Journal Home Page:
https://e-journal.unair.ac.id/JKL

Jurnal Kesehatan Lingkungan
Journal of Environmental Health
Vol. 16 No. 3
DOI: 10.20473/jkl.v16i3.2024.277-288
ISSN: 1829 - 7285 | E-ISSN: 2040 - 881X

LITERATURE REVIEW Open Access

POTENTIAL IMPACTS OF LEAD ON HEALTH: A REVIEW OF ENVIRONMENTAL EXPOSURE, POPULATION AT RISK, AND TOXIC EFFECTS

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Article Info
Submitted : 11 March 2024
In reviewed : 14 May 2024
Accepted : 5 July 2024
Available Online : 31 July 2024

Keywords : *Environment, Exposure, Health effect, Lead*

Published by *Faculty of Public Health Universitas Airlangga*

Abstract

Introduction: *Lead, a heavy metal, has been proven to influence the ecosystem negatively. The use of lead in processing or as raw materials increases Pb exposure to humans from various sources, including waste or consumed products. This study aims to determine the most recent information regarding lead contamination sourced from the environment, at-risk populations, and the health impacts of this heavy metal contamination.* ***Results and Discussion:*** *This systematic review used a database sourced from Google Scholar. The keywords searched were "lead exposure, environment, or health" in articles published in 2020-2023. After article screening and exclusion, 26 research articles were eventually reviewed. Lead was detected in water, air, and soil, generally in various foods or products consumed by humans. Environmental factors were the most frequent source of contamination. The population at risk of lead exposure were children. Several studies have found that various health impacts were significantly associated with lead exposure from different environmental sources and lead concentrations in biomarkers.* ***Conclusion:*** *Pb contamination was increasingly widespread in the environment through various sources. Exposure to lead may cause diverse health problems.*

INTRODUCTION

Lead is a heavy, grayish-blue metal, soft, and malleable. The density of this metal is heavier than water at a melting point of 327°C and a boiling point of 1,725°C (1-2). The use of lead has been recorded to cause extended contamination of the environment, exposure to humans, and health problems in diverse communities (3). Lead poisoning is estimated to occur in around 800 million children worldwide. In Indonesia, the data estimated that >8 million children had blood lead levels (BLL) more than 5 µg/dL (4). This metal has the worst effect as a toxic substance for human health and is known for its extensive distribution in the environment (2).

Previous studies on lead have been conducted over the years. Lead is exposed through the lungs (inhalation) and the digestive system. Lead will be absorbed, bound to red blood cells, and distributed to the main compartments, bones and soft tissues, liver, kidneys, bone marrow, and brain (5). Lead transfer from blood to soft tissues takes approximately 4-6 weeks, and it is mostly absorbed in the kidneys and liver (6). Compared to soft tissue, bone is more stable in lead storage, the half-life is 20 to 30 years (5-6).

To expand the knowledge on recent studies, this study aims to collect the latest information on the sources of lead contamination from the environment, populations at risk, and health impacts due to lead pollution from published research articles. Each previous study focuses on one or two lead-related topics, such as environmental lead exposure against lead contamination in biomarkers, the association of lead exposure to health disorders in

Cite this as :
Simatupang MM, Veronika E, Irfandi A, Azteria V. Potential Impacts of Lead on Health: A Review of Environmental Exposure, Population at Risk, and Toxic Effects. *Jurnal Kesehatan Lingkungan*. 2024;16(3):277-288. https://doi.org/10.20473/jkl.v16i3.2024.277-288

certain groups, or factors influencing lead concentrations. Previous research rarely integrates all these topics. The current research comprehensively reviewed previous literature on the contamination sources and factors of exposure among populations vulnerable to lead exposure, as well as the health impacts and determinants.

DISCUSSION

This systematic review collected, identified, evaluated, and interpreted literature on environmental exposure to lead, the population at risk, and toxic effects. The articles were gathered from Google Scholar and selected if their titles had the exact phrase "lead exposure" and at least the "environment" or "health" keyword. The selected articles were published from 2020 to 2023. Eighty articles were compiled with the specified keywords according to the publication period. After the screening, 40 articles were eliminated because they were not free to access, not written in English, not available with duplicates, or not having significant results. The articles for review were selected based on some criteria (Figure 1). They were focused on health impacts and environmental exposures, while articles without full texts were excluded. By these criteria, the number of articles reviewed in this research was 26 articles. The review results are described in Table 1. Further, Table 2 explains the summary of the literature review.

