Volume 65, Issue 8, 2021
Journal of Scientific Research
of
The Banaras Hindu University

Polychlorinated Biphenyls and Heavy Metals: Source of Emission, Harmful Effects and Prevention

Krystel Kieran Vaz

Department of Chemistry, Jnan Vikas Mandal's Degree College, Airoli, Navi Mumbai, India, krystel.vaz@gmail.com

Abstract: **Environmental toxicology is the study of hostile effects of various harmful chemicals on living organisms. Humans, plants and animals are increasingly being exposed to chemicals in the environment. An ever increasing use of chemicals in the industry has led to environmental pollution. Toxicants produced from various industries remain in the environment causing an adverse impact on our ecosystem. The various sources include organic and inorganic pollutants, pesticides, fertilizers, particulates, radiation, and biological agents such as mycotoxins and bacterial toxins. These toxins are often present in air, water, soil as well as food. Upon exposure, they may have long-term impacts on the health of organisms. Hence, it is very crucial to understand the various sources of toxins, their harmful effects and various measures to protect the environment from such drastic effects. Due to lack of awareness and proper treatment in India, large number of the human population tend to risk their lives. India being a developing nation is currently working on a number of policies and research programs to overcome toxic pollution caused by chemical pollutants. This review article discusses some of the sources of environmental toxicology and the appropriate measures that are essential to reduce environmental toxicology.**

Index Terms: **Environmental toxicology, hazards, heavy metals, pollutants, polychlorinated biphenyls.**

I. Introduction

Environmental toxicology is also known as ecotoxicology, envisioned by Truhaut in 1969 (Truhaut, 1977). It is the science of the effects of toxins in the air, soil, water, sediments, and all living organisms. Toxicology pertains to the effects of toxins on single living organisms -whereas ecotoxicology pertains to the effects of toxins on the ecosystem. Toxins such as environmental pollutants directly alter the environment having a huge effect on living organisms.

Ecotoxicity became a major concern during the 1950s and 1960s. The cause of such concerns were agricultural pesticides as they started to have an impact on wildlife. Pesticides are generally toxins that were intentionally released onto agricultural lands. Even though the effects of these pesticides were expected, the impact of them on other pollutants and their manifestation on the biological system were taken by a surprise by most people.

A pollutant is a substance that naturally occurs in the environment which increases in quantity due to human activities, having an adverse effect on living organisms. The difference between a pollutant and a contaminant is often undistinguishable. A contaminant is a substance that is not naturally present in the environment but is introduced due to human activities. Contaminants are usually present in small amounts and may not have an effect on the environment whereas pollutants are present in amounts that threaten the ecosystem. Some of these pollutants, in the amounts that they are present, do not effect living organisms directly, but modify their environment as to challenge their ability to survive. For Pollutants that are toxic, also known as toxicants, can directly alter the environment which has a deleterious effect on the ecosystem. Polychlorinated biphenyls (PCBs) and heavy metals are some of the sources of such pollutants. (Moriarty, 1999)

II. Polychlorinated Biphenyls

A. Source

Polychlorinated biphenyls (PCBs) are prepared by chlorination of biphenyls using a wide range of catalysts under experimental conditions (Safe, 1984). The structure is composed of a biphenyl structure with 1-10 chlorine substituted over two benzene rings (Wang et al., 2014). The industrial use of PCB is dependent on their physical and chemical properties which include, the unusual chemical stability and their ability to resist their breakdown by acids, bases, heat, light, reducing agents, and oxidizing agents. These peculiarities resulted in the use of PCBs as hydraulic fluids, plasticizers, adhesives, heat transfer fluids, wax extenders, dedusting agents, organic dilutants/extenders, lubricants, flame retardants, and dielectric fluids in capacitors and transformers. Residues of PCBs have been found in the vicinity of industrial and

polar areas. These tailings have also been detected in water bodies such as rivers, lakes, and oceans that act as sources of PCB accumulation. The tissues of infected freshwater fish are found to be especially high in PCBs. (Carpenter, 2006) Residues of PCBs also find their way into the human body (Safe, 1984). Inhalation and dermal absorption are two potential routes of PCB exposure. PCBs inhaled in the form of vapor can bioaccumulate, causing pathological changes. These vapor phase PCBs are mostly located in the vicinity of toxic hazardous waste sites (Carpenter, 2006). Entities who are frequently exposed to PCBs are found to have such residues in their blood, adipose tissue, and breast milk (approximately 2 to 10 ppb in blood and 0.5 to 1.5 ppm in adipose tissue) (Safe, 1984). These residues enter the body by ingesting PCB-contaminated products by the oral route. The Yusho poisoning incident took place in Japan in 1968 and one in Taiwan in 1979 (Safe, 1984; Higuchi, 1976; Kuratsune, 1980; Chen et al., 1981). Two of these occurrences occurred as a result of accidental PCB poisoning. Both events occurred as a result of the consumption of PBC-contaminated cooking oil via the oral route. An analysis of environmental PCBs indicated that the higher the chlorinated homologues, the longer they persist.(Safe, 1984; Kimbrough, 1980)

