, & Lowry, 2005), it was revealed that areas near Thermal Power Station Muzaffargarh has Arsenic amount in groundwater up to 906 μg/l.

According to the knowledge of the authors, majority of the literature discusses air quality and water quality in the country. Some of the studies investigated the air pollution caused by Coal-fired Power plants but there is no study present so far, which analyzed the impacts of coal power plant wastes on water resources in Pakistan.This investigation will provide a good insight to the upcoming coal power plant projects in the country. The main objective of this paper is to quantitatively evaluate heavy metals Cr, Ni, Hg, As, Pb, Cd, Mn and Coetc. emissions in fly ash, bottom ash and coal combustion waste of a coal power plant of capacity 1MW for various types of coals.

1.1 Coal in Pakistan:

In Pakistan, there has been a significant rise in prominence of coal to be used as thermal power generation of electricity from past few years, and in addition to this, future trends even shows higher contribution of coal in coming years. According to Economic Survey of Pakistan, in 2012 alone, coal share in total energy mix of the country was only 6-7%. Coal contributed 10.4% to the total energy consumption in the same year. On an average just 2-5% of coal was used for power generation purposes in the last decade (2001-2011), which has now increased dramatically up to 25.6% in just one year alone (2011-2012). Unfortunately, in Pakistan, most of the coal combustion waste disposal sites are located near drinking water resources, posing a threat to public health in those areas especially. (Ministry of Finance, 2015)

Government of Pakistan has planned to invest in the planning, preparation, construction and implementation of several coal burned thermal power plants to overcome the current power shortage dilemma. These power plants will be developed in the framework of important energy initiatives that cover three provinces, the Gadani Energy Park in Baluchistan, the Punjab Power Production Initiative in Punjab, and the Thar Coal Project in Sindh (Rauf, 2014)

In January 2014, the Government of Sindh (GoS) initiated the Thar Coal Block II Mining and Power Project which will involve the extraction of 3.8 Million tones and power generation of 660 MW; and in phase II, the extraction will go up to 13.5 million tones and power generation between 2400 MW and 3600 MW (Dawn.com, 2014). The Government of Punjab (GoPb) has also recently inaugurated the Punjab Power Production Initiative 2014 to cater to the province that consumes approximately 68% of the country's total national grid electricity. The main objective of this initiative is to increase reasonable and cheap coal based power into the national grid to rebalance the energy mix according to the goal set in the national power policy, 2013. Under this program, 6 locations have been identified in central and south Punjab where power projects of 660 MW each will be selected. (Energy Department, 2014)

Although, it might be a good step towards solving country's energy crisis but once operational these plants will produce 200-899 tons/GWh of CO_2 emissions and 4-15 tons/GWh of Sulphur Oxide emissions (Ali, Fahrioglu, Zuberi, & Qureshi, 2015). Also, recently at Paris 2015 climate summit, Pakistan vowed to cut 5% of its 2012 CO_2 emission level by 2030. ("Paris 2015," 2015)

2. Methodology

2.1 Emissions from Burning of Coal

In order to make calculations simple, the environmental aspects of 1MW coal fired power plant will be analyzed in this section, by estimating the amount of heavy metals in coal waste, which can be generated annually. Nevertheless, estimates presented in this section shows a picture of what should be expected in terms of environmental degradation, if these plant will run in future.

A power plant with capacity of 1MW can produce maximum of 31.54×10^{12} kJ of electricity ideally every year. The thermal energy that is required for running this plant, and is obtained by burning of coal can be calculated using a simple formula as shown in Equation 1. (Ali et al., 2015)

$$\text{Thermal Energy needed (kJ)} = \frac{\text{Maximum Annual Electricity Output(kJ)}}{\text{Plant efficiency (\%)}} \quad (1)$$

According to a report of International Energy Association (IEA, 2011), worldwide coal fired Power plant efficiency averages around 33%. This means that the annual thermal energy needed from combustion of coal will be 95.56×10^{12} kJ. Using this and the heat content of the coal, the amount of coal to be combusted annually can be calculated by Equation 2.

$$Amount\ of\ Coal\ (kg) = \frac{\text{Thermal Energy Needed(kJ)}}{Heat\ Content\ (\frac{kJ}{kg})} \quad (2)$$

Most common maximum and minimum concentration of heavy metals in coal are provided in the table 1. By using those values, amount of metal after burning of 1kg of coal can be calculated by Equation 3.

$$Heavy\ Metal\ in\ Coal\ (g) = Amount\ of\ Coal\ (kg) x\ Concentration\ of\ Metal\ \left(\frac{mg}{kg}\right) \quad (3)$$

