ISSN: 2710-0758
URL: https://journal.ku.ac.ke/index.php/AJPAS/article/view/642

African Journal of Pure & Applied Sciences

Journal homepage: http://journal.ku.ac.ke/index.php/AJPAS

Research Article Open Access

Human Health Effects Associated with Aluminium Poisoning and Remediation

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Received 2rd February 2025; Accepted 30th May 2025; Published online; 30th June 2025

How to Cite:
Murage , D., & Peter N. Waithaka , M. Human Health Effects Associated with Aluminium Poisoning and Remediation. *African Journal of Pure and Applied Sciences, 6(1),* 8–13. Retrieved from https://journal.ku.ac.ke/index.php/AJPAS/article/view/642

ABSTRACT

Aluminium is a common element available on the earth's surface mostly in combined form. It has numerous applications in many areas of everyday life. Aluminium has relatively superior metallic characteristics such as good thermal conductivity, it is durable, low cost, and low density. For these reasons, it is the material of choice in the manufacture of cooking utensils. Aluminium exposure to humans can result from the use of aluminium cooking utensils, cans, and wrapping foils in food preparation. Residing in areas with contaminated air and consumption of water containing aluminium ions also contribute to aluminium exposure. In addition, it is released into the environment through mining, acidic rain, and other geographical natural activities. Effects of aluminium poisoning include neurological disorders such as Alzheimer's disease, reduced intellectual capability, renal failure, and bone defects. The exposure to cookware can be reduced by the use of anodized utensils. Aluminium ions in water can be removed by adsorption, ion exchange, membrane filtration, and reverse osmosis. This paper discusses various studies done on the aluminium source and processes of its exposure human population, the effects of aluminium poisoning, remediation methods to reduce aluminium exposure, and recommendations.

Key Words: Aluminium, Alzheimer's disease, Water, Bio-accumulation, Adsorption.

INTRODUCTION

Aluminium is one of the most common elements after oxygen and silicon. Therefore, it is among the most abundant metals on the earth's surface (Hizli *et al*., 2023). It was first isolated by a Danish physicist Han Oersted in 1825 and availed by electro-synthesis by Charles Martin Hall in 1886 (Kozina and Zovko, 2022). Aluminium is found in silicates, cryolite, and bauxite rocks in nature (Alabi and Adeoluwa, 2020). In the present world, aluminium has replaced many other construction materials such as wood and bricks. Currently, it is the most used metallic construction material after steel with a wide range of uses in construction. A study done on the production and uses of aluminium in 2018 around the globe, reported that about 64 million tons were produced worldwide for industrial uses (Pedneault *et al*., 2021). Due to its high heat conductivity aluminium is the best material for cooking utensil. It's heat conductivity is more than 15 times better than of stainless steel (Saevarsdottir, *et al*., 2020).

To improve its mechanical properties, aluminium is commonly mixed with other metals to make alloys that have superior properties. These alloys are used extensively in making of different construction parts. These includes, roofs, walls, windows, and doors. In the transport industry aluminium is used to make airplanes and vehicle parts. Aluminium is the material of choice in the construction of airplane frames. This is because of its strength, low density, resistance to corrosion, and other good mechanical properties. Aluminium is also widely used in the construction of metallic structures used in satellites and space launch vehicles. Due to the excellent performance of aluminium in extreme temperature conditions at high altitudes, it is preferred in the construction of airplane engine parts (Saevarsdottir, *et al.*, 2020). Moreover, aluminium is used to make packets and and other storage materials for beverage such as milk and other foods. Alabi (2020) reported that, aluminium is also widely used in electrical equipment, food wrapping foils, road signs, funfair decorations, jewelry, explosives, dental crowns, rust-resistant chemical containers, and solid fuel rocket propellants (Alabi and Adeoluwa, 2020).

