Lead-A Silent Killer,So Faster Detection and Remediation is Essential

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Abstract: Heavy metals are a menace to the human world. Though in controlled amount these heavy metals do have some importance in human metabolic activity but if they cross permissible level they become a danger to the human race. Leadamong heavy metals poses more danger because of it's varied sources and often with long exposure with a minimal amount lead causes severe damage. Most of the detection methods of lead are costly, not easily available for common people, sooften lead gets undetected hence becomes a bigger danger.Once detected it's remediation is also important. Physical and chemical methods of remediation is again costly and not environment friendly ,bioremediation is environment friendly but this method too has it's short comings often cannot be used to remove larger percentage of lead and in human body this has not been tried out as yet as a therapeutic technique.

Key Words: Essential metals, toxicity of heavy metals, toxicity of lead ,sources of lead, symptoms of lead poisoning, detection methods of lead ,bioremediation of lead, permissible limit of lead, ways by which lead enters human body.

Introduction:

There are certain essential and non essential heavy metals.Essential heavy metals are Molybdenum , Manganese, Copper, Nickel, Iron And Zinc[1].They are helpful to the living organisms when present within certain amount of their limited concentration. Even there also TLV Threshold Limits for all.

Table 1

Essential Metals with Their Uses,Permissible Limit,Toxicity To Humans When Taken Excess

METALS	Permissible Amount.	USES	Danger Posed to human body if not taken in correct amount	Danger posed to humans when taken in excess	Source from where excess can enter into body causing toxicity
MOLYBDENUM	0.13 mg/kg.[2]	Cofactor of many enzymes,like sulfite oxidase SOX which helps in diagnosis of hepatocellular carcinoma.[2]	MoCo deficiency which will lead to improper functioning of the enzymes like SOX,XO[2] so on.	Might cause infertility, Damage to interstitial cells	Significant Fission product.[3] Lubricant Additive, And in Ceramics.
MANGANESE	2 mg/day for adults[4]	Formation of enzymes[5]	Epilepsy, Down's syndrome[4]	Alzheimer type II[4] Parkinson's disease	mining ores , crustal rocks.[4]
COPPER	900 mcg/day[6] for adults.	Haemoglobin formation ,carbohydrate metabolism[1]	Anemia and neutropenia[6]	Abdominal disorders, Metabolic abnormalities[5]	Copper polishing Plating Printing[5]
NICKEL	unknown	Cell growth[5]	In plants it causes leaf Chlorosis, stunted growth.	allergy, cardiovascular and kidney diseases, lung fibrosis, lung and nasal cancer due to	inexpensive jewelry, keys, paper clips, clothing

				nickel sulphide.[7]	fasteners so on.[7]
IRON	1.14mg/day for adult men.2.38 mg/day for menstruating female, post menopausal women 0.98mg/day[8]	Formation of haemoglobin[9],helps in DNA replication, even controls immunity	Anemia	Vomiting Diarrhea Abdominal pain Dehydration & lethargy[5]	High intake of iron supplements & oral consumption[5]
ZINC	9.5mg/day men , 7mg/day women[10]	Controls intra and intercellular activity ,helps even in repairing DNA ,thus helping in maintaining physiological ,processes.[11]zinc helps in iron uptake by the body also[9]	Cancer, diabetes, depression, Wilson's disease, Alzheimer's disease, and other age-related diseases.	Gastrointestinal disorders, Kidney & Liver abnormal functioning[5]	Oil Refining Plumbing Brass manufacturing[5]

So one sees that these essential micronutrients once they enter the body in excess they are toxic but as such they are essential for proper wellbeing of the body.

The nonessential heavy metals are added to the environment by human being and pose a danger when they cross the permissible limit.

Table 2

Toxic Heavy Metals their Effect on the Body and Sources

Toxic heavy metals	Effect on human body	Source
LEAD	1)Infertility in both male and female[12] 2)Neurocognitive disorder[13–15] 3)Nephrotoxicity[16] 4)Carcinogenecity[16] 5)Cardiovascular toxicity[16] 6)respiratory problem[14] 7)abdominal complications[17]	1)Paints[18], 2)dilapidated buildings[19], 3)leaded petrol[18], 4)cosmetics[20], 5)spices specially as lead chromate in turmeric[21], 6)unused batteries[14], 7)water pipes[18], 8)certain herbal medicine[22,23], 9)hidaliumaluminium cookware[24] 10)Ceramics[25]
CADMIUM	Itai-itai disease[16] Hepatotoxicity[16]	Industry[16]
MERCURY	Minamata[16] Skin toxicity[16]	Methyl mercury[16]
CHROMIUM	Carcinogenicity[16] Hepatotoxicity[16] Skin toxicity[16]	Industry[16]