After obtaining the amount of metal in coal, how much metal a coal fired power plant will produce in hour can be calculated by Equation 4.

$$Heavy\ Metal\ produced\ (\frac{g}{kWh}) = \frac{\text{Heavy Metal in Coal (g)}}{\text{Total Power (kWh)}} \quad (4)$$

Table 1: Concentration of Heavy Metals for most coals (Xu et al., 2004)

Heavy Metal	**Concentration (mg/kg)**	
	Min	Max
Cr	0.5	60
Co	0.5	30
Cu	5	50
Pb	0.5	80

Mn	5	300
Ni	0.2	50
Zn	0.2	300
Hg	0.5	1
Ag	0.5	2
As	0.5	80

Table 2: *Heat Content of different types of Coal and their yearly requirement (Ali et al & Fahrioglu, 2014)*

Type of Coal	Heat Content of Coal (kJ/kg)	Amount of Coal required (10^8 kg/year)
Bituminous Coal	32447.7	29.45
Sub-Bituminous Coal	23027.4	41.50
Anthracite Coal	35169.12	27.17
Lignite Coal	19426.75	49.19

Table 3: *Amount of metal produced by a coal fired power plant using different types of coal*

Type of Heavy Metal	**Heavy metal concentration (g/kWh)**							
	Bituminous Coal		Sub-Bituminous Coal		Anthracite Coal		Lignite Coal	
	Min	Max		Max	Min	Max	Min	Max
Cr	0.2	20.2	0.2	28.4	0.2	18.6	0.3	33.7
Co	0.2	10.1	0.2	14.2	0.2	9.3	0.3	16.8
Cu	0.2	16.8	0.2	23.7	0.2	15.5	0.3	28.1

Pb	0.7	26.9	0.9	37.9	0.6	24.8	1.1	44.9
Mn	1.7	100.9	2.4	142.1	1.6	93.1	2.8	168.5
Ni	0.2	16.8	0.2	23.7	0.2	15.5	0.3	28.1
Zn	1.7	100.9	2.4	142.1	1.6	93.1	2.8	168.5
Hg	0.1	0.3	0.1	0.5	0.1	0.3	0.1	0.6
Ag	0.1	0.7	0.1	0.9	0.1	0.6	0.1	1.1
As	0.2	26.9	0.2	37.9	0.2	24.8	0.3	44.9

3. Results and Discussion

The results shown in Table 3 gives clear indication that coal fired power plants wastes are a major threat to not only air but also water resources as well. According to a report by Union of Concerned Scientists (UCS, 2013), a typical 500 MW coal plant uses 1.4 million tons coal every year and it produces 125,000 tons of ash and 193,000 tons of sludge. All these wastes are either transported to waste ponds or they are buried in form of landfills. Based on the percentages presented in Table 3, the devastating effects of these toxic materials can be foreseen, which are continuously decimating the soil quality and the water aquifer also. Although Pakistan has large assets of coal which can be utilized for solving Pakistan’s energy dilemma, but they are not sustainable and are unfriendly to the environment. The direct emissions of heavy metals per kWh from coal as shown in Table 3 are way more as compare to renewable energy technologies emissions, so a right way would be replacing all these carbon-belching coal power plants with almost less emission renewable energies like solar or wind. In this paper only 1MW power plant case study was discussed for easy calculation and to give an indication of environmental impacts for future project planned by Government of Pakistan; however it is necessary to calculate coal waste of impacts of a large scale project, to get a comprehensive idea of harms done by these coal fired power plants. Hence, as a future work it would be significant to calculate all these things as well. Unfortunately, because of regulatory loopholes and poor policy implementation in Pakistan, government is subsidizing and giving work permits for the construction of coal fired power plants, without even considering the consequences of CO_2 emissions and waste water damages from coal fired power plants on environment and people health. We urge Pakistan Environment Protection Council (PEPC) and the Pakistan Environment Protection Agency (PEA) to address the risking of environment and water issues pose by construction of these power plants and to adopt some the recommendations given below related to regulatory governing of waste disposal of coal power plants.

3.1 Recommendations

- Completely monitor total and dissolved concentrations of toxics and heavy metals in ground water or any surface water body, which is receiving landfills discharges from power plants or another facility.
- There must be a contaminant limitation on effluent of CCW landfills.
- All Coal fired power plants have to fulfill the National Environmental Quality Standards (NEQS), 2000. Which specify the following standards:
- NEQS for any liquid effluent of any municipality or industry
- NEQS for gas emissions by industries
- NEQS for Quality of Ambient Air
- NEQS for Quality of Drinking Water.

