Chapter 1
Environmental Lead Exposure—A Continuing Challenge

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Abstract Lead is one the most abundantly present heavy metal on the earth crest, use of which in many can be traced back to 7000–6500 B.C. A low concentration of lead can be seen in an optimum range but when the concentration reaches up to 150–300 ppm in the environment, it can pose a serious threat to individual health. In the environment, lead can be found in both organic and inorganic forms with inorganic lead being the most predominant. The majority of lead pollution is caused by human activity to harvest and exploit the metal. In the early twentieth century, industrial workers who were working in painting, smelting, printing, plumbing, and other industries were heavily exposed to lead. Due to the use of lead in petrol after the invention of motor vehicles at the beginning of the twentieth century, there was a significant rise in ambient lead contamination. Brain and spinal cord is the most prominent organ among those harmed by lead. Young individual's intellectual development suffers long-lasting negative impacts from low-level chronic Pb exposure. Apart from that exposure to lead can have detrimental effects on different organ systems of the body. Chronic low-level lead exposure can have a long-lasting effect on the well-being of a new generation. The main focus of this chapter is to study the distribution, toxicology, and remediation of lead toxicity throughout the decades.

Keywords Lead · Environment · Metal · Exposure · Contamination

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1.1 Introduction

Ever growing development of industries comes with huge drawbacks, including water and air pollution and contamination of soil with toxic heavy metals emitted from those industries. This significantly deteriorates the quality of life for animals as well as for humans. All farm animals get affected by this contamination of the environment with heavy metals, because of their natural habit of pasturing in fields in the neighbourhood of the emission sources. These elements can be present on the body hair and on the skin of an animal and act as exogenous reserves, which can go inside of an animal and can get absorbed in the alimentary canal while licking their hair and also while grazing on the field. These endogenous reserves of ingested heavy metals get distributed to different organs and tissue by blood and get taken up by the hair during its growth phase, which subsequently increases the number of trace elements in an animal's body (Kabata-Pendias and Mukherjee 2007). Due to their toxicity, endurance, and capability to get absorbed into the body tissues via different modes of exposure, heavy metals are among the most harmful pollutants in the natural environment. When these toxins accumulate in body tissue more quickly than the body can eliminate them, a progressive build-up of the toxins takes place (Khudzariet al. 2013). Chronic low-level exposure to heavy metals also can have serious health effects just as much as excessive exposure to them. Even though some of these exposures and their negative effects are frequently subtle, especially on an individual level, the damage can be significant on a population level (Reis et al. 2007).

Lead is a silver-grey heavy metal with a melting temperature of 327.5 °C and a molecular mass of 207.19. Although this soft metal has good corrosion resistance, it is soluble in hot sulfuric and nitric acids. For inorganic lead compounds, the typical valence state is +2. Lead sulphide and lead oxides are not very soluble in water, but nitrate, chlorate, and chloride salts are very soluble in cold water. In addition, stable organic molecules like tetraethyllead and tetramethyllead, as well as organic acids like lactic and acetic acids, form salts with lead (WHO 1995). Despite having four electrons in its valence shell, lead only readily ionizes two of the electrons. Therefore, instead of +4, the typical oxidation state of lead in inorganic compounds is +2. The chloride, nitrate, and, to a much lesser extent chlorate, are water-soluble. Although the acetate is rather soluble, some of the salts produced with organic acids, such as lead oxalate, are similarly insoluble. Physio-chemical properties of lead salts.

Lead comes under non-essential heavy metals for living organisms, which is hazardous to biota even at a minute concentration. Traces of this metal can generally be found in the soil with an optimum concentration of 15–40 ppm. But with the increase in the concentration of lead up to 150–300 ppm in the environment, it can pose a serious threat to individual health (Dikmen et al. 2023). Because of the excessive emission from human activities over millennia, it is now impossible to accurately estimate the natural concentration of lead in the environment. According to multiple researches, natural air-lead concentrations were four to five folds lower than today's atmospheric concentration. Because of it, lead is now considered one of the most life-threatening heavy metal presents in the environment by many countries (Kazantzis et al. 1989). In the environment, lead can be found in both organic and inorganic forms with inorganic lead being the most predominant. The physical and chemical form of lead, as well as the size of lead particles, has a direct influence on its distribution, absorption into a living organism, sedimentation, and toxicity.