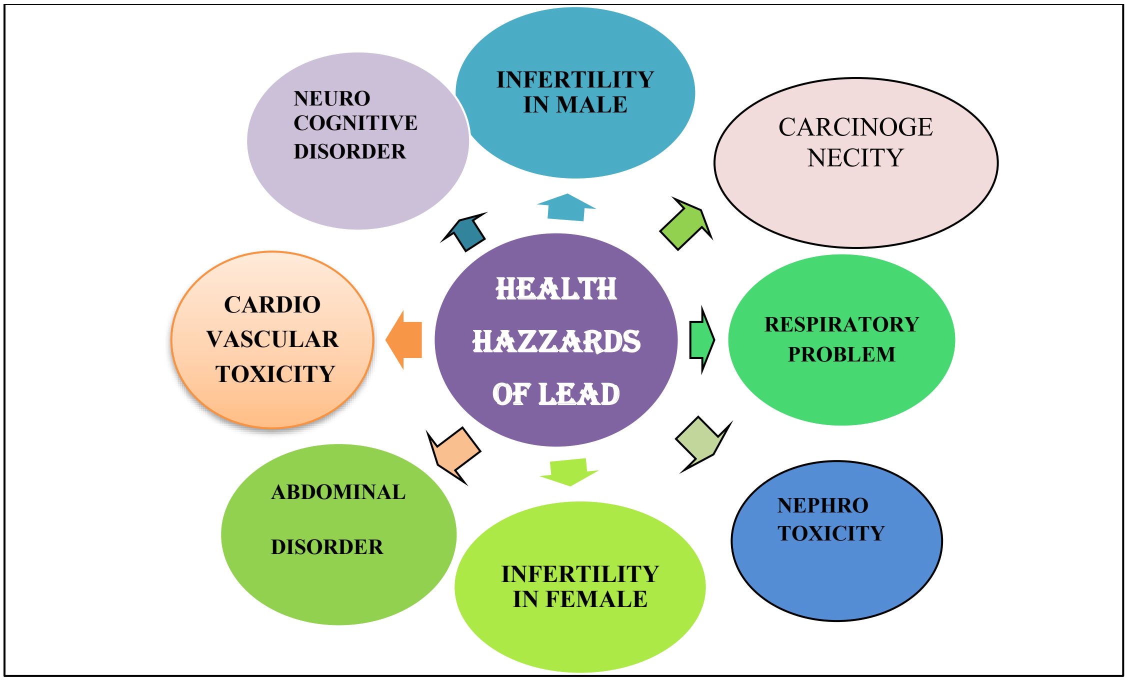


Fig 1Health Hazzardsof Lead

Table 3:

Permissible Limits of Lead

Medium	**Standard**	**Limit**
Drinking Water	WHO / BIS IS 10500	**0.01 mg/L**
Ambient Air	CPCB (India)	**0.5 µg/m³ (annual)**
Milk & Food Products	FSSAI / Codex	Varies by food (e.g., 0.02 mg/kg in infant formula)

Table 4:

International Standards

Standard Body	**Standard Title/Code**	**Application**
WHO Guidelines	*Guidelines for Drinking-Water Quality (4th Ed)*	Sets acceptable lead limits (0.01 mg/L in water)
ISO 17294-2:2016	Water Quality – Application of ICP-MS	Lead in drinking and wastewater
AOAC Official Methods	AOAC 999.11, 986.15, etc.	Lead in foods (ICP/AAS methods)

Standard Body	Standard Title/Code	Application
USEPA 200.9 / 6020B / 3050B	EPA methods for lead in water, solid waste	U.S. regulatory testing (AAS, ICP-MS)
Codex Alimentarius	*Codex General Standard for Contaminants in Food (CXS 193-1995)*	Maximum limits for Pb in different foods