REFERENCES

Adaikpoh, E. O., Nwajei, G. E., & Ogala, J. E. (2005). Heavy metals concentrations in coal and sediments from River Ekulu in Enugu, Coal City of Nigeria. *Journal of Applied Sciences and Environmental Management*, *9*(3), 5–8.

Ali et al, & Fahrioglu. (2014). An environmental and economic assessment of a coal fired power plant project in Pakistan. Presented at the 7th International Ege Energy Symposium & Exhibition, Usak, Turkey. Retrieved from https://www.researchgate.net/publication/264512405_An_environmental_and_economic_assessment_of_a_coal_fired_power_plant_project_in_Pakistan

Ali, Fahrioglu, Zuberi, & Qureshi. (2015). Environmental feasibility analysis of a coal fired power plant project in Gadani, Pakistan. *International Journal of Global Warming*, *7*(4). Retrieved from https://www.researchgate.net/publication/280625614_Environmental_feasibility_analysis_of_a_coal_fired_power_plant_project_in_Gadani_Pakistan

Baba, A., Gurdal, G., & Sengunalp, F. (2010). Leaching characteristics of fly ash from fluidized bed combustion thermal power plant: Case study: Çan (Çanakkale-Turkey). *Fuel Processing Technology*, *91*(9), 1073–1080. https://doi.org/10.1016/j.fuproc.2010.03.015

Baba, A., & Kaya, A. (2004). Leaching characteristics of solid wastes from thermal power plants of western Turkey and comparison of toxicity methodologies. *Journal of Environmental Management*, *73*(3), 199–207. https://doi.org/10.1016/j.jenvman.2004.06.005

British Petroleum. (2015, February). BP Energy Outlook 2035. British Petroleum. Retrieved from http://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2016/bp-energy-outlook-2014.pdf

Cleaning Pakistan's Air: Policy Options to Address the Cost of Outdoor Air Pollution. (2014). The World Bank. Retrieved from http://elibrary.worldbank.org/doi/book/10.1596/978-1-4648-0235-5

Coal. (n.d.). Retrieved October 12, 2016, from http://www.iea.org/topics/coal/

Dai, S., Ren, D., Chou, C.-L., Finkelman, R. B., Seredin, V. V., & Zhou, Y. (2012). Geochemistry of trace elements in Chinese coals: A review of abundances, genetic types, impacts on human health, and industrial utilization. *International Journal of Coal Geology*, *94*, 3–21. https://doi.org/10.1016/j.coal.2011.02.003

Dawn.com, A. |. (2014, January 31). Nawaz, Zardari launch Thar coal power project. Retrieved October 25, 2016, from http://www.dawn.com/news/1084003

Deng, S., Shi, Y., Liu, Y., Zhang, C., Wang, X., Cao, Q., … Zhang, F. (2014). Emission characteristics of Cd, Pb and Mn from coal combustion: Field study at coal-fired power plants in China. *Fuel Processing Technology*, *126*, 469–475. https://doi.org/10.1016/j.fuproc.2014.06.009

EIA. (2009, May). U.S. Carbon Dioxide Emissions from Energy Sources. U.S. Department of Energy. Retrieved from http://www.eia.gov/oiaf/1605/flash/pdf/flash.pdf

ENERGY DEPARTMENT. (2014). *ANNUAL PLAN & STRATEGY 2012-2013*. ENERGY DEPARTMENT. Retrieved from http://www.energy.punjab.gov.pk/_publications/ED_Annual_Plan_2012_2013.pdf

Farooqi, A., Masuda, H., & Firdous, N. (2007). Toxic fluoride and arsenic contaminated groundwater in the Lahore and Kasur districts, Punjab, Pakistan and possible contaminant sources. *Environmental Pollution*, *145*(3), 839–849. https://doi.org/10.1016/j.envpol.2006.05.007

Greenpeace. (2010, September). The True Cost of Coal— An Investigation into Coal Ash in China (2010). Retrieved from http://www.greenpeace.org/eastasia/Global/eastasia/publications/reports/climate-energy/2010/the-true-cost-of-coal-investigation-into-coal-ash-in-china.pdf

Greenpeace. (2015, April 15). "Clean Coal" Pumps up "Green Oil." Retrieved October 25, 2016, from http://www.greenpeace.org/usa/clean-coal-pumps-green-oil/

IEA. (2011). Power generation from coal. International energy agency. Retrieved from https://www.iea.org/publications/freepublications/publication/Power_Generation_from_Coal2011.pdf