The first case of occupational lead poisoning was documented around 370 B.C. In the early twentieth century, industrial workers who were working in painting, smelting, printing, plumbing, and other industries were heavily exposed to lead. In 1767, several patients were hospitalized at La Charite Hospital in Paris with symptoms, which were not recognized then are now showing similarities with those of lead poisoning. Evidence showed that all those workers to some extent were exposed to lead from their occupational environment (Tong et al. 2000). Lead has been classified as a possible human and animal carcinogen and has well-documented effects on every organ system, including the immunological, reproductive, cardiovascular, and renal as well as on teeth and bones. However, the neurological system is particularly susceptible to lead's effects (White et al. 2007). Lead exposure is thought to be harmful and is linked to cognitive impairment, neuromuscular weakness, behavioural abnormalities, and hearing deficiencies in both people and animals. No "safe" level of lead exposure has been found, nor is there any level of lead that appears to be required or advantageous for the body (Flora et al. 2012). In many nations, exposure has declined as a result of the elimination of lead from gasoline. Lead has been extensively employed in industries nevertheless and levels are still high in many places because of its malleability, resilience to corrosion, and low melting point (Wang et al. 2012). Deposition of lead in the body tissue differs with the type of tissue and with the age group. 80–90% of lead deposition can be seen in the bone of adults, whereas about 70% of total lead deposition can be seen in the bone of children. A maximum amount of exposed organic lead get absorbed in the body and then may be present in different body fluid whereas inorganic lead remain unchanged and excreted through urine.

Children have a particularly high risk of lead poisoning since they absorb 4–5 times more ingested lead than an adult from a similar source. In addition, due to their natural curiosity and age-appropriate hand-to-mouth activity, children often swallow lead-containing or lead-coated particles, such as dust, flakes, and contaminated soil. Individuals who have pica, a psychological condition that causes excessive and persistent cravings for non-food objects, are more likely to pick at and consume lead paint from furniture, doorframes, and walls, which increases the risk of exposure. Children in Nigeria, Senegal, and other nations have experienced widespread lead poisoning and several deaths as a result of exposure to lead-contaminated soil and dust brought on by battery recycling and mining (WHO 2022).

Recently, the focus on lead poisoning has shifted from adults, highly exposed to this heavy metal from industrial effluent to asymptomatic children with minimal chronic lead exposure. Since chronic low-level lead exposure can have a long-lasting effect on the well-being of a new generation. In this chapter, we are going to discuss the development of knowledge on the distribution, toxicology, and remediation of lead toxicity throughout the decades of lead study.