Sources of Lead in India

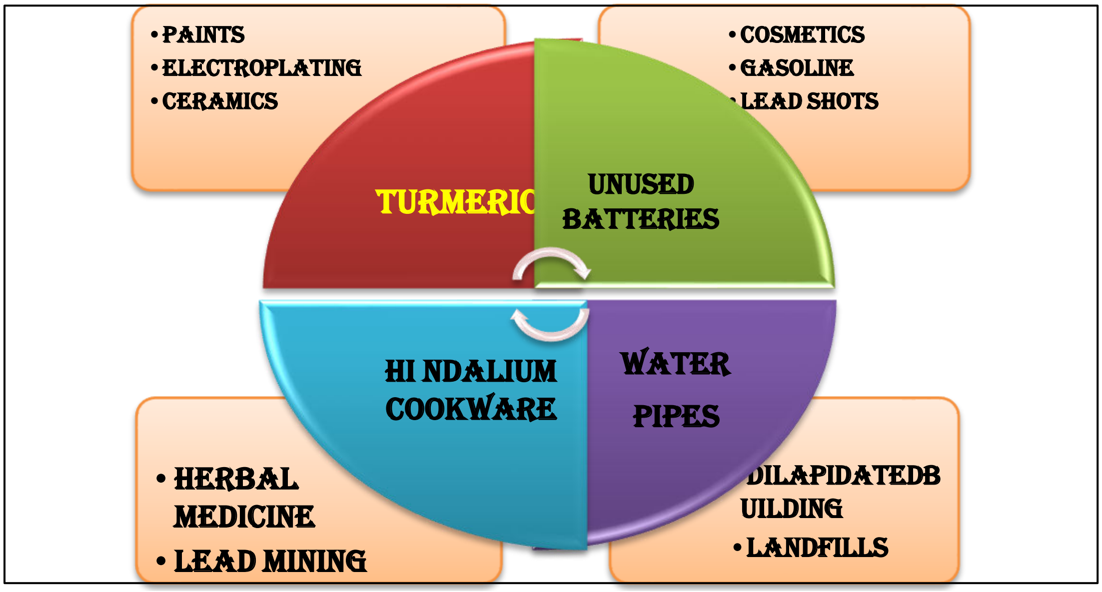
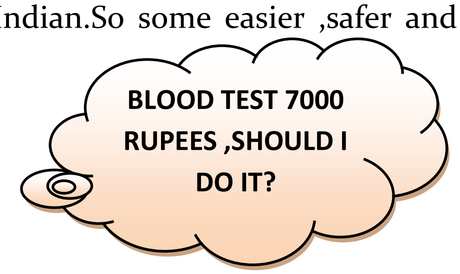


Fig 2:Sources of Lead as Prevalent in India[22,25]

Looking into the above table one can see that lead a non essential heavy metal has entered the environment through anthropogenic activities as lead was one of the very few metals which were used by human for it's easy availability and easy extraction method[17].In 20th century leaded petrol (lead present in the form of tetra ethyl lead)was contributing the maximum percentage of lead in the environment.In India policies were adopted as early as 2000[26]to stop the sell of leaded petrol.Yeteven after 10 years when blood lead level of many Indians were tested,higher percentage of lead was found in the bloodof many Indians specially those staying near lead smelting sites[20].Other sources remained as before like spices,cosmetics,herbal medicines mainly the ones which were marketed[23].

These blood tests costed around rupees 7000 in India ,which is not easily affordable by every Indian.So some easier ,safer and cheaper method of detection was essential.



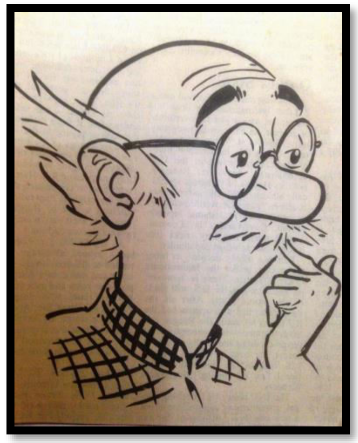


Fig3:Can every Indian afford to do blood test for lead?

Since these blood tests are costly so people should be aware of certain symptoms of lead poisoning so that if they see these symptoms[22,25,27] or experience them they start taking proper measures themselves.

Symptoms of Lead Poisoning:

1
- **Clonic seizure lasting for 5-10mins followed by postictal drowsiness.**
- **Frequent vomitting with intermittent irritability**
- **Diarrhea**

2
- **Behavioural Changes**
- **Low IQ in children**
- **Slow learning**

3
- **Skin allergy**
- **Anemia**
- **Kidney malfunction**
- **Low bone density**

Fig 4:Symptoms of lead poisoning

Since one can see that lead causes such a lot of human body disfunctioning so one should also know how does lead enter human body.So that if these symptoms occur those sources can be checked and tested.

Methods by which lead enters human body

1. Dermal contact[25]
2. Drinking water[28]
3. Easy absorbtion of inorganic lead in the body[29]
4. Key exposure factors for adults include smoking, alcohol consumption, dietary habits involving bread-based and homegrown livestock products, and the year of housing construction.[30]
5. farm-to-fork pathways as major environmental routes for human exposure to lead.[31]
6. contamination in food[31]
7. Inhalation[1]
8. radionuclides enter the environment through wastewater[32]
9. Traditional medications[33,34]
10. occupational exposure[33]
11. substance abuse[33]