Lockwood, & Hood. (2009, November). Coal's Assault on Human Health. Physicians For Social Responsibility. Retrieved from http://www.psr.org/assets/pdfs/coals-assault-executive.pdf

Macknick, J., Newmark, R., Heath, G., & Hallett, K. C. (2012). Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. *Environmental Research Letters*, *7*(4), 045802. https://doi.org/10.1088/1748-9326/7/4/045802

Ministry of Finance. (2015). *Highlights of Pakistan Economic Survey 2013-14*. Retrieved from http://finance.gov.pk/survey/chapters_14/Highlights_ES_201314.pdf

Newspaper, F. the. (2013, August 7). Pollution from coal-fired power plants. Retrieved October 25, 2016, from http://www.dawn.com/news/1034713

Nickson, R. T., McArthur, J. M., Shrestha, B., Kyaw-Myint, T. O., & Lowry, D. (2005). Arsenic and other drinking water quality issues, Muzaffargarh District, Pakistan. *Applied Geochemistry*, *20*(1), 55–68. https://doi.org/10.1016/j.apgeochem.2004.06.004

Nriagu, J. O. (1989). A global assessment of natural sources of atmospheric trace metals. *Nature*, *338*(6210), 47–49. https://doi.org/10.1038/338047a0

Nriagu, J. O., & Pacyna, J. M. (1988). Quantitative assessment of worldwide contamination of air, water and soils by trace metals. *Nature*, *333*(6169), 134–139. https://doi.org/10.1038/333134a0

Paris 2015: Tracking country climate pledges. (2015, September 16). Retrieved October 25, 2016, from https://www.carbonbrief.org/paris-2015-tracking-country-climate-pledges

Praharaj, T., Powell, M. A., Hart, B. R., & Tripathy, S. (2002). Leachability of elements from sub-bituminous coal fly ash from India. *Environment International*, *27*(8), 609–615. https://doi.org/10.1016/S0160-4120(01)00118-0

Rauf, S. (2014). *Environmental Impact Assessment Guidance for Coal Fired Power Plants in Pakistan*.

Reddy, M. S., Basha, S., Joshi, H. V., & Jha, B. (2005). Evaluation of the emission characteristics of trace metals from coal and fuel oil fired power plants and their fate during combustion. *Journal of Hazardous Materials*, *123*(1–3), 242–249. https://doi.org/10.1016/j.jhazmat.2005.04.008

Sandelin, K., & Backman, R. (2001). Trace Elements in Two Pulverized Coal-Fired Power Stations. *Environmental Science & Technology*, *35*(5), 826–834. https://doi.org/10.1021/es000035z

Sushil, S., & Batra, V. S. (2006). Analysis of fly ash heavy metal content and disposal in three thermal power plants in India. *Fuel*, *85*(17–18), 2676–2679. https://doi.org/10.1016/j.fuel.2006.04.031

UCS. (2013). Environmental impacts of coal power: wastes generated. Retrieved October 25, 2016, from http://www.ucsusa.org/clean_energy/coalvswind/c02d.html

US EPA. (2008, November). Clean Air Mercury Rule [Collections and Lists]. Retrieved October 25, 2016, from https://www.epa.gov/cair

US EPA, O. (2015, August). Mercury in Your Environment [Collections and Lists]. Retrieved October 25, 2016, from https://www.epa.gov/mercury

Van der Wall, E. E. (2015). Air pollution: 6.6 million premature deaths in 2050! *Netherlands Heart Journal*, *23*(12), 557–558. https://doi.org/10.1007/s12471-015-0763-9

Xu, M., Yan, R., Zheng, C., Qiao, Y., Han, J., & Sheng, C. (2004). Status of trace element emission in a coal combustion process: a review. *Fuel Processing Technology*, *85*(2–3), 215–237. https://doi.org/10.1016/S0378-3820(03)00174-7

Younos, T., & Grady, C. A. (2014). *Potable Water: Emerging Global Problems and Solutions*. Springer.

Yousuf, I., Ghumman, A. R., Hashmi, H. N., & Kamal, M. A. (2014). Carbon emissions from power sector in Pakistan and opportunities to mitigate those. *Renewable and Sustainable Energy Reviews*, *34*, 71–77. https://doi.org/10.1016/j.rser.2014.03.003

Zaman, & Kumar. (2014). Pakistan's Coal Rush: A Bubble Waiting to Burst | Inter Press Service. Retrieved October 25, 2016, from http://www.ipsnews.net/2014/06/pakistans-coal-rush-a-bubble-waiting-to-burst/