1.2 History of Lead Uses

Being the first metal to get melted and discovered by humans, a trace of lead was found in different ancient ornaments dating back from 7000 to 6500 B.C. (Kazantzis et al. 1989). Lead was extensively used during Roman Empire, in their construction, cooking utensils, and other day-to-day objects. Lead was utilized by the ancient Romans to make water pipes and line baths. Due to its sweet flavour, lead was useful in winemaking to balance out the astringent taste of grape tannic acid. Roman upper classes consumed a lot of lead-sweetened wine, which can have up to 20 mg of lead per litre (Needleman 2004). The use of lead was started in mediaeval times for statues, ornaments, cisterns, tanks, gutters, roofs, and coffins. Lead was also used in the past to make the strips that connected the pieces of coloured glass in church windows. A little statue from Turkey that dates back to 6500 B.C. is the oldest known object manufactured by humans that contains lead. Between 3000 and 4000 B.C. Egyptian pharaohs utilized lead to glaze ceramics. Chinese, ancient Greek, and Roman coinage were made of lead 4000 years ago (Smith 1984). Lead poisoning has been linked to theories linking the fall of Rome to the Roman aristocracy's concurrent decline in fecundity and rise in psychosis (Gilfillan 1965). Smith (1882) reported cases of lead poisoning in the eighteenth century among weavers working with lead dichromate-containing dye in a cotton mill with symptoms of Jaundice and a blue line on the gums. A stricter regulation of the dyeing of the yarns and the use of personal protective equipment by mill workers resulted from an investigation into the poisonings, which ultimately eliminated all occurrences of lead poisoning. Due to their flexibility and capacity to be moulded into different diameters, in the nineteenth century lead has previously been utilized to relieve blockages in the lacrimal and nasal ducts. Burridge cites multiple cases of using the consumption of lead acetate in the treatment of dysentery and other diarrheal disease (Burridge 1851). Due to the use of lead in petrol after the invention of motor vehicles at the beginning of the twentieth century, there was a significant rise in ambient lead contamination. Throughout much of the century, this led to an increase in the community's exposure to environmental lead (Tong et al. 2000).

1.3 Lead in the Environment

The removal of gases and particles from the atmosphere is accomplished by atmospheric deposition. However, it is also a serious environmental issue in numerous regions of the world due to worries about natural ecosystem acidification and eutrophication, bioaccumulation of hazardous compounds and metals, effects on biodiversity, animal health, and global climate change. Increased pollutant concentrations in the atmosphere caused by human activities result in increased pollutant deposition, which has a negative impact on human health, crop yields, and terrestrial and marine ecosystems (Pan and Wang 2015). Lead exists in the earth's crust and is naturally found in the environment via a variety of mechanisms such as volcanic emissions and geochemical weathering. However, the majority of lead pollution is caused by human activity to harvest and exploit the metal (Fewtrell et al. 2003). Lead emissions from human activity into the environment can occur directly in the air, water, and soil. There is a constant flow of lead between these compartments even though emissions into these media may be easily monitored. Particle size has a significant impact on where atmospheric lead is found geographically concerning the source of emission. A surface, such as plants, soil, bodies of water, man-made surfaces, or the respiratory tracts of animals, eventually receives the majority of airborne lead through dry or wet deposition processes. Dry deposition occurs either through the impaction of all sizes of particles, mainly smaller particles, or the gravitational settling of bigger particles (> 10 m). Wet deposition is the outcome of either the build-up of particles by falling precipitation or the integration of particles into water droplets within clouds. Most of the lead in water is caused by industrial discharges, highway runoff, and sewage effluent, with some wet atmospheric lead deposition and direct dry deposition, which is more relevant for big bodies of water. The chemical nature of the lead affects how it disperses in water. The main causes of lead deposition in soils are the wet and dry deposition of atmospheric lead, especially close to the sources of emissions, and the discharge of sewage sludge, frequently onto agricultural land (Pattee and Pain 2003).

Soils are not excellent natural historical archives of contamination because metals are dispersed between anthropogenic and geogenic sources, and younger anthropogenic depositions cannot be separated exactly from older depositions. As a result, tree rings, peat deposits, and lake/marine sediments, in particular, are better recorders of pollution history, frequently dating back thousands of years (Savard et al. 2006). Although the historical development of Pb isotopic composition in sediments and tree rings is usually comparable, the process of metal acquisition differs. Nonetheless, soil humic layers, together with lake and bay sediments and trees, acted as effective receptor media for detecting cumulative metal pollution (particularly when Pb isotope studies were used), even at sites located a significant distance (N100 km) from the contamination source (Komárek et al. 2008). The lead concentration of various meals varies greatly, with plant-based foods being the primary source. Total diet studies in industrialized countries show a lead intake of 200–300 g per day, while values ranging from less than 100 to more than 400 g/day have been recorded. Lead solder in cans, dust ingestion by young children, and lead plumbing in places with soft-water sources all contribute significantly to daily lead intake.