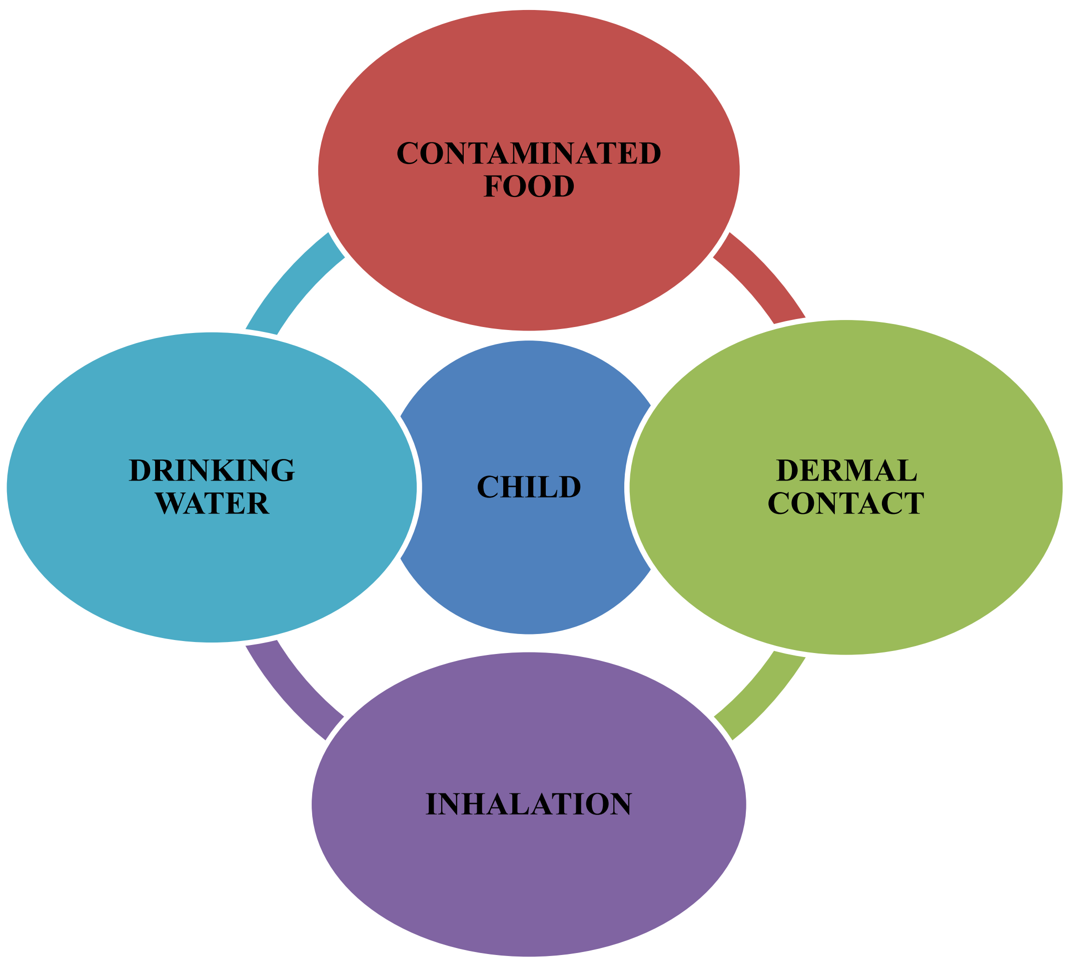


Fig5:Ways by which humans especially children get exposed to lead

Mechanism of Lead Absorbtionby Human Body Once absorbed, water-soluble heavy metals pass through the intestines into the circulatory system, where they are transported to various organs.Lead has a more easier way to enter human body's metabolic activities as lead can mimic[25]Calcium.So where ever calcium ions are required in cellular activity lead substitutes it and causes toxicity IF IT IS PRESENT BEYOND THE PERMISSIBLE LIMIT OF 5µg/dL .So even at low concentrations, these metals can damage the respiratory system and cellular structures[1], including endothelial and epithelial cells, leading to long-term health complications.. At BLLs below 30 micrograms per deciliter, adults may experience anemia and reproductive issues. Levels as low as 10 µg/dL can lead to hypertension, an increased risk of premature birth in pregnant women, and cognitive impairments in children, including reduced IQ scores and poor academic performance[22].

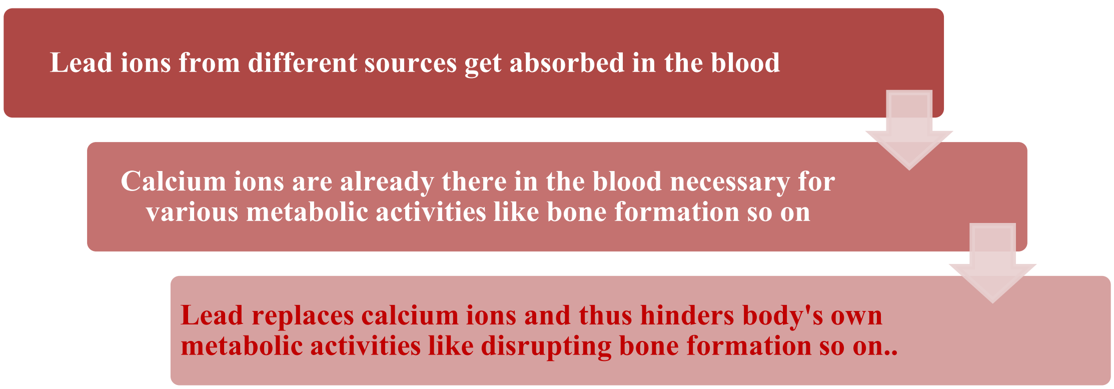


Fig6:Mechanism of lead absorbtion by human body

Methods of detection of lead.

