

Trace Lead (Pb) and Cadmium (Cd) in Table Salt from Banda Aceh and Their Implications for Food Safety

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ABSTRAK

Air laut yang terkontaminasi serta proses pengolahan garam yang tidak tepat dapat menyebabkan masuknya logam berat berbahaya, terutama timbal (Pb) dan kadmium (Cd), yang berpotensi menimbulkan risiko bagi kesehatan manusia. Penelitian ini bertujuan untuk menganalisis kandungan logam berat timbal dan kadmium pada garam konsumsi yang dipasarkan di Kota Banda Aceh. Sebanyak dua sampel garam bermerek (Mamasuka dan Suprasalt) dan dua sampel garam tidak bermerek (produksi Bireun dan Lhama) diambil secara purposif di Pasar Mahira Kota Banda Aceh untuk dianalisis kandungan logam berat menggunakan AAS. Preparasi sampel dilakukan melalui pelarutan dan pengasaman menggunakan HNO_3 , kemudian dianalisis pada panjang gelombang spesifik untuk masing-masing logam. Hasil penelitian menunjukkan bahwa seluruh sampel garam mengandung Pb dan Cd dengan kisaran konsentrasi Pb sebesar $0,0040\text{--}0,0054\text{ mg kg}^{-1}$ dan Cd sebesar $0,0020\text{--}0,0024\text{ mg kg}^{-1}$, baik garam bermerek maupun tidak bermerek. Nilai tersebut berada jauh di bawah ambang batas maksimum yang ditetapkan dalam SNI 3556:2024, yaitu $2,0\text{ mg kg}^{-1}$ untuk Pb dan $0,5\text{ mg kg}^{-1}$ untuk Cd. Nilai EDI Pb dan Cd masing-masing sebesar $0,00045$ dan $0,00020\text{ }\mu\text{g kg}^{-1}\text{ berat badan hari}^{-1}$. Nilai tersebut jauh lebih rendah dibandingkan dengan Provisional Tolerable Monthly Intake. Hasil uji ANOVA menunjukkan bahwa merek atau produsen garam tidak berpengaruh signifikan terhadap konsentrasi timbal dan kadmium di dalam garam. Oleh karena itu, dapat disimpulkan bahwa keempat sampel garam tersebut aman untuk dikonsumsi.

Kata kunci: Garam konsumsi, logam berat, timbal (Pb), kadmium (Cd), Atomic Absorption Spectrophotometer (AAS), kurva kalibrasi

ABSTRACT

Contaminated seawater and improper processing may introduce heavy metals, particularly lead (Pb) and cadmium (Cd), posing potential risks to human health. This study aimed to determine the concentrations of lead and cadmium in commercial table salt marketed in Banda Aceh City. Two branded salt samples (Mamasuka and Suprasalt) and two unbranded salt samples (produced in Bireuen and Lamnga) were purposively collected from Mahira Market, Banda Aceh, and analyzed for Pb and Cd using Atomic Absorption Spectroscopy (AAS). Sample preparation involved dissolution followed by acidification with HNO_3 , after which the samples were analyzed at the characteristic wavelengths of each metal. The data were analyzed using one-way analysis of variance (ANOVA) to determine whether salt brand or producer significantly affected heavy-metal concentrations. All salt samples contained detectable levels of Pb and Cd, with Pb concentrations ranging from 0.0040 to 0.0054 mg kg^{-1} and Cd concentrations ranging from 0.0020 to 0.0024 mg kg^{-1} in both branded and unbranded salts. These concentrations were well below the maximum permissible limits established by the Indonesian National Standard (SNI 3556:2024), namely 2.0 mg kg^{-1} for Pb and 0.5 mg kg^{-1} for Cd. The EDI values for Pb and Cd were 0.00045 and $0.00020\text{ }\mu\text{g kg}^{-1}\text{ body weight day}^{-1}$, respectively; these values are far lower than the Provisional Tolerable Monthly Intake. ANOVA results indicated that salt brand or producer had no significant effect on the concentrations of Pb and Cd. Therefore, all four salt samples can be considered safe for consumption.