B. Harmful Effects

The human population is exposed to PCBs in an environmental, occupational or accidental manner. The effect of these pollutants on humans have major effects and cause symptoms like complaints associated with neurological damage, chloracne and several dermal changes, respiratory problems, increased serum (and adipose tissue), levels of PCBs alterations in steroid metabolisms, ocular damage and immunologic effects. These symptoms were observed in the Yusho poisoning incident in Japan as well as the Taiwan PCB poisoning incident. (Safe, 1984)

Although humans who are occupationally exposed to PCBs are expected to show most symptoms, only a few of these symptoms are observed among these exposed workers. It is unclear as to why the latter does not show more serious symptoms than the PCB poisoning incident since the serum levels of the workers were found to be equal and higher than the victims of the PCB poisoning. Toxic polychlorinated dibenzofuran (PCDF) and other halogenated aromatic compounds in contaminated rice-oil may have led to increased toxicity of PCBs during the PCB poisoning incident. Approximately 35.4% of the Yusho victims who were exposed to PCBs during the poisoning event died of cancer. Although the cancer fatality rate was higher than expected in the normal population, it would be premature to assume that high mortality is linked to the laying of PCBs.(Safe, 1984) Polychlorinated biphenyls are listed by the World Health Organization as " probable human carcinogens ". This implies that the carcinogenic effects of PCBs cannot be verified because PCBs accumulate with many other fat-soluble contaminants. PCBs are also known to induce changes in the skin of the thyroid, kidney, liver, pancreas and cardiovascular system. As a corollary of these acts on the multiple organ system, humans who are exposed to PCBs are at significantly increased risk of cancer, hypothyroidism, infections, infertility, decreased cognitive function followed by adverse behavioral effects, ischaemic heart disease, arthritis, hypertension, asthma and diabetes, as well as giving birth to infants of lower than average birth weight. Detrimental effects such as IQ defects cannot be treated and are permanent, but other ailments such as cancer may be treated if they are identified at an early stage.(Carpenter, 2006)

C. Prevention

PCB liquids are primarily used in transformers and capacitors as they tend to be non-inflammable and have excellent high chemical stability. Transformers or capacitors are often used to provide better electrical protection, to prevent dust or for other ecological reasons. PCB accidents typically occur as a result of either cold leakage or arc explosions and fires. Cold leakage is triggered when transformers and capacitors have not been exposed to heat, and the leakage is usually harmless. If PCB liquid makes its way into a river or lake, or if it contaminates food or feed, it could pose a danger to the health of biological entities. Arc explosions are caused by a voltage difference or perhaps a high voltage circuit resonance owing to harmonic currents. (Pajari, 1985)

Measures can be implemented to avoid the exposure of PCBs, such as the replacement and thorough disposal for most PCBs and PCBs polluted transformers and capacitors. Transformers such as retro-filled transformers typically have a concentration just under 50 ppm. Resampling is then conducted after 90 days to assure that the concentration stays below the 50 ppm margin. Conducting a re-sampling test every 6 months will guarantee that not only the concentration stays below 50 ppm, but rather that the internal components soaked in PCB-contaminated fluid have not rereleased PCBs overtime. It is necessary to establish proper maintenance and decommissioning to avoid accidental leakage of PCBs. (Panero et al., 2005) Accidents triggered by arc explosions and fires could be avoided by minimizing the risk of fire and the transmission of smoke; updating electrical repair work on PCB-filled equipment in areas where there are significant possible hazards; educating firefighters, ambulance staff and staff in facilities where PCB-filled equipment is stored. (Pajari, 1985)

III. Heavy Metals

A. Source

The main causes of environmental emissions emerge from the ecosystem itself (Das et al., 2014). In earlier times, heavy metals were commonly found in soils as organic substances; furthermore, their existence in the atmosphere has been elevated due to anthropogenic activities. This is a common issue globally in regions where high amounts of heavy metals such as Cd, Pd, As, Cr, Hg and Se can be detected in soil.(Perfus-Barbeoch et al.,