Aluminium packet of Yoghurt

Release of aluminium into the environment can also occur following natural processes like acidic rain and mostly following human activities (Hizli *et al.*, 2023). Industrial gaseous discharge, waste waters or by solid wastes greatly contributes to release of aluminium into environment. For example, waste waters from leather tanning industries contains high aluminium concentration sometimes above WHO limits (Krupińska, 2020). Aluminium has many superior mechanical properties which includes, low density, malleability, good heat conductivity, mechanical strength and resistance to corrosion. Therefore, it is used by many companies to make kitchen utensils, industrial equipment, building materials, and packaging (Kozina and Zovko 2022).

Aluminium cooking utensils which are made using recycled aluminium, and sold at lower prices than those made by anodized aluminium are commonly used in developing countries. Due to their poor quality, research has shown their use results in elevated aluminium leaching into food (Prasad *et al.*, 2022). Research on aluminium exposure as a result from cooking utensils is a new area of interest by researcher concern with human health. Study by Mathee and Street (2020) reported it important to use high quality anodized or coated aluminium utensils to reduce metal leaching into the food during cooking. It has been observed that it is very difficult to completely eliminate aluminium exposure because of its widespread presence of in the environment and foodstuffs (Mathee and street, 2020; Prasad *et al.*, 2022). Exposure of aluminium to human beings results in bioaccumulation in human organs such as the liver and brain with detrimental consequences. According to Byliński *et al.*, (2023), studies have reported that aluminium damage human bone structure, central nervous, and hematopoietic systems.

ALUMINIUM EXPOSURE

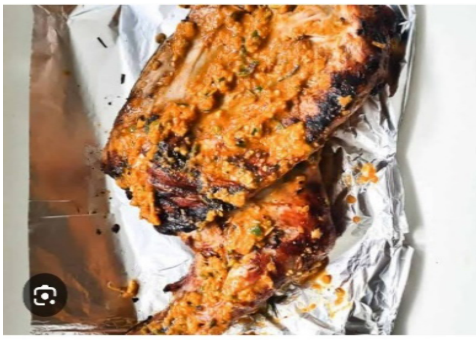
i. Exposure through food.

Aluminium exposure in elemental form may result from a variety of sources which include the following. The largest source is the leaching from aluminium utensils occurs during normal cooking. This is common especially in the use of uncoated and non-anodized cookware. Aluminium utensils result in a substantial increase in aluminium food. Hence, the consumption of food stored in aluminium cans increases the risk of aluminium intake as contrasted with a natural diet (Farhat *et al.*, 2020).

A study by Alabi and Adeoluwa (2020) on leaching tests on locally manufactured aluminium cooking utensils samples. They reported that acetic acid commonly used in food preparation creates an acidic cooking environment that simulates weakly acidic foods such as tomato sauce. After cooking for two hours, the solutions were analyzed for metal concentration. The results of the study indicated an average of 125 mg per serving of 250 mL which is about six times higher than the WHO maximum limit of 20 mg per day for 70 kg adult (WHO, 2011; Alabi and Adeoluwa, 2020; Krupińska, 2020).

Aluminium cookware

In Pakistan, a study on aluminium content in fruits juices and other soft drinks in aluminium packets was carried out. The study reported elevated aluminium content in the beverage samples. It was found the aluminium content was higher than acceptable limits set by WHO (Farhat *et al.*, 2020). In Kenya, grilled meat is commonly wrapped in aluminium foils to retain moisture and heat. It is also used to cover cooking ware during storage of hot food. Alabi and Adeoluwa, (2020) found that aluminium poisoning can be caused by consumption food heated when wrapped in aluminium foils. This is caused by the aluminium which leaches into food. The amount of aluminium leak into food is dependent on variables such as temperature of heating, duration and pH value of the food to mention a few. A study carried out by Fatunsin *et al* (2022) on effect of change in pH on aluminium leaching in water when aluiminium pots was used to boil de ionized water, it was reported that optimum leaching occurred at pH 5 and decreased with rise in pH. Increase in temperature was found to increase aluminium leaching into the food. Other studies have demonstrated that the extent of aluminium leaching can be increased by addition of citric acid, salt and other spices (Alabi and Adeoluwa, 2020). In addition, aluminium is intrinsically present, many natural foods, like vegetables, fruits, cocoa, and cereal products (Niu, 2023).