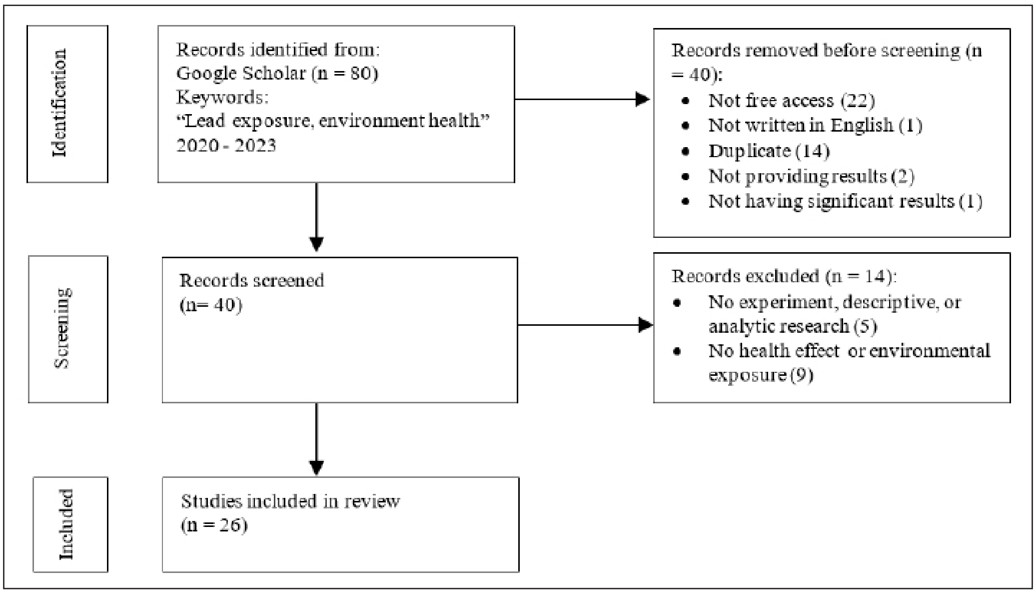

Figure 1. Literature Search and Selection Process

Table 1. Literature Review Results

Article	Methods and Population	Outcomes and Conclusion
Human Health Risk Assessment of Lead, Cadmium, and Mercury Co-Exposure from Agricultural Soils in the Tuzla Canton (Bosnia and Herzegovina) (7)	Lead level measurement, human health risk assessment Population: community and the environment in agricultural areas around industry	1. Lead concentrations were found in agricultural soil in industrial areas. 2. Children had the highest hazard index. 3. The highest hazard index of the exposure route was ingestion.
Impact of Cadmium and Lead Exposure on Camel Testicular Function: Environmental Contamination and Reproductive Health (18)	Lead level measurement in the environment	1. Soil and air in industrial areas contained high lead level. 2. Lead accumulation in the organs and tissues of camels that graze in industrial areas, and negative impacts on reproductive ability were found.
A Systematic Review of the Health Effects of Lead Exposure From Electronic Waste in Children (17)	Lead level measurement Population: communities around the electronic waste recycling area	Exposure to Pb from electronic waste affected blood lead level and children's health, such as decreasing serum cortisol levels, inhibiting hemoglobin synthesis, impacting neurobehavioral development, affecting physical development.
Evaluation of Occupational Lead Exposure in Informal Work Environment in Kenya (9)	Lead level measurement Population: welding and painting workers	1. Pb levels in the air were significantly higher in welding and painting area. 2. Long working duration increased workers' exposure to Pb.
One Map: Using Geospatial Analysis to Understand Lead Exposure across Humans, Animals, and the Environment in an Urban US City (22)	Geospatial analysis	Due to lead exposure, children under 5 years old lost IQ points, while adults' mortality were affected due to cardiovascular disease.
Health Exposure and Ecological Risk Assessment of Cadmium and Lead in Agricultural Soil in Uasin Gishu, Kenya (15)	Sample analysis	Lead concentrations were found in agricultural soil, because of excessive use of fertilizers and pesticides.