2002) Most of the pollutant is created by human intervention, which causes an increase in the level of exposure. However, anthropogenic sources contribute more harmful contaminants to the ecosystem than natural sources do (Ohyama et al., 1988). The sources of pollutants can be completely normal, such as from earthquakes, radon emissions, storms, volcanic eruptions and floods (Das et al., 2014). Majority of substances such as iron, arsenic, manganese, chloride, fluoride, sulphate and radionuclide are naturally found in some rocks and soils; these chemicals contaminate when immersed in water, while organic and natural substances are transported straight to the ground aquifer (Mukhopadhyay et al, 2005). Heavy metals are discharged into the atmosphere from numerous anthropogenic practices such as mining, electroplating, energy and fuel production, wastewater sludge disposal, radioactive fuels and agricultural waste (Reimann & de Caritat, 2005). Smokestacks of power stations, conventional biomass incineration and waste burning are static contributors of greenhouse gas emissions and PAHs in the atmosphere, whereas automobiles, marine vessels and aircraft are mobile sources (Uherek et al, 2010).

B. Harmful Effects

Heavy metal pollution has become a major problem for aquatic and marine environments. The concern for metal contamination in marine ecosystems began with the minor catastrophe created by the ingestion of mercury-contaminated fish at Minamata. Physical factors such as temperature, the presence of other metals and pH salinity influence the toxicity of the metals to marine life in aquatic environments. Cadmium and mercury toxicity are much more common in freshwater than in hard water or marine water. Mercury when converted to methyl mercury at a lower PH is more hazardous than metallic or inorganic mercury. Cadmium reduces kidney function and triggers skeletal deformities in fish. The impact of cadmium on marine life are directly or indirectly fatal. Cadmium negatively affects the growth of marine plants, which in addition heavily influences the ecosystem. Cellular damage has been documented in the hepatopancreas of marine invertebrates that have experienced extended exposure to cadmium. Pb is particularly toxic to aquatic plants and algae and inhibits the activity of enzymes associated with photosynthesis. (Wright & Welbourn, 2002) PAHs are pollutants that persist in aquatic ecosystems. PAHs result in five environmental effects: leaching, bioaccumulation, volatilization, degradation and sequestration (Meador et al., 1995). PAHs were classified as a priority pollutant by the United States EPA and the European Union (Maiti et al, 2012).

Terrestrial habitats are marked by minimal water supply and higher temperature variations. There is a higher availability of gases and sunlight in terrestrial environments compared to marine ecosystems. The influence of metals and PAHs on terrestrial animals is somewhat close to that of humankind. Movement of Pb is primarily due to air pollutants, Hg through vegetation, and As via water. Plant species can accumulate a lot of metals in terrestrial habitats. The uptake method for radioactive metals is much like the uptake process for essential metal ions micronutrients. (Patra et al, 2004) In extreme concentrations, metals induce phytotoxicity due to bonding to the Sulfuryl (-SH) groups, changes in membrane permeability, reactions with phosphate groups and active groups of adenosine di-phosphate or Adenosine tri-phosphate groups, and replacement of essentials. Metals like Pb can have a significant effect on the moisture content of plant tissues. Alfalfa (Medicago sativa) studies indicate that PAHs can greatly reduce the absorption of Cu and Zn. (Carlo-Rojas & Lee, 2009) An increase in the concentration of heavy metals has been confirmed to pose a hazard to the function and growth of roots (Rautio et al., 2005).

A safe lifestyle needs certain heavy metals, albeit in limited amounts. These heavy metals or their derivatives are widely found in fruit, foodstuffs and vegetables, and in commercially available multivitamin supplements. Strong metal poisoning happens when the body is not metabolized and accumulates in various areas of the body, like those of soft tissues in human beings. After the early days of metallurgy, human were exposure to heavy metals. After the industrial revolution, exposure to heavy metals became a significant cause of various health consequences. The most studied heavy metal contamination syndrome is metal fume fever (MFF) also categorized as " Monday morning fever" as it is commonly known. This is self-restraint inhalation syndrome observed in employees exposed to metal oxide gases. Prolonged exposure to cobalt dust induces pneumoconiosis, chronic renal failure, pulmonary fibrosis, osteoporosis and emphysematous lung damage. PAHs are considered to be carcinogenic. The toxicity of PAHs may result in dermatitis, chronic cough irritation, skin irritation, photosensitization, chronic bronchitis, pilolosebaceous reactions and bronchogenic cancer. PAHs can also cause hemotopoietic, reproductive, neurological and immune systems. The metabolites of PAHs or their variants can be potent mutagens. The most prevalent component of coal tar, naphthalene is a skin irritant that can induce vomiting, headache, diaphoresis and nausea. (Das et al, 2014)