Grilled Chicken wrapped in Aluminium foil

Some commercial food additives are aluminium based compounds. These aluminium salts are commonly are used as preservatives and as food coloring compounds. A study by Farhat (2020) found that each serving of ready-to-eat pancakes contained almost 180 mg of aluminium. This was attributed to the use of wheat flour containing aluminium-based food additives (Farhat, *et al.*, 2020; Byliński *et al.*, 2023; Niu, 2023).

ii. Exposure to the local environment

Aluminium occurs naturally in combined form with as cation with oxidation charge of +3 (Al^{+3}). Most common aluminium compounds include oxides, hydroxides and aluminium silicates. In addition, aluminium can combine with non-metals such as fluorine, phosphorous, sulphur, and chlorine. Aluminium also may occur in organo-metallic compounds. The release of aluminium into environment can arising from human activities as well as result of natural processes such as weathering rocks (Hizli *et al.*, 2023). Aluminium is known to get into the environment through the natural weathering of rocks and minerals containing aluminium (Shetty *et al.*, 2021). Igbokwe *et al.*, (2019) reported that it has been observed that natural processes may release higher volumes of aluminium into the environment when compared to anthropogenic activities.

Exposures to aluminium may occur to workers working in scrap metal recycling firms and in natural minerals processing plants. In addition, workers in production of aluminium compounds are also in higher risk of aluminium exposure. Study has also reported that people handling aluminium metal get exposed to poisoning during cutting, filing, sawing, and welding. Lastly, communities and animals living in areas contaminated by waste from industries can also be exposed to aluminium (Farhat *et al.*, 2020).

iii. Exposure to medical drugs and cosmetics

Previous studies have reported that aluminium exposure can be caused by the use of personal care products and cosmetics. Some beauty products such as sunscreens, antiperspirants, and toothpastes have high levels of aluminium content. These products make the body absorb aluminium through the skin or mouth (Byliński *et al.*, 2023). Aluminium compounds are commonly used in anti-acids and as adjuvants in vaccines. This aluminium may be easily absorbed by the body. Patients having kidney failure may also suffer from high aluminium poisoning due to exposure to dialysis fluids which are known to contain high aluminium content. This has long-term effects on dialysis patients (Farhat *et al.*, 2020; Fatunsin *et al.*, 2022).

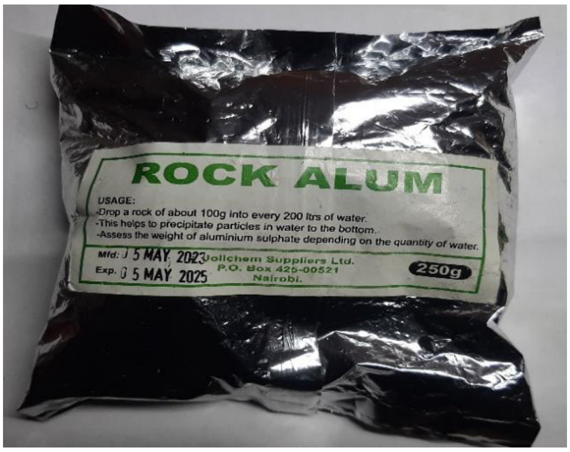
iv. Exposure by consumption of water

In majority of all developing countries, they obtain drinking water from natural sources such as rivers, lakes or from underground wells. However, because of population growth, increased and urbanization, demand for clean water has greatly increased. Industrialization and other human activities have contributed tremendously to pollution. Industrial processes, large volumes of water are used. The waste waters discharged into natural water sources may be containing toxic substances such as aluminium ions and other heavy metals (Wasike *et al.*, 2019). This water together with dissolved toxic substances infiltrates down into the soil thereby contaminating surface and underground water sources. Consumption of water from these polluted sources exposes consumers to aluminium poisoning (Farhat *et al.*, 2020).