Keywords: Table salt, heavy metals, lead (Pb), cadmium (Cd), Atomic Absorption Spectrophotometry (AAS), calibration curve

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1. INTRODUCTION

Salt is an essential food commodity composed primarily of sodium chloride (NaCl), which plays a

vital role in maintaining fluid balance and supporting various physiological processes in the human body. In addition to household consumption, salt serves as an

important raw material in the food, pharmaceutical, chemical, and textile industries (Butarbutar *et al.*, 2021; Codex Alimentarius Commission, 2013; Dawa *et al.*, 2023; Hall & Guyton, 2011). Most table salt in Indonesia is produced through the evaporation of seawater, making its quality highly dependent on coastal environmental conditions. Pollution from domestic waste, industrial effluents, and port activities may introduce heavy metals into seawater, resulting in contamination of the salt produced (Hamdani & Farmiati, 2022; KKP, 2025; Radityo & Pratomo, 2024). Among environmental contaminants, lead (Pb) and cadmium (Cd) are of particular concern because they are toxic, persistent, and bioaccumulative. Chronic exposure to Pb can impair the nervous system, kidney function, and children's cognitive development, whereas Cd is recognized as a nephrotoxic and carcinogenic metal that can also disrupt bone metabolism (ATSDR, 2020; WHO, 2021). Therefore, regular monitoring of Pb and Cd concentrations in table salt is essential to ensure food safety and protect public health.

Indonesia produced approximately 2.04 million tons of salt in 2024. However, this production remains insufficient to meet the national demand of approximately 4.5 million tons, making salt imports necessary (KKP, 2025). Salt production is concentrated mainly in East Java, Central Java, West Java, and East Nusa Tenggara (BPS, 2025; KKP, 2025). In contrast, salt production in Aceh Province is relatively limited and still relies largely on traditional methods, with low productivity attributed to high rainfall, inadequate production infrastructure, and inefficient crystallization processes (DKP Aceh, 2025; Rochwulaningsih, 2013). In addition to production constraints, the quality of the coastal environment in Aceh may influence the safety of locally produced salt. Bahagia and Afrizal (2019) reported an average Pb concentration of 0.2878 mg/L in seawater collected from several coastal areas of Aceh. Heavy metals present in seawater may accumulate in salt during the evaporation process, potentially reducing product quality and causing the salt to exceed the safety limits established by the Indonesian National Standard (SNI 3556:2024) (Bahagia & Afrizal, 2019; BSN, 2024; Samsiyah *et al.*, 2019).

Banda Aceh was chosen as the study site due to its status as the capital city of Aceh Province and its distinction as the most densely populated area in the province. The population's diverse educational backgrounds contribute to a substantial demand for edible salt. Additionally, residents may be especially susceptible to heavy metal exposure through the consumption of contaminated edible salt. In Banda Aceh, table salt available in the market consists of locally produced salt manufactured using traditional methods and commercially branded salt distributed from other regions. These two types of salt are produced using different processing methods. Branded salt undergoes modern processing and

fortification, whereas unbranded salt is traditionally produced without fortification. These differences may result in variations in the heavy metal concentrations detected in the final products (Kumar *et al.*, 2019; Maflahah *et al.*, 2020; Habin *et al.*, 2025). Despite their widespread consumption, information regarding Pb and Cd contamination in these products remains limited. To date, no published study has compared the concentrations of Pb and Cd in locally produced and branded table salt marketed in Banda Aceh.

This lack of information represents an important research gap, considering the high consumption of salt and the potential health risks associated with long-term exposure to heavy metals. Therefore, this study aimed to determine the concentrations of lead (Pb) and cadmium (Cd) in table salt marketed in Banda Aceh and to evaluate their compliance with the Indonesian National Standard (SNI 3556:2024). The findings are expected to provide scientific evidence to support salt quality monitoring and strengthen food safety management in Aceh Province.

2. MATERIALS AND METHODS

2.1. Research Location and Time

This study was conducted in January 2026. Sample collection was carried out at Al Mahira Market, Lamdingin, Banda Aceh City. The analysis of heavy metal content in salt samples was performed at the Chemistry Laboratory, Industrial Standardization and Services Center (BSPJI), Banda Aceh, Ministry of Industry of the Republic of Indonesia.