C. Prevention

A number of technologies exist to remediate metal-contaminated soils. Techniques to clean up contaminated soil have been classified into three categories: In situ or ex situ harsh soil destructive measures, gentle in situ remediation and in situ harsh soil restrictive measures. In situ or ex situ harsh soil restrictive and in situ or ex situ harsh soil destruction measures aim to prevent hazards to humans, plants or animals. The primary objective is to restore soil fertility through soft in situ rehabilitation that allows a safer use of soil. (Gupta et al., 2000) Techniques to remediate contaminated soils have been widely classified into source control and containment remedies. Source control is based on in situ and ex situ treatment techniques. In situ

or on-site means that contaminated soil is treated in its initial location. In situ treatment technologies process or remove the pollutant from the soil without excavating or removing the soil. Ex situ is the excavation or removal of contaminated soil from the site or subsoil. (USEPA, 2007)

Hyperaccumulator plants can be planted in order to remove heavy metals from the soil. Removal of heavy metals takes place after the contaminant is selectively absorbed by roots of hyperaccumulator plants, and then gets translocated, bio accumulated resulting in degradation. Organic farming has proved to be beneficial for reducing heavy metals from entering our body. Use of pesticides is avoided and the water treatment has to be in the purified form. Biodiversity is also used as a safe method to remove insects from water. (Briffa et al, 2020) The most important factors for elimination of heavy metals from water are pH, Temperature, ionic strength, and organic matter. Agricultural wastes and dairy manures work best for eliminating heavy metals from water. however, the least effective solution of heavy metal separation is using mineral deposits and soil. (Joseph et al., 2019) Several foods are also known to be a chelating agent with heavy metals once they enter human body, namely. Cilantro, wild blue berries, garlic, lemon water, curry, green tea, spirulina and many such foods helps in removal of heavy metals through excretion. (Briffa et al, 2020)

IV. Environmental Toxicology in India

Today, India is facing many problems when it comes to environmental toxicology. In India toxicology is included only in higher degrees in life sciences. Implementing educational programs on occupational and environmental hazards due to ecotoxicology will contribute to improving the current situation in India. (Saiyed & Tiwari, 2004) Sukinda in Orissa and Vapi in Gujarat located in India are among the 10 most polluted cities globally, as per a leading American business magazine. Large areas of surface water and potable water in Sukinda contain elevated levels of covalent chromium. Whereas in Vapi, chemical pollutants present in the air and heavy metals from industrial estates have affected human habitat for years. In certain parts of Vapi, mercury in the groundwater is observed to be 96 times higher than the standard measures issued by World Health Organization (WHO). (Braune & Malone, 2005) Moreover, around 50 million people in the state of west bengal are affected due to the high increase in level of arsenic in groundwater as per WHO (Mishra et al., 2008). The presence of these toxic chemicals in ground water have caused serious health hazards to the locals. The role of heavy metals like chromium, arsenic and mercury is effective in geochemical cycles. Their occurrence during mining and processing are hazardous and can cause tremendous damage to human health even causing immune diseases, cancer, certain allergies, Lupus and respiratory disorders. Ingestion of mercury, arsenic and fluoride also results in diseases like Minamata, Arsenicosis and fluorosis. Indian government is introducing certain policies to keep in check the use and disposal of harmful chemicals and pollutants. However, implementation of such laws at local level is minimal. Recently, the Indian Medical Association reported that lack of proper disposing units for industrial wastes leads to contaminated drinking water on a large scale. (Flora, 2008) The bad quality of water in these regions caused a number of health issues like carcinoma, chemical dermatitis and skin, lung and throat cancers. Many Incidents of women facing infertility and problems during pregnancy have also been reported. Its challenging to deal with poison cases in India due to the fact that only two hospitals are facilitated with intensive care units for poisoning cases. These cases are treated in emergency wards of hospitals in India. Currently, there are only a handful of hospitals that carry out research and study programmes related to toxicology in India. They work on crucial topics like environmental pollutants, chemical warfare agents and toxicants. These research laboratories are namely., Indian Institute of Toxicology Research (IITR) (Lucknow), Central Drug Research Institute (CDRI) (Lucknow), Defense Research and Development Establishment (DRDE) (Gwalior), and Food and Drug Toxicology Research Centre (FDTRC) at the National Institute of Nutrition (NIN) (Hyderabad). (Flora et al., 2006; Vijayaraghavan et al., 2005) Various academies like the Society of Toxicology (STOX), the Indian Pharmacological Society (IPS) are also on board with development of the toxicology branch in the country. Various meetings and conferences are organized annually to generate young researchers and spread awareness of the impact of toxic pollution on human and environmental health. (Flora, 2008)