Natural raw water is sometimes found to contain high levels of aluminium ions. This is attributed to water from rivers, streams or underground sources having passed through rocks containing aluminium salts (Farhat *et al.*, 2020). Consumption of this water exposes humans and animals to aluminium poisoning. In research about aluminium content in natural waters and soils in

Turkey, Hizli *et al* (2023) reported that water contained elevated levels of aluminium ions. The aluminium in soil comes from weathering of aluminium bearing rocks. Interaction of natural waters with rocks and soils. It was found that natural waters with pH lower 5 contained higher aluminium content of about 100mg/L. Waters with higher pH values had lower content, ranging from 0.0001-1mg/L. This observation was attributed to reduced solubility of aluminium at higher pH values. In addition, anthropogenic activities such as industrial pollution also contributes to elevated aluminium in natural waters and air (Hizli *et al.*, 2023).

Water treatment using aluminium sulphate which is used as a coagulant, greatly contributes to having residual aluminium ions in the treated water meant for domestic use. Previous study has reported that human water treated using aluminium salts has higher concentrations of low molecular mass polyaluminium compounds. These molecules have higher chemical reactivity and are easily absorbed in to human bodies. Consumption of water with elevated aluminium residues results to aluminium poisoning (Krupińska, (2020).



Aluminium based coagulant

According to Krupińska, (2020) in commercial drinking water treatment, aluminium sulphate, and poly aluminium chlorides are commonly used. Their role is to facilitate coagulation and hence removal of particulate, colloidal, and other dissolved substances in water. However, some residual aluminium ions remain in water after treatment when compared with raw water. Human consumption of treated water results in aluminium exposure (Krupińska, 2020; Bryliński *et al.*, 2023).

METHODS OF REMOVAL OF ALUMINIUM FROM WATER

Drinking water should be safe and free from dissolved metal ions. However, presence of aluminium in drinking water is matter of great concern whether in raw or treated water. This brings the need to study the most effective and economical methods of removing aluminium ions from water (Krupińska, 2020). Dissolved aluminium ions in water can be removed from contaminated water using various methods. These methods include ion exchange, electrodialysis, membrane filtration, chemical precipitation and reverse osmosis among others. However, these methods have many disadvantages due to being very expensive, delicate operating conditions, poor efficiency, and generation of toxic sludge to mention a few (Murage, 2022). Aljamali, *et al* (2021) contend that adsorption is a cheaper and more effective method of removing metal ions from water.

Chemical precipitation

It involves the introduction of a soluble precipitating compound into water containing undesirable metal ions. The metal ions react forming precipitates which can be removed from water by allowing them to settle or by filtration (Qasem *et al.*, 2021).

Ion exchange

In ion exchange, the working principle is similar to chemical precipitation. Ions are precipitated in the form of insoluble hydroxides, oxides, sulphates, etc. The precipitates are removed by coagulation and flocculation (Saleh *et al.*, 2022).

Electrodialysis

Electrodialysis is a membrane-based separation technique, where contaminated water is passed through semi-permeable membranes under effect of electric field. The dissolved metal ions where metal ions are preferentially discharged by the electric field of the membrane. This separation allows only anions or cations selectively flow through, therefore removing the metals of interest from the water (Qasem *et al.*, 2021;Veerman, 2023).

Reverse osmosis

Reverse osmosis is a separation technique where a pure solute is filtered by pressure through a membrane allowing solute, suspended particles, and other dissolved substances to be retained on one side of the membrane (Marbach, 2019; Qasem *et al.*, 2021).

Adsorption

The adsorption process involves interaction between adsorbate ions with the adsorbent surface. The metal ions form electrostatic bonds between metal ions in water and electronegative functional groups on the adsorbent surface. This results in an effective method of removal of metal ions from water (Aljamali, *et al.*, 2021).