Since lead is easily absorbed by the human body through a large number of ways and is such a menace to the human body so it's easy detection is essential.Mainly 3 ways of detection till now has been used; physical,chemical and biological methods are used.

1. Recent technological advancements in high-precision lead stable isotope ratio analysis using multi-collector induced coupled plasma mass spectrometry[18] (MC-ICP-MS) have provided new avenues for identifying and eliminating prevalent lead sources contributing to elevated BLLs.
2. Fluorescent nanosensors have gained recognition as an effective analytical tool due to their high sensitivity, selectivity, cost-effectiveness, and rapid on-site detection capabilities. Unlike conventional organic dyes such as cyanine, fluorescein, and rhodamine, which suffer from drawbacks like photobleaching, low absorption coefficients, and low stability, fluorescent nanosensors offer enhanced performance for lead detection.[35]

3. Fluorimetry and colorimetry techniques have emerged as preferred methods for detecting heavy metal ions in aqueous solutions, as they can be easily integrated into commercial microfluidic devices and dipstick assays.[35]
4. Unique properties of crown ethers[36], which possess a remarkable ability to selectively bind with specific ions. Studies demonstrate that integrating silicon photonics with crown ether amine conjugation, achieved through Fischer esterification in an environmentally friendly manner, enables real-time and cost-effective detection of lead ions (Pb^{2+}) in field samples.This new technique is effective in monitoring heavy metal contamination, thus controlling environmental pollution.
5. Noble metal nano clusters (NMNCs) have become important due to their superior biocompatibility, high catalytic activity, and exceptional photoluminescence properties, making them important material for optical sensors. These nano sensors are designed to detect food poisons efficiently by increasing NMNCs' unique properties.[37]

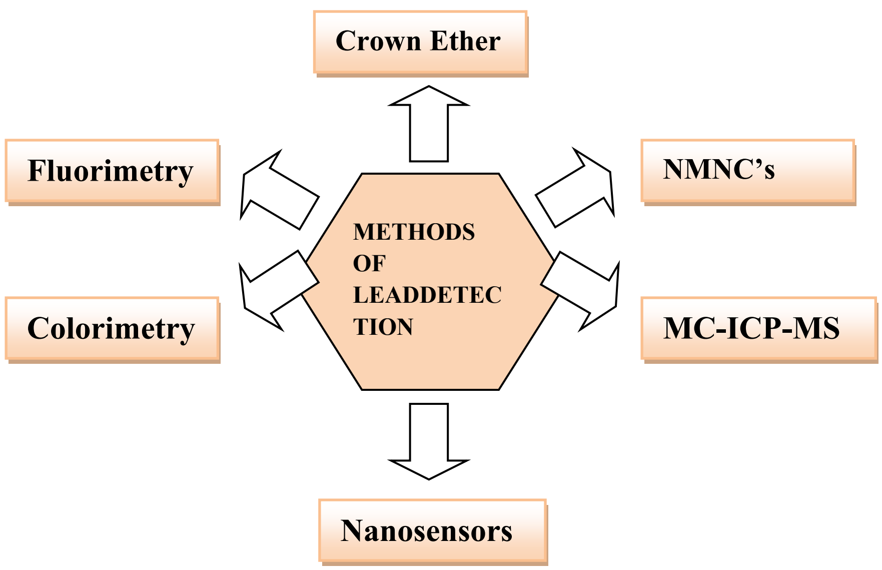


Fig 7:Methods of lead detection

Table 5:
Instruments for Lead (PB) Analysis

S.No	Instrument Name	Application Area	Notes
1	**Atomic Absorption Spectrophotometer (AAS)**	Water, Food, Soil	Widely used; flame or graphite furnace method
2	**Inductively Coupled Plasma Mass Spectrometry (ICP-MS)**	Water, Food, Air Particulates	Ultra-trace detection of lead (ppt level)
3	**Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)**	Water, Food	Multi-elemental analysis, ppm detection
4	**Graphite Furnace AAS (GFAAS)**	Food, Water	Sensitive; specific for trace Pb
5	**X-ray Fluorescence Spectrometry (XRF)**[38]	Soil, Food, Air Dust	Rapid, non-destructive; portable models available
6	**Anodic Stripping Voltammetry (ASV)**	Water	Electrochemical method for trace Pb
7	**UV-Visible Spectrophotometer (after complexation)**	Water	Colorimetric methods using dithizone etc.
8	**Portable Lead Analyzer (e.g., LeadCare II)**	Food, Blood	Used in field for fast screening
9	**Neutron Activation Analysis (NAA)**	Research, food	Highly sensitive; used in labs
10	**Mass Spectrometer with Laser Ablation (LA-ICP-MS)**	Solid food matrices	High-resolution spatial detection in solids