2.2. Sampling Location and Sample Collection

Sampling was conducted using a purposive sampling technique, in which samples were intentionally selected based on specific criteria established by the researcher. The salt samples analyzed in this study were selected based on the edible salt products that were most widely available and predominantly sold at Mahira Market, one of the major markets in Banda Aceh. Therefore, a total of four salt samples were selected, consisting of two branded salts (Mamasuka and Suprasalt) and two locally produced salts (Bireun and Lamnga) purchased from Al Mahira Market, Banda Aceh City. This market was chosen because it is one of the main food distribution centers in Banda Aceh and therefore considered representative of table salt circulating in the local community.

A total of 100 g of each salt sample was purchased from vendors at Al Mahira Market, Banda Aceh City. Each sample was selected based on the criterion that it must be produced from seawater-based raw materials. All samples were subsequently analyzed for heavy metal content using an Atomic Absorption Spectrophotometer (AAS) at the Chemistry Laboratory, BSPJI Banda Aceh, Ministry of Industry of the Republic of Indonesia. The analysis was performed in four replicates.

2.3. Preparation of Standard Solutions

In preparing mixed standard solutions of Cd and Pb for AAS analysis, acidified distilled water was first prepared by carefully mixing 2 L of distilled water with 6 mL of concentrated HNO_3 . Subsequently, 5 mL of 1000 ppm Cd stock solution and 5 mL of 1000 ppm Pb stock solution were transferred into a 50 mL volumetric flask and diluted to the mark. Working standards were prepared by pipetting 0.1 mL (0.2 ppm), 0.2 mL (0.4 ppm), 0.5 mL (1.0 ppm), and 1.0 mL (2.0 ppm), respectively. Each solution was then diluted to a final volume of 50 mL, homogenized, and used as calibration standards for AAS analysis.

2.4. Sample Preparation

Sample preparation is a critical step in heavy metal analysis using Atomic Absorption Spectrophotometry (AAS, SHIMADZU AA-7000) as it influences measurement accuracy. In this study, sample preparation followed the Indonesian National Standard (SNI 3556:2024). A total of 10 g of salt sample was weighed and dissolved in 100 mL of distilled water until completely dissolved. Then, 2 mL of concentrated nitric acid (HNO_3 , 65%) was added to oxidize organic matter and maintain metals in dissolved ionic form, preventing precipitation. The solution was acidified to a pH below 2 to ensure metal stability in solution.

The mixture was then diluted to a final volume of 500 mL with distilled water and homogenized before analysis. A blank solution was prepared using the same procedure without sample addition to serve as a control for contamination detection and instrument correction. Heavy metal analysis was performed using flame Atomic Absorption Spectrophotometry (AAS) at wavelengths of 228.8 nm for Cd and 283.3 nm for Pb.

The linearity of the calibration curve was evaluated using the coefficient of determination (R^2), yielding values of 0.9996 for Pb and 0.9985 for Cd. These values indicate a strong linear relationship between the standard solution concentration and absorbance within the concentration range used.

2.5. Estimation of Daily Intake of Salt

In addition to determining Pb and Cd concentrations, this study also calculated the estimated daily intake (EDI) of salt among the Indonesian population, assuming an average adult body weight of 60 kg and an average daily salt intake of 5 g, by using this formula:

$$\text{EDI} = (\text{C} \times \text{IR}) / \text{BW}$$

Where EDI is estimated daily intake ($\mu\text{g kg}^{-1}$ body weight day⁻¹), C = concentration of heavy metals in salt ($\mu\text{g g}^{-1}$), IR = average daily consumption (g day^{-1}), and BW = average body weight (kg).

2.6. Data Analysis

Data analysis was conducted quantitatively based on the measured concentrations of Pb and Cd in each

salt sample using atomic absorption spectrophotometry (AAS). Absorbance values were recorded at specific wavelengths for each target metal and then compared with calibration curves to determine metal concentrations. The obtained data were further analyzed using one-way analysis of variance (One-Way ANOVA) to evaluate differences among samples.