Article	Methods and Population	Outcomes and Conclusion
The Association between Mercury and Lead Exposure and Liver and Kidney Function in Pregnant Surinamese Women Enrolled in the Caribbean Consortium for Research in Environmental and Occupational Health (CCREOH) Environmental Epidemiologic Cohort Study (74)	Lead level measurement Population: pregnant woman	The site of a settlement affected blood lead levels.
Spatial Modelling for Health and Exposure Data-Child stunting and Blood Lead in Kabwe, Zambia (14)	Lead level measurement (secondary data) Population: communities around the mining site	1. Distance from the mine site and wind direction affected blood lead levels. 2. Due to hand-to-mouth activity tendency, children increased oral absorption of lead, made them more susceptible.
Lead Exposure of Four Biologically Important Common Branded and Non-branded Spices: Relative Analysis and Health Implication (25)	Sample analysis	Concentrations of lead were found in spice which are turmeric, coriander, red chilies, and cumin powder.
Calculating the Potential Risks of Environmental and Communities Health due to Lead Contaminants Exposure a Systematic Review (11)	Sample analysis Population: sample analysis	Lead which was found in vegetables and fish could enter human body through digestion from consumption of vegetables and fish.
Exposure of the Residents around the Three Gorges Reservoir, China to Chromium, Lead and Arsenic and their Health Risk via Food Consumption (23)	Sample analysis	1. Lead was contained in sweet potatoes and fish. 2. Smoking habits were positively correlated with the amounts of fish consumed.
Human Health Risk Assessment from Lead Exposure through Consumption of Raw Cow Milk from Free Range Cattle Reared in the Vicinity of a Lead–Zinc Mine in Kabwe (16)	Sample analysis	1. Milk cow around the mining sites contained lead. 2. Contamination distribution patterns were associated to direction of wind and pollution resources distance.
Human Health Risk Assessment of Exposure to Cadmium, Lead and Chromium through Consumption of Well and Bottled Water in Lusaka District, Zambia (24)	Sample analysis	1. Lead concentrations were found in well water and bottled drinking water. 2. The lead hazard index of well water and bottled water showed negative impacts on human health.
Lead Exposure through Eggs in Iran: Health Risk Assessment (13)	Sample analysis	Lead concentrations were found in eggs on farms near industrial areas.
Trace Metal Lead Exposure in Typical Lip Cosmetics from Electronic Commercial Platform: Investigation, Health Risk Assessment and Blood Lead Level Analysis (26)	Sample analysis	Pb substances were found in about 58,82% of lip treatment products (0 – 0.5237 mg/kg).
Occupational Lead Exposure Health Risk Assessment and Heme Biosynthesis: A Study on Batik Artisans in Yogyakarta, Indonesia (8)	Measurement Population: batik workers	Lead inhalation levels were lower in batik workers who worked outdoors.
Oral and General Health Effects of Prolonged Exposure of Three Siblings to Occupational Hazards Associated with Domestic Lead-acid Battery Manufacturing - A Case Report (20)	Case report Population: Children living close to industrial battery workshops	Oral health impacts were found in child respondents who were exposed to sulfuric acid fumes produced by lead-acid battery manufacture.
Adverse Health Effects of Lead Exposure on Physical Growth, Erythrocyte Parameters and School Performances for School-Aged Children in Eastern China (57)	Data collection and sample analysis Population: a public primary school student	1. Having passive smoker in the house environment was associated with blood lead levels. 2. Exposure to lead could adverse health effects such as decreased erythrocytes, BMI, and school performance in children.
Occupational Health Hazards on Workers Exposure to Lead (Pb): A Genotoxicity Analysis (56)	Data collection and lead level measurement Population: workers exposed to inorganic Pb environment	1. Smokers exposed to Pb significantly increased the blood lead level. 2. Lead exposure increased genotoxic potential due to accumulation of Pb over many years.
Potential Health Risks of Lead Exposure from Early Life through Later Life: Implications for Public Health Education (58)	Literature study	1. Calcium and iron intake can reduce lead absorption in children, while fat increases its absorption. 2. Lead could cause brain disorders, decrease in IQ, learning abilities, focus and behavioral problems among children
Lead and Mercury Exposure and Related Health Problems in Metal Artisan Workplaces and High-Risk Household Contacts in Thimphu, Bhutan (19)	A cross-sectional study Population: metal artisan employees and their household contacts	Blood lead levels increased in metalworkers and their household contacts.
Related Health Hazards with Occupational Exposure to cadmium and Lead during Spray Painting in Car and Furniture Workshops (21)	Lead level measurement Population: car and furniture spray painting workers	Increased serum lead levels caused significant decrease in hemoglobin, red blood cell, and thrombocyte, significant increase in leukocyte, and urine lead concentration in car and furniture painting workers.
Global Health Burden and Cost of Lead Exposure in Children and Adults: A Health Impact and Economic Modelling Analysis (64)	Modelling study Population: children <5 years, people aged 25 years or older	Due to lead exposure, children under 5 years old lost IQ points, while adults' mortality was affected due to cardiovascular disease.
Developing a Health Impact Model for Adult Lead Exposure and Cardiovascular Disease Mortality (67)	Literature review	The decrease in cardiovascular case may be caused by a decrease in lead blood levels.
Association of Low-Level Lead Exposure with All-Cause and Cardiovascular Disease Mortality in US Adults with Hypertension: Evidence from the National Health and Nutrition Examination Survey 2003–2010 (68)	Cohort study Population: adults with hypertension	1. Blood lead levels showed linear dose-response relationship with cardiovascular disease-related mortality 2. Escalated blood lead levels were associated with increased cardiovascular mortality in adults with hypertension.