Before using the above instruments sample preparation often includes acid digestion (e.g., HNO_3-HCl mix), microwave digestion, or filtration before testing and **QA/QC** procedures must include use of certified reference materials, blank, and spike recovery and since **all this require sophisticated laboratory instruments detection of lead till now is not possible by common man.**

Methods of remediation

1. Physical approaches[39]include the translocation of contaminants, which is useful for localized areas but presents challenges in disposing of contaminated materials safely.
2. Vitrification, where soil is melted at high temperatures to trap lead in a solid mass, is a long-term but expensive solution.
3. Electrophoresis-based soil cleaning is waste-free but limited to saturated soil and groundwater.
4. Chemical methods reduce lead bioavailability and solubility, making them cost-effective for preventing lead absorption, though they do not provide a permanent solution.
5. Solidification involves fixing lead-contaminated waste into large solid structures with cement-based binders, offering an affordable and practical solution.
6. A way[40] to control heavy metal poisoning can be by chelation therapy.
7. Bioremediation techniques using microorganisms like *Pseudomonas*, *Nitrosomonas*, and *Mycobacterium* can neutralize lead toxicity. Certain bacterial strains, such as *Lactobacillus acidophilus* and *Oceanobacillusprofundus*, have demonstrated significant lead removal efficiencies of 73.9% and 97%, respectively[41].
8. Research work[42] has demonstrated that earthworm gut bacteria play a crucial role in biodegradation processes, further enhancing the potential for microbial remediation of heavy metal contamination.
9. Additionally,[41] various species of algae and fungi have shown promising potential in lead remediation. The biodegradation of lead through microbial activity presents a sustainable and cost-effective method for reducing heavy metal contamination, making it a valuable strategy for environmental restoration efforts.
10. Phytoremediation harnesses plants[39] to extract lead from polluted soil and water. Advancements in transgenic plants and microbial research are expected to enhance lead removal capabilities, making bioremediation more effective in the future.
11. Plants have [43]evolved various strategies to mitigate the toxic effects of heavy metals, such as restricting metal uptake to the cell wall, vascular sequestration, and synthesizing biochemical compounds like phyto-chelators and organic acids. These mechanisms bind free-moving metal ions, reducing their toxicity.

Understanding the genetic, molecular, and cell signaling pathways involved in heavy metal tolerance is crucial for developing strategies to enhance phytoremediation. This method relies on hyperaccumulator[44] plants to extract and degrade inorganic and organic pollutants, utilizing solar energy as the main source of energy. Further studies on model plant species can provide deeper insights into these mechanisms of phytoremediation[45], facilitating practical applications for heavy metal detoxification in contaminated environments.

12. Phytohormones[46] play a crucial role in increasing plant stress tolerance by activating signaling cascades and antioxidant defenses. Understanding these tolerance mechanisms in metal-resistant plants can help in developing strategies to prevent heavy metal accumulation in food crops, thereby reducing their entry into the human food chain and thus decreasing associated health risks.

13. As an in-situ phytorestoration approach, rhizoremediation[47]is cost-effective, environmentally sustainable, and easily applicable in field conditions. Additionally, seed inoculation with pollutant-degrading microbes can further enhance the success of this method. Identifying suitable plant species and microbial strains is crucial for maximizing the effectiveness of rhizoremediation in future environmental cleanup efforts.