3. RESULTS AND DISCUSSION

The salt samples analyzed in this study consisted of branded salts (Mamasuka and Suprasalt) and locally produced salts from Bireuen and Lamnga, Aceh Besar, obtained from Al Mahira Market, Lamdingin, Banda Aceh City. Analysis using a Shimadzu AA-7000 Atomic Absorption Spectrophotometer (AAS) revealed that all samples contained detectable levels of the heavy metals Pb and Cd. Lead (Pb) concentrations ranged from 0.0040 to 0.0054 mg kg^{-1} , while cadmium (Cd) concentrations ranged from 0.0020 to 0.0024 mg kg^{-1} . The highest Pb concentrations were found in Mamasuka and Suprasalt, each at 0.0054 mg kg^{-1} , whereas the lowest concentration was observed in the Bireuen local salt sample at 0.0040 mg kg^{-1} . For Cd, the highest concentration was recorded in Mamasuka salt at 0.0024 mg kg^{-1} , while the lowest was found in Suprasalt salt at 0.0020 mg kg^{-1} . The results of the one-way ANOVA indicated that salt type or producer had no significant effect on the concentrations of Pb and Cd in the analyzed table salt samples ($P > 0.05$), and there was no statistically significant difference among salt samples (Table 1).

If the concentrations of heavy metals Pb and Cd in this study are compared with the Indonesian National Standard (SNI 3556:2024) for iodized table salt, all samples show metal levels below the maximum permissible limits, which are 2.0 mg kg^{-1} for Pb and 0.5 mg kg^{-1} for Cd. The comparison of Pb and Cd concentrations with the maximum permissible limits according to SNI 3556:2024 is presented in Figure 2.

The analysis of estimated daily intake of salt for Indonesian people showed The results of the Estimated Daily Intake (EDI) analysis show that the estimated daily exposure to lead and cadmium through the consumption of salt is extremely low. When the highest heavy metal concentrations recorded in the samples are used, together with an average daily salt intake of 5 g and an average adult body weight of 60 kg, the EDI values obtained are 0.00040 μg per kg of body weight per day for lead and 0.00018 μg per kg of body weight per day for cadmium (Table 2).

The present study confirmed the presence of lead (Pb) and cadmium (Cd) in all table salt samples, albeit at very low concentrations. Pb levels (0.0040–0.0054 mg kg^{-1}) consistently exceeded Cd (0.0020–0.0024 mg kg^{-1}), reflecting the stronger affinity of Pb for particulate matter and sediment phases in marine environments, whereas Cd is more mobile in dissolved forms under high-salinity conditions

(Mahfud *et al.*, 2025; Piwowarska *et al.*, 2024; Yona *et al.*, 2020). Such geochemical partitioning likely contributes to differential incorporation of these metals into salt during seawater evaporation.

The occurrence of Pb and Cd in salt is primarily attributed to seawater quality as the raw material. Coastal systems receive continuous anthropogenic inputs from industrial discharge, agricultural runoff, domestic waste, and maritime activities. Pb is commonly associated with fuel combustion residues, port operations, vehicular emissions, and industrial effluents, whereas Cd input is largely derived from phosphate fertilizers, pesticides, and wastewater transported via riverine systems (Adibrata *et al.*, 2021; Fauzan *et al.*, 2024). During evaporation, non-volatile metals are retained in brine and progressively concentrated within crystallizing salt matrices (Ekrami *et al.*, 2021).

Although minor variations were observed among samples, one-way ANOVA revealed no significant differences in Pb and Cd concentrations ($p > 0.05$), indicating that contamination levels were not influenced by product type or producer. This homogeneity likely reflects the use of seawater sources with comparable environmental characteristics, coupled with conventional solar evaporation processes that lack selective removal of dissolved or particulate metals (Muslimah *et al.*, 2024; Rochwulaningsih, 2013). In addition, coastal hydrodynamic processes—such as tidal mixing and current-driven dispersion—may further homogenize

contaminant distributions in raw seawater (Adibrata *et al.*, 2021; Yona *et al.*, 2020).