Lead as well as compounds can enter the environment at any time throughout the mining, smelting, processing, usage, recycling, or disposal processes. Extensive uses of lead can be seen in batteries, gasoline additives, cables, solder, pigments, and steel products are among the many applications. In countries where leaded gasoline is still used, mobile and stationary sources of gasoline combustion account for the majority of air pollution. Air pollution is particularly severe in areas near lead mines and smelters (WHO 1995). Before the industrial revolution, environmental lead exposure to human and animal populations was comparatively minimal, but industrialization and large-scale mining have increased this heavy metal exposure. Compared to other non-essential elements, lead contamination in the environment significantly affects an organism's livelihood (Tong et al. 2000). As of 2022, Australia had the greatest lead deposits in the world, totalling 37 million metric tonnes. Despite having the second-largest lead reserves in the world, China was the world's top lead producer in 2022. They generated over two million metric tonnes of lead in that one year. Approximately, 12.3 million metric tonnes of refined lead were consumed globally in 2021 (Statista 2023a, b).

In the majority of developed countries, deliberate efforts have resulted in a decrease in the ambient lead concentration in recent years, reflecting a decline in lead's commercial use, particularly in petrol. Due to the phase-out of lead in petrol and the decrease in ambient exposure to the metal over the past 20 years, blood lead levels in the general population in these countries have decreased significantly (Tong et al. 2000). In developing nations where there are wide variations in exposure sources and pathways, lead continues to be a serious public health issue.

1.4 Toxicology and Effects of Lead (Pb) Exposure

A divalent cation, lead, has a considerable affinity for the sulfhydryl groups on proteins. Brain and spinal cord are the most prominent organ among those harmed by lead. Lead is a diverse toxin that has a variety of targets, but the deformation of enzymes and structural proteins is thought to be a major contributor to its toxicity. The endogenous opiate system's development is hampered by lead. There is no sign of a threshold as it catalytically and effectively cleaves the ribophosphate backbone of tRNA at particular places. Because of its capacity to imitate or compete with calcium, lead exhibits several hazardous qualities (Needleman 2004). As per Bailey and Kitchen (1985) lead competes with calcium for binding sites on cerebellar phosphokinase C at picomolar doses, which alters neural signalling. Because of the high lead sensitivity of astrocytes and olegodendrocytes, lead has a significant effect on blood–brain barrier and myelin sheath formation. Lead interferes with vascular permeability by interfering with collagen formation.

According to WHO's 2021 report on the impact of chemicals on Public health, lead exposure cost around a million of lives from all the over the world. According to estimates, chronic lead exposure is estimated to cause 30% of the total intellectual disability, 4.6% of the total cardiovascular diseases and 3% of kidney diseases worldwide due to its chronic effect on the health. Children's health may suffer severely from lead exposure. Lead damages the brain and spinal cord at high exposure levels, resulting in unconsciousness, convulsions, and even death. Children who recover from severe lead exposure may nevertheless have behavioural and intellectual problems. Lead is now understood to induce a spectrum of harm across numerous physiological systems at lower exposure levels that don't immediately manifest any symptoms. Lead, in particular, can have an impact on how children's brains develop, which can lower IQ, change behaviour in the form of increased antisocial behaviour and decreased attention span, as well as lower scholastic achievement. Anaemia, renal impairment, hypertension, toxicity to the reproductive organs, and immunotoxicity are further effects of lead exposure. Lead is thought to have permanent impacts on the brain and behaviour (WHO 2023). Numerous instances of anaemia have been linked to lead poisoning because lead inhibits the enzymes ferrochelatase and porphobilinogen synthase, inhibiting the production of porphobilinogen and the integration of iron into protoporphyrin IX, which blocks the synthesis of heme in blood or causes defective heme synthesis, leads to microcytic anaemia (Ara and Usmani 2015). Lead act as a calcium analogue, which interacts with ion channels, which is one of the processes by which it impairs cognition. Lead can disrupt the ultrastructure of mitochondrion and cell membrane permeability; replace essential elements like Zn, Ca and Fe, and increase the synthesis of reactive oxygen species (ROS), in addition to activating some enzyme and non-enzymatic antioxidants. At very low dose also lead can have a detrimental effect on living cell. In addition to oxidizing intracellular proteins, lipids, and nucleic acids, ROS (H_2O_2, hydroxyl radical, superoxide anion) also cause membrane damage, enzyme deactivation, and lipid peroxidation (Zhang et al. 2023). Acute and chronic exposure to lead can have a huge impact on the reproductive organs of an individual. In a study comparing infertile and fertile males, lead levels in the blood of infertile men were found to be higher (12.5 μ/dl and 6 μg/dl, respectively) (Pant et al. 2003). Epidemiological studies also demonstrate elevated blood lead levels in male employees, ranging from 10 to 40 μg/dl, as well as an increased risk of infertility as a result of lead exposure. Another study of 4000 male workers with elevated blood levels of lead more than 25 g/dl revealed that these individuals had fewer children than the control group (Ganesh 2023). According to Oehninger (2000), infertility cases involving men account for about half of all cases; environmental exposure, particularly occupational exposure in developing countries, as well as a lack of awareness of safety precautions while working in hazardous environments are the main causes of male-related infertility in men.