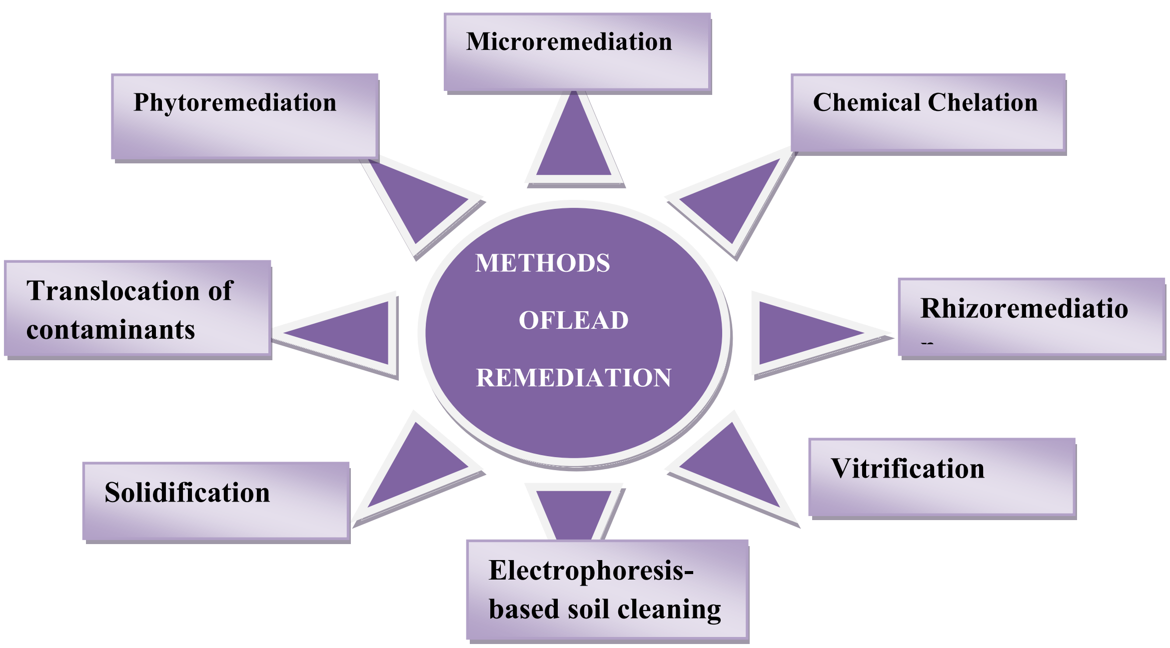


Fig 8:Methods of lead Remediation

Methodology

Web of Science, Google Scholar, Medline, PubMed, Scopus,and various data bases were searched from 1991 to 2025 to construct this review article.Further more articles with keywords like 'essential heavy metal' , ' non essential heavy metals', 'daily requirement of zinc', 'daily requirement of iron', 'daily requirement of copper', 'daily requirement of molybdenum', 'daily requirement of nickle', 'sources of lead toxicity', 'symptoms of lead toxicity', 'why lead absorbtion by human body is easy', 'method of lead detection', 'methods of lead remediation', 'polycies to curb leaded petrol' ,'health hazards of lead toxicity'.

Critical Analysis

1. Further research and development will help refine nanosensor technology, making lead detection more accessible and efficient for widespread environmental and public health applications.[35]
2. Work is required to make unique biosensors [48]which are stable and can be used to detect quiet a large number heavy metals at one time.
3. A study of the soil samples from Kanpur district revealed alarming levels of contamination, which required immediate attention and fast remediation. The findings made it evident that strategic interventions of the legislative body is essential and environmental agencies need to take steps to safeguard soil quality and protect public health.[49]
4. Future studies should focus on refining the synthesis of atomically precise NMNCs to enhance catalytic activity and optical performance. Also, adding NMNCs with micro fluidic devices, developing high throughput multimode sensing techniques, and enhancing storage and transportation conditions can further improve their uses in detecting adulterants in food[37].
5. Testing soil at different depths will also help to maintain ecological stability and bring an end to the potential risks associated with heavy metal contamination.[50]
6. Research studies has been conducted to study the various sources of lead exposure in India and this brought forward loop holes in the existing monitoring systems for regulating lead levels in paints[51]. The findings showed the need for improved oversight and stricter enforcement of lead regulations. The study suggests for the formulation of new legislative policies to enhance lead control measures, ensuring better protection of the public health.
7. Hindalium pans and brass cookware,[24] dissolved enough lead which can cause serious health risk to children. In contrast, stainless steel cookware was found to dissolve lower levels of lead, making it a better and safer option for cooking.

These findings make it important that strict regulations on cookware manufacturing is required and consumer awareness regarding lead exposure from kitchen utensils is essential.

8. Research studies have revealed that carnivorous fish exhibited higher THQ(target hazard quotient) values, particularly during the pre-monsoon season, indicating significant lead accumulation. This suggests that lead contamination in water bodies has entered the food chain through fish consumption, posing a potential health risk to humans.[52]
9. Karp,R.;et.al[53] in 2023 madehistorical studies that have revealed that government policies played a significant role in lead exposure and contamination. In 1934, the Federal Housing Authority designated certain neighborhoods as "hazardous"—marked in red on maps—if they were home to non-White families or if the housing conditions were deteriorated. These policies resulted in environmental contamination and disproportionate lead exposure in marginalized communities. Additionally, federal and local governments failed to regulate and limit lead content in gasoline, paint, and drinking water for decades, leading to widespread lead poisoning risks, particularly among children. It was only after legislative restrictions were placed on lead in industrial products that exposure levels began to decline. Continued legislative efforts and policies are crucial to ensuring environmental safety and protecting all children from lead poisoning and similar public health threats.
10. Hauptman,M.;et.al;[54] conducted a study in 20232023 in Rhode Island and found out discrepancies in lead poisoning at the neighborhood level. Researchers used a geographic approach to pinpoint high-risk areas where lead exposure was maximum. This method helped to design primary prevention programs and population management methodologies to reduce lead poisoning risks. By focusing on small geographic regions with high lead exposure, public health initiatives can be more effectively constructed to minimize lead-related health hazards and protect exposed populations.
11. Lead poisoning is a preventable pediatric health issue that remains a significant concern worldwide. Infants and children are particularly vulnerable due to their smaller body size, higher lead absorption rates, and behaviors such as pica (hand-to-mouth activity), which increases ingestion of lead-contaminated dust, soil, and paint particles. Additionally, lead exposure can occur through contaminated food, milk, and water. Nutritional deficiencies, such as iron and calcium deficiencies, further increase the gastrointestinal absorption of lead[55]
12. Lead exposure in children has been linked to a range of hematopoietic and cognitive effects, even at low blood lead levels (BLLs). Studies indicate that