All samples complied with the Indonesian National Standard (SNI 3556:2024), remaining far below the maximum limits for Pb (2.0 mg/kg) and Cd (0.5 mg/kg) (BSN, 2024). Compared with previous studies reporting substantially higher contamination levels in other Indonesian coastal regions (Pratomo *et al.*, 2023; Samsiyah *et al.*, 2019), the present findings indicate relatively low environmental loading of »heavy metals in the study area, likely reflecting limited industrial activity and better coastal water quality. A similar finding was reported in salt materials of biopore infiltration holes (Sarminingsih *et al.*, 2025). Despite regulatory compliance, Pb and Cd remain toxicologically relevant due to their persistence, bioaccumulative behavior, and absence of biological function in humans.

The EDI values for Pb and Cd were 0.00040 and 0.00018 µg/kg body weight/day, respectively, which corresponds to 0.0120 µg/kg body weight/month (Pb) and 0.0054 µg/kg body weight/month (Cd). These values indicate that the exposure to Pb and Cd through the consumption of the salt samples in this study was relatively low. The EDI values for Pb and Cd were much lower than the Provisional Tolerable Monthly Intake (PTMI) of 25 µg/kg body weight/month (WHO-JECFA, 2011). Therefore, the salt intake of 5 g/day (the same as one teaspoon) by people is still safe in terms of exposure to Pb and Cd.

Table 1. Lead (Pb) and Cadmium (Cd) Concentrations in Table Salt Samples from Al-Mahira Market, Banda Aceh City. Mean $\pm$ SD Values Within the Same Row Followed by Different Superscript Letters are Significantly Different ($p < 0.05$). The Analysis was Performed with Four Replicates ($n = 4$)

Parameters	Salt Sampel				Thresholds	R ²
	Mamasuka	Suprasalt	Bireun	Lamnga		
Lead (mg kg ⁻¹)	0.0054 $\pm$ 0.00000 ^a	0.0054 $\pm$ 0.00076 ^a	0.0040 $\pm$ 0.00030 ^a	0.0045 $\pm$ 0.00012 ^a	2.00	0.9996
Cadmium (mg kg ⁻¹)	0.0024 $\pm$ 0.00032 ^a	0.0020 $\pm$ 0.00025 ^a	0.0023 $\pm$ 0.00026 ^a	0.0022 $\pm$ 0.00017 ^a	0.50	0.9985

Table 2. Estimated Daily Intake (EDI) of Pb and Cd

Heavy Metals	Average Concentration of in the Samples	Estimation Salt Intake of Indonesia People	Average Body Weight Adult People	Estimated Daily Intake (EDI)
Pb	0.0048 mg kg ⁻¹	5 g day ⁻¹	60 kg	0.00040 µg kg ⁻¹ bw day ⁻¹
Cd	0.0022 mg kg ⁻¹	5 g day ⁻¹	60 kg	0.00018 µg kg ⁻¹ bw day ⁻¹

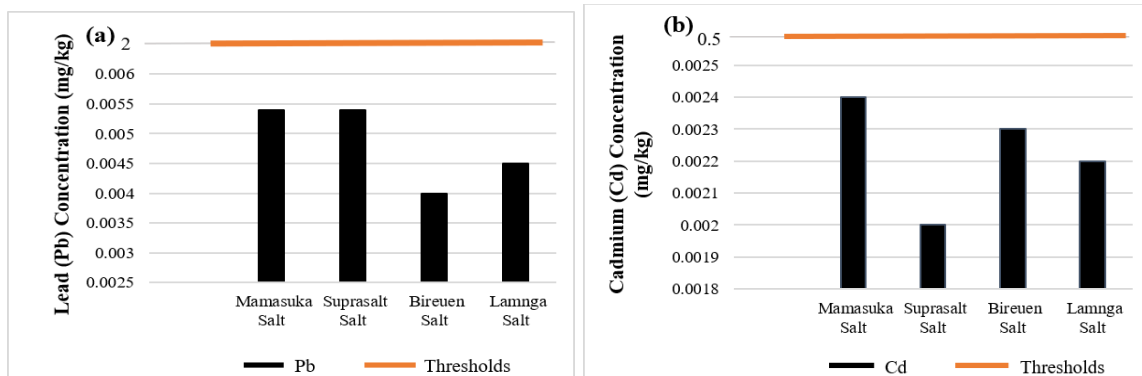


Figure 1. Comparison of Heavy Metal Concentrations and Maximum Permissible Limits based on the Indonesian National Standard (SNI 3556:2024): (a) Lead (Pb), (b) Cadmium (Cd)