Conclusion

Environmental toxicology is become a major problem worldwide. Environmental toxicants like PCBs and Heavy metals cause a detrimental impact on the ecosystem. Improper disposal of these industrial wastes leads to contaminated drinking water causing a number of health issues like carcinoma, chemical dermatitis and skin, lung and throat cancers. In India, there are only a handful of hospitals that carry out research and study programmes related to toxicology in India. Hence spreading awareness about environmental toxicology and its sources becomes very important. By Implementing educational programs on occupational and environmental hazards of ecotoxicology we become aware about our situation. This would lead to understanding the impacts of these toxicants on the society which in turn would contributes in making our situation better. India is organizing various meetings and conferences to spread awareness about environmental toxicology in hope that we can have a safer country to live in.

Acknowledgment

I am grateful to our principal, Dr. Leena Sarkar, my guide Ms. Savita Kumari, and my professors for giving the means to write this review article on the topic Polychlorinated Biphenyls and

Heavy Metals: Source of Emission, Harmful Effects, and Prevention. It aided me in conducting extensive research, and I learned about many new topics as a result. Furthermore, I would want to thank my parents and friends for their assistance in completing this project in such a short period of time.

REFERENCES

Braune, B. M., & Malone, B. J. (2005). Mercury and Selenium in Livers of Waterfowl Harvested in Northern Canada. Archives of Environmental Contamination and Toxicology, 50(2), 284–289.

Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon, 6(9), e04691.

Carlo-Rojas, Z., Lee, W. Y. (2009). Cu and Zn Uptake Inhibition by PAHs as Primary Toxicity in Plants. Proceedings of the 2007 National Conference on Environmental Science and Technology, 41-46.

Carpenter, D. O. (2006). Polychlorinated Biphenyls (PCBs): Routes of Exposure and Effects on Human Health. Reviews on Enviromental Health, 21(1), 1-24.

Chen, P. H., Chang, K. T., & Lu, Y. D. (1981)Polychlorinated Biphenyls and Polychlorinated Dibenzofurans in the toxic rice-bran oil that caused PCB poisoning in Taichang. Bull. Environ. Contam. Toxicol., 26,489-495.

Das, S., Raj, R., Mangwani, N., Dash, H. R., & Chakraborty, J. (2014). Heavy Metals and Hydrocarbons. Microbial Biodegradation and Bioremediation, 23-54.

Flora, S. J. S. (2008). Status of Toxicological Research in India. Chemical Research in Toxicology, 21(7), 1317-1319.

Flora, S. J. S., Flora, G., & Saxena, G. (2006). Environmental Occurrence, Health Effects and Management of Lead Poisoning. Lead, 158-228.

Gupta, S. K., Herren, T., Wenger, K., Krebs, R., & Hari, T. (2000). "In situ gentle remediation measures for heavy metal-polluted soils," in Phytoremediation of Contaminated Soil and Water, Terry, N. & Banuelos, G. (ed.) (pp. 303–322), USA: Lewis Publishers.

Higuchi, K. (ed.), (1976). PCB Poisoning and Pollution, Kodansha, Tokyo: Academic press.

Joseph, L., Jun, B. M., Flora, J. V. R., Park, C. M., & Yoon, Y. (2019). Removal of heavy metals from water sources in the developing world using low-cost materials: A review. Chemosphere 229, 142–159.

Kimbrough, R. D. (1980). Occupational exposure. In: Kimbrough, R. D. (ed.) Halogenated Biphenyls, Terphenyls, Naphthalenes, Dibenzodioxins and related products. Elsevier North-Holland, Amsterdam, 373–399.

Kuratsune, M. (1980) Yusho. In: Kimbrough R. D. (ed.), Halogenated biphenyls, terphenyls, naphthalenes, dibenzodioxins and related products. Elsevier North-Holland, Amsterdam, 287.

Maiti, A., Das, S., & Bhattacharyya, N. (2012). Bioremediation of High Molecular Weight Polycyclic Aromatic Hydrocarbons by Bacillus thuringiensis Strain NA2. Journal of Science, 1 (4), 72-75.