Article	Methods and Population	Outcomes and Conclusion
Exposure to Common-Use Pesticides, Manganese, Lead, and Thyroid Function among Pregnant Women from the Infants' Environmental Health (ISA) study, Costa Rica (63)	Lead level measurement, thyroid hormones sampling and analysis Population: >15 years aged woman with a gestational age of <33 weeks	Lead exposure stimulated thyroid function in pregnant women affected fetal development and early child development.

Table 2. The Articles' Result Summary

	Frequency	Conclusion
Contamination source in the environment	11/26 (42.3%)	Pb contamination was found in soil, air, water, food (spices, vegetables, fish, sweet potato, milk, egg) drinking water, and lip treatment
Factors influencing exposure	12/26 (46.2%)	Contamination source, exposure distance, wind, jobs, exposure route, closed room
Population at risk	8/26 (30.8%)	Children
Health effect	17/26 (65.4%)	High blood lead level, decreasing serum cortisol levels, inhibiting hemoglobin synthesis, impacting neurobehavioral development, affecting physical development, cardiovascular disease, oral health problems, decreased erythrocytes, and BMI
Influenced factor of health impact	5/26 (19.2%)	Smoking habit, nutrition, exposure duration

Lead Exposure and Its Route in the Environment

The highest hazard index of exposure comes from ingested lead, followed by skin contact, and the lowest index draws from inhalation (7). Contamination in closed rooms and the duration of exposure have also been found to increase levels of lead exposure (8-9). Lead in the environment can cause this pollutant to be swallowed or inhaled. Lead is primarily transmitted through the inhalation. Lead can spread due to the possibility of dispersal in the atmosphere (10). The inhalation route exposure drives lead to enter the lungs. Lead in the body will be distributed through blood, and thus it induces long-term health impacts (11).

Lead is released into the atmosphere through industrial processes and vehicle exhaust. The contaminant spreads over the soil and water. Lead exposure to humans can also occur through food intake or drinking water. Lead poisoning can also occur due to swallowing polluted soil, dust, or lead-based paint by accident (1,12).

The environmental and health problems caused by lead exposure occurred in industrial areas, electronic waste recycling areas, agricultural areas, mining, painting, welding, and batik artisan working environments (7–9,13–18). Therefore, people working in welding, painting, batik, and metal industry, along with their members in the same house and the society, whose houses are close to battery factories are also at risk of lead exposure (9,19–21).

Lead may spread through soil, air, water, and even food such as spice powder, vegetables, fish, sweet potatoes, milk, and eggs (7–9,11,13,15,16,18,22–25). Lead is also detected in lip cosmetics, such as lip balm, lipstick, and lip gloss (26).

Human activities that expose the environment to lead are mining, smelting, refining, recycling of lead, water pipes and soldering, gasoline and fuel pumping for aviation, lead-acid batteries, paint, glaze, and glass in some traditional medicines and cosmetics, jewelry, ceramics, electrical and electronic goods, informal and cottage industries, as well as recycling operations (10). Distance to pollution sources (roads, gas stations, and mining sites), wind direction, and excessive use of fertilizers and pesticides in agricultural areas are some factors that influence lead contamination (14–16,22).

Hazardous materials in mining areas can pollute the environment through mining waste or stockpiles, and mining activities contaminate surface water and groundwater (27). Mining waste storage is frequently difficult to control as it contaminates mine drainage (28). In addition, rice fields with irrigation sources from polluted rivers are potentially contaminated. Solid waste of tailings from the amalgamation process increased the levels of heavy metals in the soil. However, the spatial distribution of Pb was found to decrease in areas far from the mining site (27).