Chronic Pb exposure is associated with neurotoxicity, hematological impairment, and renal dysfunction, while Cd accumulates primarily in kidneys and bones, leading to progressive organ damage and metabolic disturbances (ATSDR, 2020; Balali-Mood *et al.*, 2021; WHO, 2021). Given their cumulative nature, even trace-level exposure through frequently consumed commodities warrants continued monitoring. The absence of significant inter-sample differences further suggests that variability in metal concentrations is driven primarily by environmental conditions rather than branding or production source. The narrow range of variation indicates a relatively uniform contamination background across raw material sources, consistent with previous reports on salt produced from environmentally similar coastal systems (Astika, 2023; Salsabila *et al.*, 2023).

From a marine biogeochemical perspective, heavy metal contamination in salt reflects cumulative coastal pollution dynamics. Metals enter marine systems through river discharge, atmospheric deposition, urban runoff, and maritime activities (Afnani *et al.*, 2022). Pb preferentially binds to fine sediments and organic matter, whereas Cd remains more soluble through stable chloride complexation in saline waters (Gantayat & Elumalai, 2024). During evaporation, progressive water loss concentrates these metals in residual brine, facilitating their incorporation into salt crystals. Although production and post-harvest handling may influence salt quality, their impact appears limited in this study, as both branded and locally produced salts exhibited similarly low contamination levels. This could be due to the fact that heavy metals are not removed by heating or evaporation processes, so they persist in the final product (Inobeme *et al.*, 2022). This suggests that raw seawater quality is the dominant controlling factor. Branded salts typically undergo refinement and iodization (KIO₃ addition), while local salts are traditionally produced without further purification steps (BSN, 2024; Ekott & Etukudo, 2025).

The two branded salt products in this investigation exhibited higher quantities of heavy metals than the locally made Acehnese salt. This could be because, despite the use of conventional techniques, the saltwater used as a raw material is comparatively clean and uncontaminated by heavy metals. However, as the study did not examine the saltwater quality directly, this is merely a conjecture. Further investigation is required to determine whether heavy metal levels are influenced by the quality of the raw materials. However, there were no discernible variations in heavy metal concentration amongst these groups.

Iodized salt plays a critical role in preventing iodine deficiency disorders, as iodine is essential for thyroid hormone synthesis and metabolic regulation. However, both iodine imbalance and excessive salt intake pose health risks, including thyroid dysfunction and cardiovascular disease (Farebrother *et al.*, 2019;

WHO, 2021). Thus, ensuring both nutritional adequacy and contaminant safety is essential in table salt production. Salt purity, commonly expressed as NaCl content, is also a key quality parameter. According to SNI 3556:2024, iodized salt should contain 94–99.7% NaCl. Variations in traditionally produced salt are typically attributed to residual mineral impurities, whereas refined branded products exhibit higher NaCl purity due to controlled processing (Deglas & Yosefa, 2020; Kharismanto *et al.*, 2021). Importantly, NaCl purity is not directly correlated with heavy metal contamination, which is governed primarily by environmental exposure. Overall, the low Pb and Cd levels observed suggest relatively unpolluted coastal conditions in the study area compared to more industrialized regions. However, increasing anthropogenic pressure may alter this balance over time. Continuous monitoring of coastal water quality and table salt contamination is therefore essential to safeguard long-term food safety and environmental sustainability.

4. CONCLUSION

Pb and Cd were found in all of the table salt samples from Banda Aceh City that were examined, but their amounts were far lower than the upper limits set by SNI 3556:2024. Therefore, in terms of Pb and Cd contamination, the examined salt products can be regarded as safe for consumption based on the current regulatory standards. However, the discovery of these hazardous and bioaccumulative metals emphasizes the necessity of keeping an eye out for possible contamination sources in salt production systems and coastal habitats. In order to ensure food safety, future research should look into the sources and pathways of heavy metal contamination, especially the quality of seawater and the raw materials used to make salt. It should also include regular monitoring of heavy metals in both coastal waters and commercially available edible salt.

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