Meador, J., Casillas, E., Sloan, C. A., & Varanasi, U. (1995). Comparative bioaccumulation of polycylic aromatic hydrocarbons from sediment by two infaunal invertebrates. Marine Ecology-progress Series 123. 107-124.

Mishra, D., Mehta, A., & Flora, S. J. S. (2008). Reversal of Arsenic-Induced Hepatic Apoptosis with Combined Administration of DMSA and Its Analogues in Guinea Pigs: Role of Glutathione and Linked Enzymes. Chemical Research in Toxicology, 21(2), 400–407.

Moriarty, F. (1999). Ecotoxicology:The Study of Pollutants in Ecosystems: Introduction (pp 1-9). London: Academic Press.

Mukhopadhyay, J., Gutzmer, J., & Beukes, N.J. (2005). Organotemplate structures in sedimentary manganese carbonates of the Neoproterozoic Penganga Group, Adilabad, India. Journal of Earth System Science.114(3), 247-257.

Ohyama, S., Ishinishi, N., Hisanaga, A., et al. (1988). Comparative chronic toxicity, including tumorigenicity, of gallium arsenide and arsenic trioxide intratracheally instilled into hamsters. Applied Organometallic Chemistry. 2, 333-337.

Pajari, J. (1985). Safety Measures for Prevention of PCB Accidents; Environmental Health Perspectives, 60, 347-350.

Panero, M., Boehme, S., & Munoz, G. (2005). Pollution Prevention and Management Strategies for Polychlorinated Biphenyls in the NY/NJ Harbor. New York Academy of Sciences, New York, 39-79.

Patra, M., Bhowmik, N., Bandopadhyay, B., & Sharma, A. (2004). Comparison of mercury, lead and arsenic with respect to genotoxic effects on plant systems and the development of genetic tolerance. Environmental and Experimental Botony, 52 (3), 199-223.

Perfus-Barbeoch, L., Leonhardt, N., Vavasseur, A., & Forestier, C. (2002). Heavy metal toxicity: cadmium permeates through calcium channels and disturbs the plant water status. The Plant Journal, 32(4), 539-548.

Rautio, P., Kukkola, E., & Huttunen, S. (2005). Growth alterations in Scots pine seedlings grown in metal-polluted forest soil: implications for restorative forest management. Journal of Applied Botony and Food Quality, 79, 52-58.

Reimann, C., & de Caritat, P. (2005). Distinguishing between natural and anthropogenic sources for elements in the environment: regional geochemical surveys versus enrichment factors. Science of The Total Environment, 337(1-3), 91-107.

Safe, S. (1984) Polychlorinated biphenyls (pcbs) and Polybrominated biphenyls (pbbs): Biochemistry, Toxicology, and Mechanism of Action. CRC Critical reviews in Toxicology 13 (4), 319-395.

Saiyed, H. N., & Tiwari, R. R. (2004). Occupational Health Research in India. Industrial Health, 42(2), 141–148.

Institute of Science, BHU Varanasi, India

Truhaut R. (1977). Ecotoxicology: Objectives, Principles and Perspectives. Ecotoxicology and Environmental Safety 1, 151-173.

Uherek, E., Halenka, T., Borken-Kleefeld, J., Balkanski, Y., Berntsen, T., Borrego, C., Gauss, M., Hoor, P., Juda-Rezler, K., Lelieveld, J., Melas, D., Rypdal, K., Schmid, S., (2010). Transport impacts on atmosphere and climate: Land transport, Atmospheric Environment, 44(37), 4772-4816.

USEPA. (2007). Treatment technologies for site cleanup: annual status report (12th edition), EPA-542-r-07-012, Solid Waste and Emergency Response, Washington, D.C.

Vijayaraghavan, R., Kulkarni, A., Pant, S. C., Kumar, P., Lakshmana Rao, P. V., Gupta, N., Gautam, A., & Ganesan, K. (2005). Differential toxicity of sulfur mustard administered through percutaneous, subcutaneous, and oral routes. Toxicology and Applied Pharmacology, 202(2), 180–188.

Wang, S., Hao, C., Gao, Z., Chen, J. & Qiu, J. (2014). Theoretical Investigation on Photodechlorination Mechanism of Polychlorinated Biphenyls. Chemosphere, 95, 200-205.

Wright, D.A., & Welbourn, P. (2002). Environmental toxicology; Cambridge University Press, Cambridge 11, 249-348.

***