Lead-acid battery production uses approximately 85% lead worldwide. This battery is used for various needs such as transportation, electricity supply, telecommunications, and other energy sources. The increasing number of motorized vehicles worldwide has also resulted in the rapid growth of lead-acid batteries. It is estimated that the number of cars, trucks, and buses is expected to reach around 2 billion by 2040. The number is even higher in warm and humid regions, and this condition requires a battery to be replaced every 2 years (29).

Lead content in lead-acid batteries can be reused through recovering and recycling. Many countries lack laws regarding monitoring and worker safety in the recycling process of lead-acid batteries. Law enforcement is necessary to prevent environmental contamination and secure occupational safety in the lead-acid recycling sector. Huge waste lead-acid batteries processed near community settlements will be unmanaged and hard to organize due to unregulated operations. With a lack of knowledge about safe recycling processes, they abandon personal protective equipment and technology to control lead emissions. They throw lead plates, lead-contaminated smoke, and particulates into the environment (29).

High blood lead levels (BLL) in Indonesia are caused by the short distance from housing to recycling sites. Observations on 128 children aged 1–5 years showed that most of these children had lead content in their blood at more than 10 µg/dL, and some experienced various health problems such as abnormal body mass index (BMI), underweight, stunting, anemia, and basophilic stippling. The lead level in these children's blood was approximately at 17.03 µg/dL (30).

Lead is used for various manufacturing purposes. Lead is added to paint to provide certain characteristics, such as pigment, and drying agent, and to prevent corrosion (6,10). In addition, lead compounds are added to paint to make the paint coverage well, protect the paint and the surface beneath from degradation due to exposure to sunlight, make the paint dry more quickly and evenly, and inhibit rust or corrosion of metal surfaces (31).

A study was conducted to measure the lead levels of 120 paints sold freely in 10 cities in Indonesia. The analysis results show that white color and one or more brightly colored paints such as yellow, red, orange, or green were selected from 66 different brands. The results found that 73% (88/120) of the paint was proven to contain lead, and 39% (47/120) contained lead at a concentration of >10,000 ppm, consisting of orange, yellow, green, and red. Information about lead content or the health impacts of lead is reported in some paints (32). Similarly, research in North Jakarta investigated 35 paint colors in 35 kindergartens. The study found that 80% of enamel paint in the kindergarten did not meet the requirements. The highest levels of lead content are indicated by yellow color (33). The Indonesian National Standard regarding organic solvent-based decorative paint sets the maximum concentration of lead content in the paint at 90 ppm. However, this maximum level is a voluntary standard (34).

Experimental studies on mice given two different treatments address how the skin is exposed to lead in the paint for 7 days and 14 days. The study found that the mice exposed longer to the paint had higher blood lead concentrations (35). Some communities in Indonesia work as street singers and often use silver paint throughout their bodies to attract attention. Twenty workers had blood lead levels ranging from 23.9–61.9 µg/dl, and the mean value was 37.3 µg/dl (36).

The United Nations Environment Program (UNEP) designed a strategic approach to international chemicals management (SAICM) to control chemical substances in the environment. Besides, the Lead Paint Laws program reinforced 21 countries passing lead paint laws and 18 countries drafting lead paint laws by 2022. Twenty-five paint manufacturers in seven countries have completed paint reformulation trials and can produce lead-free paint, and 104 countries have raised awareness by holding International Lead Poisoning Prevention Week (37).

Moreover, lead is used as an octane booster in gasoline because of its lubricating properties and ability to reduce the possibility of pre-ignition (38). Adding organic compounds of lead such as *Tetra Methyl Lead* (TML) and *Tetra Ethyl Lead* (TEL) can escalate octane numbers and increase the quality of the gasoline to make combustion. Gasoline with a low octane number can cause the engine to lose power, waste fuel consumption, and cause damage to the engine (39). Even though several innovations have replaced the lead content in gasoline, some research has found low lead levels in gasoline. The measurement results showed that the lead content in the premium oil at seven gas stations ranged from 0.131-0.258 mg/L, while the lead content in the Pertamax Turbo oil ranged from 0-0.1316 mg/L (40).