HEALTH EFFECTS ON HUMAN

Mild exposure

Aluminium uptake through the gastrointestinal tract is low. Previous study reported the uptake to be between 0.1 and 1%. However, higher uptake has also been observed (Byliński *et al*., 2023). Mainly aluminium excreation routes includes hair, semen, skin, nails, sweat, and sebum and also through faeces and urine aluminium is excreted (Fatunsin *et al*., 2022). Ninety five percent of aluminium is excreted efficiently through human kidneys. This explains why human beings can robustly cope with the daily consumption of aluminium from the environment. Nevertheless, kidneys minimize but cannot completely eliminate the risk of accumulation of aluminium in other parts of the body (Alabi and Adeoluwa, 2020).

Acute aluminium exposure

Acute exposure to aluminium in large quantities over a long period, results in the accumulation of the metal in bones, lungs, muscles, liver, and brains affecting the health of the victim (Fatunsin *et al*., 2022).

i. Compromised Central Nervous System

Previous studies have reported that aluminium poisoning has detrimental effects on human health. Exposure to aluminium compromises bone structure, central nervous, and hematopoietic systems (Byliński *et al*., 2023). Aluminium poisoning beyond the tolerable limits of the human body, is linked to various neurological disorders like multiple sclerosis and Parkinson's disease (Farhat *et al*., 2020).

ii. Alzheimer's Disease

Medeiros *et al*., (2011) described Alzheimer's disease (AD) as a chronological disorder that is characterized by spatial disorientation, memory problem, and gradual degeneration of intellectual ability. Exposure to aluminium higher than the human ability to excrete is directly related to the development of Alzheimer's disease and many other related neurological disorders including Parkinson's disease, and multiple sclerosis (Bogale *et al*., 2021). According to Byliński *et al* (2023), exposure to aluminium through the consumption of aluminium-contaminated water may expose a healthy person to Alzheimer's disease and associated disorders. Previous study, demonstrated that exposure to aluminium through water causes acute episodes of dementia mainly in people with renal insufficiency (Kruspinska, 2020; Bogale *et al*., 2021).

iii. Renal Failure

Accumulation of aluminium is often observed in the bones of intestinal permeability patients, patients undergoing dialysis for chronic renal failure, and patients who have taken antacids for a long period. (Farhat *et al*., 2020). High oral consumption of aluminium-containing antacids and phosphate binders, particularly in individuals with impaired renal function (Coulson, 2022).

iv. Bone Defects

Exposure to aluminium increases the risk of bone-related disorders such as osteomalacia and osteoporosis among children who are in the early bone developmental stage (Farhat *et al*., 2020; Coulson, 2022).

CONCLUSION

- Exposure to aluminium beyond human excretion capacity has irreversible long-term negative health effects on the victims.
- Cooking using aluminium cook utensils creates a risk of aluminium metal entering into food and eventually into the human body after consuming such foods (Alabi *et al*., 2020).
- Young children below the age of five years are at higher risk of suffering from aluminium poisoning than adults due to their underdeveloped excretion capability.
- Water treated using aluminium-based coagulants needs to be treated further by eliminating aluminium residue to make it fit for human consumption.
- Aluminium-based medical drugs such as anti-acids are a major source of aluminium.

RECOMMENDATIONS

i. The anodization process and coating of aluminium using plastic material helps minimize the leaching of metals into food.Avoiding use of aluminium cookware worn out by scratching which removes a protective layer of aluminium oxide, exposing aluminium to leaching into food.

ii. Cooking of highly acidic or strongly alkaline foods using aluminium cookware should be avoided.

iii. Extended use of aluminium-based medications such as anti-acids, and dialysis fluids should be discouraged

iv. Water meant for human consumption should be de-ionized to remove as many residual aluminium ions as possible. Some of the methods that can be employed include adsorption, ion exchange, electrodialysis, membrane filtration, etc.

v. Aluminium-based water treatment compounds should be discouraged.

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