adverse effects can occur at BLLs as low as 4 μg/dL,[56] with severe cases reaching levels as high as 88.39 μg/dL. Lead toxicity affects multiple biochemical pathways, leading to gastrointestinal disorders, neuromuscular impairments, cardiovascular complications, kidney damage, and hematological dysfunctions such as anemia.Children exposed to lead may experience cognitive deficits, behavioral syndromes like hyperactivity, and developmental delays. Additionally, lead-induced encephalopathy can cause neurological symptoms, including confusion, headaches, seizures, and, in severe cases, stupor. While medical treatment can help manage some symptoms, many children who recover from acute lead poisoning continue to face long-term cognitive and behavioral challenges. These findings highlight the urgent need for policy interventions and public health initiatives to prevent and mitigate lead exposure in children.

13. Levin,R.;et.al[57] in the year 2021 conducted a research and found that because of human activities, particularly housing and transportation practices from 19th century, tons of lead has accumulated in the cities which has affected humans, animals and plants.
14. While phytoextraction[58] offers a sustainable detoxification method, it has limitations, including prolonged remediation times, low biomass production of hyperaccumulators, and limited effectiveness in highly polluted sites. Future research should explore chelate-assisted phytoextraction techniques and genetic modifications to enhance plant efficiency in removing heavy metals from contaminated environments.
15. Ericson,B.;et.al;[59] in 2021 did an extensive research to show that even after banning the use of leaded petrol, exposure of lead is still more in low or middle income group countries. Knowing the fact that lead causes toxicity even at low concentrations , this study proved that urgent attention is required to continue population-based sampling in countries with no or minimal data to control lead exposures .
16. Food cans, packaged[60] goods and where ever lead can be present like in cosmetics and drinking water lead is to be tested and controlled.
17. Lead chromate,[61] often added to turmeric powder to enhance its yellow hue, can be identified using a simple detection method: when turmeric is mixed with water in a beaker, the presence of lead chromate causes the liquid to release streaks of water-soluble color.To ensure food safety, consumers are advised to purchase properly packed spices with Agmark or ISI certification from reliable sources. Grinding whole spices at home is another effective method to obtain pure, fresh, and unadulterated spice powders. Furthermore, stricter

enforcement of food safety regulations and harsher penalties for those involved in adulteration are necessary to curb this unethical practice and protect public health.

18. Although laws and public[13] health initiatives have significantly reduced lead exposure, inadequate enforcement in certain regions allows the problem to persist. The most effective strategies for addressing this issue include primary prevention measures and identifying high-risk populations to implement targeted interventions, ensuring a cost-effective approach to mitigating lead-related health hazards.
19. . Further research[62] is needed to better understand the mechanisms used by bacteria, fungi, and algae in heavy metal removal, ensuring the effective purification of natural resources and the preservation of environmental health.
20. The development of transgenic[63] plants with improved plant-microbe interactions is also a promising avenue for enhancing phytoremediation efficiency and ensuring long-term lead remediation
21. Fu,Z.;Xi,S.; [64]in the year 2020 conducted a study and concluded heavy metal contamination in drinking water has exceeded recommended safety limits in various regions worldwide, making it a primary source of human exposure to toxic metals. The primary mechanism of heavy metal toxicity involves the production of reactive oxygen species (ROS), leading to oxidative damage at the cellular level. This process adversely impacts health, contributing to increased morbidity and mortality rates globally. Addressing this issue requires stringent water quality regulations, advanced filtration technologies, and public awareness campaigns to mitigate the risks associated with heavy metal exposure through drinking water.
22. A study conducted by the Environmental[19] Protection Agency (EPA) highlighted that current residential dust lead regulations do not offer adequate protection for children, putting them at a higher risk of lead poisoning. The study recommended the adoption of more stringent dust lead standards to safeguard children's health and reduce the risks associated with lead exposure in indoor environments.

Conclusion:

Though one can see that lead enters human body very easily and through almost all possible ways but with the advancement of science and technology new methods which are cheaper and easily available by common people to detect lead are on the process of evolving.So lead detection is becoming easier;but due to lack of awareness and less availability common people cannot detect lead .Government policies are there but it is the citizen who are unaware of it so often miscreants are not caught .Awareness among people about symptoms of lead poisoning, it's immense danger to the living world ,some new methods of easy detection and knowledge of it's easy and safe remediation will save the humans from this silent killer.

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