Lead content is detectable in food during the cooking and packaging processes or plant contamination from soil, water, or air. Cans and ceramics used to package or wrap food/drinks, or ink may contain lead, thus causing these pollutants to contaminate food/drinks (6,10). The use of lead in ceramics and cooking utensils aims to protect the utensils from corrosion and provide a shiny waterproof coating (29). The acidic nature of foods/drinks causes lead to be released and mixed into the food and beverage products (10).

Spices planted near lead-polluted areas can absorb dust particles and lead residues from smelting, battery manufacturing, and lead mining activities. Lead can also enter the food chain through contaminated soil and water from polluted air and fertilizer (29). Lead can contaminate spices during the cooking process (10). Grinding machines whose elements use lead can also contaminate cooking spices. Irresponsible manufacturers mix this heavy metal to increase its color and fraudulently add profits by adding weight (29).

Tobacco is a plant that can absorb lead from the environment, and thus smoking tobacco can increase lead intake (10). A study measured dust samples collected from vacuum cleaners in houses occupied by smokers and non-smokers. Tobacco smoke is a significant source of lead pollution in house dust. These indoor pollutants may last a long time after smoking. In an apartment with an area of 65 m^2, the total amount of Pb in settled house dust is around 2,000 μg (41).

With contaminated soil and sediment, Pb can mix with soil components, enter plant tissue, and enter the food chain (42). Pb pollution can also reduce soil nutrient content, microbial diversity, soil microbial activity, and soil fertility. One of the microbes affected by lead pollution is earthworms. Pb accumulation in the soil also inhibits the plant's absorption system from the soil (43).

Pesticides or fertilizers that contain lead can be absorbed by the roots and then stored in the leaves (6). Several studies have found lead content in several parts of the plants such as roots, shoots, fruits, stems, and leaves. Dicot plants accumulate lead in greater amounts in the roots than monocot plants. Some plants that contain lead are flowering plants, mango, cabbage, sunflower, basil, several types of ferns, *kirinyuh* (jack in the bush), horse grass, and rice (44).

The condition of an organism absorbs or secretes a substance rapidly, faster than the substance destroyed through the process of catabolism and excretion induced by bioaccumulation. Therefore, a long biological half-life may escalate chronic toxicity risk even though the pollutant in the environment is at a low level (2). Contaminated plants consumed by animals or humans may cause biomagnification in the food chain (44).

Phytoremediation is an effort to restore an environment polluted by heavy metals by using green plants to remove, reduce, or detoxify toxic metals (45). There are several mechanisms in the process of phytoremediation to decontaminating pollutants, which are phytoextraction (pollutants accumulate in leaves and stems), hemofiltration (adsorption process by roots), phytostabilization (the process of stabilizing pollutants in roots so they are not carried away by water flow), biodegradation (the decomposition of contaminants around the roots by microbial activity), phytodegradation (the decomposition of pollutants by plants with the help of enzymes), and phytovolatilization (the transpiration of pollutants in plants into the atmosphere) (45-46).

Different types of pesticides may be composed of lead. A study has found an influence of active pesticide compounds on farmers' blood lead levels. The respondents exposed to organophosphate pesticides had lead levels ranging from 2.5 to 6.6 μg/dL in their blood with a mean value of 4.36 μg/dL. Meanwhile, respondents exposed to pesticides with the active ingredient carbamate had blood lead levels ranging from 1.7 to 5.1 μg/dL (47).

Various physical and chemical variables specifically temperature, pH, time of biomass contact, and concentration must be calculated in the phytoremediation process (48). The effectiveness of phytoremediation depends on the type of heavy metal and plants used. Potential plants to reduce lead levels include *Helianthus annuus, Lathyrus sativus, Ludwigia peploides, Thlaspi caerulescens*, *Medicago sativa, Usnea amblyoclada plants*, and *Luzula campestris* (45). Plants used for phytoremediation must be non-invasive and native to decontaminated areas. Humans or animals should avoid certain parts of the plants that absorb the lead from the environment as they are dangerous. Pollutants from contaminated locations to uncontaminated areas must also be avoided (48).

Water pollution is triggered by a piping system that uses polyvinyl chloride (PVC) pipes as lead compounds can leach into water (10). Lead concentration can vary depending on water use, contact duration, temperature, and pH (10,29). Lead-contaminated water is caused by pipes, corrosion, or connected pipes. Lead pipe is preferred because it lasts longer than iron-based materials and is easily bent (29).