Young individual’s intellectual development suffers long-lasting negative impacts from low-level chronic Pb exposure (Bellinger and Bellinger, 2006). In their study, Bailey and Kitchen (1985) found out that monkeys fed with lead acetate @ new born to 200 days of age, their blood lead levels ranged from 3 to 25 μg/dl. They underwent a delayed alternation test at the age of 7–8 years, in which the crucial positive stimulus was switched. The ability to learn was compromised in treated monkeys, especially at longer periods of delay. Epidemiological data show that lead exposure during early childhood results in a noticeable loss in cognitive development during the subsequent childhood years. Children are more likely to experience negative effects from lead exposure than adults because: they consume more lead per unit of body weight; they frequently put things in their mouths when they are young, possibly increasing their intake of lead; they consume more lead per unit of body weight than adults; children have higher physiological uptake rates of lead than do adults; young children are developing quickly and have underdeveloped systems, making them more susceptible to the effects of lead than do adults (Tong et al. 2000).

Lead exposure at high levels may result in renal impairment. The same issue could arise even from very little lead exposure. Acute and chronic nephropathies are the two different forms of impaired renal function. Nuclear enclosing bodies, which contain lead protein complexes, and degenerative alterations in the tubular epithelium can be used to classify acute nephropathy both visually and functionally, as can a mechanism of decreased tubular transport. It may enhance an abnormal secretion of amino acids, phosphates, and glucose, a combination known as Fanconi's syndrome, although it is not the cause of protein appearing in the urine. Chronic nephropathy, on the other hand, is easier to treat and can result in permanent morphological and functional abnormalities characterized by, hypertension, hyperuricemia and renal breakdown caused by tubulointerstitial and glomerular abnormalities (Baranowska et al. 2012). According to Carmignani et al. (2000)'s review, lead exposure has a detrimental effect on both human and animal kidneys, leading to the development of renal toxicity due to the stress on the body's oxidative system that it creates. The earlier study, however, revealed that such an impact primarily affects the kidney in chronic exposure that becomes clinically significant and that kidney injury does not typically occur in asymptomatic/acute situations. Rarely do we find information in the literature about how acute Pb exposure causes oxidative stress in an animal's kidney. When compared to other groups, the injection of lead acetate resulted in a substantial rise in urea and creatinine levels. According to a recent study by Sharma and Singh (2014), exposure to Pb acetate at doses of 10 and 150 mg/kg BW for 24 h increased the amount of thiobarbituric acid reactive substances (TBARS) in the kidneys, which is a sign of lipid peroxidation. In the bones, lead is meant to be stored in two compartments. The exchangeable pool situated at the bone surface and the non-exchangeable pool found deep within the bone cortex. Lead could move to the surface after leaving the non-exchangeable pool because it can easily reach plasma from the exchangeable pool and is actively being reabsorbed. Adults' bones contribute between 40 and 70% of the released lead in the blood, according to stable lead isotope analysis. Adults keep roughly 85–95% of their lead in their bones, but children's soft tissues contain about 70% of their high quantity of lead (Patrick 2006). Age, pregnancy dosage and rate, lead exposure, race, and gestation are only a few of the variables that affect how much lead is mobilized and stored in bones. According to Al Naimi et al. (2011), administering lead acetate at a dose of 75 mg/kg BW at 20 and 40 days results in a mild hyperplasia of haemopoietin tissue with megakaryocyte proliferation and the appearance of thin trabeculae of calcified cartilage coated by a thin coating of bone. In comparison to normal, healthy bones, the mineralized cartilage bars that developed as a result of defective osteoclast resorption are wider and extend further into the metaphyseal marrow cavity.