Drinking water contamination influences the blood lead level (6). The Hazard Index (HI) is calculated from the lead level in water to predict its impact on health. A study on well water or bottled water proved a negative impact of lead contamination on health for long-life water consumption (24). Cold tap water will be safe if the water flows for a few minutes (29).

Heavy metals can leach into drinking water from water pipes because of mining activities, petroleum refineries, electronics factories, municipal waste disposal, and cement factories, or because they are naturally contained in the soil. Heavy metals can contaminate wells through groundwater seepage and surface water runoff (49). Previous research examined 10 wells near agricultural areas, and it found that lead concentration in the well water ranged from 0.0074 - 0.0866 mg/L (50).

Lead content is also detected in coastal water in Indonesia. Ship activities such as sea transportation possibly become a source of pollution (51-52). Pb levels (1.225 μg/L) were found in damwater from a riverbank (53). Even though water analysis showed lead levels below the quality standard (51) value based on the Indonesian Government Regulation No. 22 of 2021, it is necessary to consider the bioaccumulation and biomagnification processes.

Furthermore, lead metal pollutants are possible to accumulate and distribute from one organism to another (biomagnification). Contaminated water and food supply, as well as permeable membranes such as muscles and gills may threaten aquatic organisms (2).

Ship repair companies around the coast and transportation routes of coal ships contribute to lead contamination in marine life. A study identified lead content in "rebon" shrimp (*Acetes sp*) and water at two locations. (54). Another study found shrimp paste samples positive for Pb (55).

Population at Risk

Several factors have been proven to influence high blood lead levels or lead levels in other biomarkers such as gender, age, smoking habits, and amounts of fish consumed (23,56-57). The most vulnerable group to the health impacts of lead exposure is children (7,14,20). Certain nutritional intake can also affect lead absorption in children. For example, calcium and iron can reduce the absorption, while high-fat food can increase this process (58).

Oral lead exposure among children is higher than other routes because they tend to put hands or other lead-contaminated objects in their mouths (14,59). The lowest lead exposure is harmful for infants, children (especially children under 5 years), and expectant mothers (59). Lead is absorbed 4–5 times more in children's bodies than adults besides expectant mothers because of a higher ratio between lead intake and weight. An underdeveloped child's brain mechanism will endanger the body to be exposed to toxic substances. Frequent exposure to lead induces miscarriage, stillbirth, premature birth, and low baby birth weight (10).

Compared to the body size, children also breathe more air than adults. Children generally absorb around 40-50% of the lead in food they consume, while adults only absorb around 10-15%. Released and excreted lead is also higher in adults than in children (5). Children whose activities expose them to the sources of pollutants have high health risks (60). The main lead exposure in children at active mining sites is household dust (61). Lead poisoning in children can be prevented by consuming three main meals and two snacks daily, keeping hands clean, and drinking uncontaminated water (62).

Lead can interfere with thyroid function, affecting fetal development and early child development (63). Lead exposure can also affect BMI, IQ development, and school performance (57,59,64-65). Children with low blood lead levels have truncated intelligence, ability to focus, and academic achievement. Brain and nervous system damage caused by lead reactions in the body results in adverse effects on the child's growth and development, learning ability, hearing, and speaking ability, and problems with behavior as well. This condition influences the decrease in child's IQ and difficulty concentrating, which causes poor performance at school (59,65).

Children with high lead levels are twice more likely to be underweight, 1.017 times more likely to develop anemia, and about twice more likely to suffer from basophilic spots (30). In addition to metal smelting, mining is a major source of lead pollution. Research conducted in lead mining areas found that the average blood lead level (BLL) of 193 children was 5.5 μg/dL. Measurement of anthropometry results showed that 23.3% of children were stunted. Lead levels in children aged two to nine years are associated with stunting (66). Children contaminated with lead may face decreasing ability to build social interaction and achieve their educational targets (10).

Health Effects

Pb exposure is proven by finding lead concentrations in blood, hair, and urine (19,21,23,56). Venous blood concentrations are definitive biomarkers of lead exposure and clinical diagnosis. Pb is distributed to various organs, such as the brain, liver, kidneys, and bones besides teeth and bones. Lead level in bone is the proof of cumulative long exposure which does not represent the current exposure (10).

High blood lead levels can substitute essential ions such as calcium, magnesium, iron, and sodium in the body, disrupting the biological metabolism of cells. The metabolism disruption can cause brain disorders, IQ decrease, learning abilities, focus difficulty, and behavioral problems (8). Additionally, Pb inhibits enzymes from carrying out their normal activities. Lead even interferes with the normal DNA transcription process and causes bone defects (60).

Lead has been proven to be associated with various health problems. Several health problems include chronic kidney disease, cardiovascular disease, decreased hemoglobin, red blood cells, and thrombocytes, increased leukocytes, inhibited neurobehavioral development and physical development, genotoxic potential, and oral health problems (17,20-21,23,56,63-64,67-68). Lead tends to accumulate in various organs and tissues, causing adverse impacts on the reproductive system (18).

Lead inhibits the synthesis of enzymes that play a role in red blood cell production and disrupts the cell's antioxidant defense system, thereby increasing free radicals, reducing endogenous antioxidant reserves, disrupting enzyme activation, and inhibiting mineral absorption (12). Pb's impact on the development of children's nervous system is the most dangerous toxicity effect of this heavy metal. Adverse impact on intellectual quotient (IQ) is observable from the blood lead level at <3.5 μg/dL and gradually escalates with the increase of blood lead levels (10). Treatment intervention is recommended only if blood lead levels are ≥5 μg/dL (69).

No organ or tissue is not affected by lead content (12,60). Lead toxicity depends on absorbed dose, exposure route, and exposure duration. Lead may accumulate in the environment and endanger humans (12).

Chelation therapy can be used to treat metal toxicity (70). Blood lead levels can be reduced with this treatment (71). This therapy is a medical procedure involving compounds that can detoxify heavy metals from the body through infusion or intravenous injection. Chelating agents will help the body remove harmful chemicals that accumulate in tissues and organs, thereby reducing the risk of adverse health effects. Chelation agents can be dimercaprol, penicillamine, sodium calcium edetate, and succimer (72).

The number of chelation treatments and the kind of medicine depend on the blood lead levels and the child's response to the medicine. Some children may consume only pills, but others need injections. The chelation medicines have side effects (73). Nausea, vomiting, increased blood pressure, and various other side effects depend on the type of therapy. It is important to take all doses of the medicine (62). If the treatment is not completed, lead levels may stay high (73).

Chelation therapy can be performed on children with high lead levels. Identification of lead exposure must be carried out in the most vulnerable groups, including children, at a lead level of ≥5 μg/dL. If the lead level is higher (≥45 μg/dL), chelation therapy is given immediately to a poisoned child after lead exposure stops. If the level is below this concentration, re-evaluation should be taken after 2-4 weeks to re-monitor her/his blood lead levels. However, if the blood lead level is ≥70 μg/dL, changes in clinical symptoms should be closely observed, such as routine neurological examinations during and after chelation therapy (62). If the child demonstrates neurological symptoms related to lead intoxication (encephalopathy), then she/he should be given chelation therapy immediately and monitored in the High Care Unit (HCU). If symptoms of severe toxicity persist, therapy is continued until there is clinical recovery. If symptoms of encephalopathy do not exist, no monitoring in the HCU will be required. After the therapy is given, blood lead levels should be re-evaluated. If the blood lead levels are still ≥70 μg/dL, chelation therapy can be considered again. Re-evaluation can be held after 2-4 weeks with lead blood levels at >30 μg/dL and 1-3 months at 5-29 μg/dL. If the child has received therapy several times without improvement, her/his guardian should ask for an expert opinion. If blood lead levels rise again above normal limits, other sources of lead exposure must be investigated (62).

ACKNOWLEDGMENTS

The authors would like to thank all the researchers or institutions for providing sources and references in this manuscript.

CONCLUSION

Humans are exposed to lead not only in soil, air, and water but also the food and cosmetic ingredients. The current research findings indicate an increasingly widespread distribution of Pb in the environment. Lead accumulating, especially in water and soil, causes bioaccumulation and biomagnification in the food chain and induces exposure through digestion and respiration. Lead contamination must be prevented especially in children although they are the most vulnerable group to be exposed to lead due to their special profile. Nervous system damage caused by lead contamination has been found to affect children's growth, learning abilities, behavioral problems, and performance at school. Previously, lead has been known to cause anemia because of its effect on red blood cell production. Meanwhile, the current research reveals more results where lead decreases hemoglobin, red blood cells, and platelets, but increases leukocytes. Lead also affects body mass index and increases leukocytes. Other body organs such as the kidneys, heart, and reproductive system might experience the negative impacts of lead contamination.

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