If the damage is too severe, especially to the nervous system's cells or tissue, treatment could not be effective. Following lead exposure, cattle is given calcium disodium edentate (Ca-ethylenediaminetetraacetic acid [EDTA]) subcutaneously or intravenously for three days. 5% dextrose and a similar amount compartmentalized to 4 treatments per day were administered subcutaneously to dogs for 2–5 days. After a one-week break from the end of the therapy, a second 5-day treatment may be required if the clinical indicators don't go away. There isn't a suitable veterinary product with Ca-EDTA on the market at the moment. Thiamine reduces the amount of lead that accumulates in tissues, which can help lessen the clinical symptoms. Thiamine and Ca-EDTA therapy appeared to have the most beneficial response (Payne and Livesey 2010). It has been demonstrated that the chelating agent succorer (meso 2, 3-dimercaptosuccinic acid [DMSA]) is effective in both dogs and birds. Compared to Ca-EDTA, DMSA has a lot fewer adverse effects. Lead removal from the GI tract may benefit from cathartics such a rumenotomy magnesium sulphate. For cases exhibiting convulsion episodes, tranquillizers or barbiturates may be administered as supportive therapy. The oxidative damage caused by severe lead poisoning may be reduced by antioxidant therapy paired with a chelating agent. However, DMSA has been utilized in conjunction with antioxidants such N-acetylcysteine. Using endoscopically guided forceps, it is feasible to extract the swallowed lead pieces from the stomach in chelonian. This should be followed by two weeks of Ca-EDTA therapy (Kaneko et al. 2008).

1.5 Steps to Prevent Lead Exposure

WHO has listed lead as one of the most 10 hazardous elements presents in the environment. Through its website, WHO has made a variety of lead information accessible, including resources for advocacy, technical advice, and information for policy makers. In order to provide policymakers, public health authorities, and health professionals with evidence-based guidance on the steps they can take to protect the health of young and adult individuals from lead exposure, WHO has developed guidelines on clinical management of lead exposure and is currently preparing guidelines on prevention of lead exposure. The Centres for Disease Control and Prevention (CDC) has a long-standing obligation to safeguard children against lead poisoning, with the elimination of lead exposure among young children as its main objective. The CDC has assisted regional health agencies in creating lead poisoning prevention initiatives since the early 1970s. Public health organizations have long depended on blood lead screening tests to detect exposed individuals because lead exposure does not manifest evident symptoms until after serious harm has already been done. An integrated programme to identify and limit sources of exposure and offer case management for kids with elevated blood lead levels must include blood lead screening for primary or secondary prevention (Ettinger et al. 2019). The Global Alliance to Eliminate Lead Paint was established by WHO and the United Nations Environment Programme due to the ongoing exposure risk posed by leaded paint in many nations.

Humanity has long been aware of lead poisoning, which first came to light in the eighteenth century during the industrial revolutions. Lead has no known biological role in the body, so when it gets inside of you, you risk major health problems that could have a deadly outcome.

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