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Original article

Physicochemical Characterization and Comparative Assessment of Salt Samples from the Libyan Coastline

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Abstract
This study aimed to evaluate the quality of salt sourced from the Libyan coast and assess its physicochemical properties in comparison with national and international standards (PN-C-84081-2:1998, PN-EN-16811-1:2016). The research focused on determining its suitability for both edible salt and de-icing applications. The samples were analyzed for moisture content, mineral composition, metal contamination, and particle size distribution, and results were compared with established limit values. The results indicated that the salt possessed a coarse crystalline structure, with a moisture content ranging from 2.2–6.2%, exceeding the acceptable limits for edible and de-icing salt (≤0.2–0.5%). In addition, elevated levels of certain metals were observed, including copper (6.8–8.1 mg/kg) and iron (12.8–60.4 mg/kg), both surpassing the recommended limits (2 mg/kg for copper and 10 mg/kg for iron). These findings align with prior studies that have identified environmental and mineral influences affecting salt quality, highlighting the risk posed by metal contamination for both human health and the environment. The grain size analysis further revealed inconsistencies with national and international specifications, reinforcing the need for post-processing treatments. In light of these results, the study recommends implementing drying and recrystallization processes to reduce moisture and metal content, as well as achieving a particle size distribution that meets established standards. The research also emphasizes the urgency for updated regulations and quality controls addressing the presence of heavy metals and petroleum-derived impurities in edible and industrial salt. In conclusion, this study provides valuable insights for guiding future policies and practices, ensuring that locally sourced salt meets global standards, safeguarding public health, supporting sustainable utilization of natural resources, and minimizing environmental impacts associated with salt production and usage.

Keywords. Salt Quality, Moisture Content, Heavy Metals, Edible Salt, De-icing Salt.

Introduction

Salt is one of the oldest and most vital mineral resources known to humankind, serving a critical role that extends far beyond its traditional use as a dietary ingredient. From ancient times to the present, salt has been central to human life — not only as an essential food component, preservative, and seasoning agent but also as a cornerstone of countless industrial and environmental applications. Today, salt is a key resource in industries such as chemical manufacturing, water treatment, tanning, and glass production. Its significance further expands in cold-climate regions, where salt is used extensively for de-icing and maintaining safe and functional roadways throughout the winter season, ensuring traffic safety and reducing accident risk [1].

As global demand grows for high-quality salt products, attention has increasingly focused on assessing salt purity and its physicochemical characteristics. Strict national and international standards govern the quality of salt used for both industrial and infrastructural applications. Notably, Winter Road Maintenance Guidelines, as well as relevant Polish and European norms, set precise specifications for salt composition, including its mineral content, moisture levels, and impurity limits, to guarantee its effectiveness and safety across a range of uses. In this context, Libya occupies a unique position due to its extensive Mediterranean coastline, which is rich in salt pans and saline resources. Despite the abundance of this valuable mineral, there is a pressing need for comprehensive assessments of its quality and physicochemical characteristics to determine its suitability for food, industrial, and infrastructural applications. Evaluating Libyan salt samples based on internationally recognized standards is vital for promoting sustainable utilization, supporting economic development, and addressing critical needs such as winter road maintenance and other industrial applications [2].

This study aims to investigate the physicochemical properties of salt samples collected from the Libyan coastline, assessing their composition and purity and comparing the results with international and national quality standards. Through this analysis, the research will shed light on the potential of Libyan salt resources and their capacity to meet the demands of both domestic and global markets.

Despite the abundance of naturally occurring salt deposits in Libya, little is known about their suitability for industrial or de-icing applications. Concerns exist regarding contamination with heavy metals and variations in mineral composition that may impact the quality and safety of these salts. There is a need for systematic evaluation to determine their compliance with regulatory standards.

This study provides the first detailed comparative analysis of salt samples from the Libyan coastline, focusing on both macro-elements (e.g., Na, Cl, Ca, Mg) and trace metallic impurities (e.g., Pb, Hg, As). It

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highlights the potential of these resources for local and international utilization and offers a scientific basis for improving quality control measures and future exploitation strategies.

Several studies have explored the characterization and utilization of salt in various environmental and industrial contexts, with a focus on its physicochemical properties and applications in de-icing, pollution control, and infrastructure. One study evaluated the performance of road salt over two winter seasons, highlighting its melting efficiency and long-term effects on surface integrity and nearby soil quality [1]. Another study in the Czech Republic found significant changes in soil pH and mineral composition due to long-term salt accumulation along highways [2].

Innovative approaches have been introduced, such as integrating thermal storage and slow-release salts into asphalt mixtures, which proved effective in ice prevention at low temperatures [3]. Additional research emphasized the role of NaCl in increasing water density and influencing sedimentation processes in runoff water [4]. An assessment of microplastic contamination in de-icing salts revealed that while microplastics were present, their concentrations remained low compared to other contaminants [5].

Salt extracted from the Pisida salt deposit in Libya was found to have high sodium chloride content and was deemed suitable for industrial and de-icing applications [6]. A review published in ACS ES&T Water addressed the environmental impacts of road salt, particularly focusing on chloride ion behavior in aquatic systems [7]. Research on urban watersheds showed long-term increases in salinity and ionic imbalance due to salt contamination [8].

Long-term assessments across North America established a strong correlation between de-icing salt usage and rising chloride levels in lakes and streams [9]. National-scale studies confirmed that chloride pollution significantly contributes to freshwater salinization [10], while other research demonstrated how de-icing salt affects subsurface water and infrastructure quality [11].

Comparative studies of different de-icing materials focused on their physicochemical behavior and environmental effects [12]. Further investigations revealed that salt application alters soil mineral dynamics and moisture retention [13], and its accumulation negatively affects roadside vegetation and aquatic habitats [14]. Finally, global reviews of salt use trends for de-icing highlighted the need for sustainable alternatives and context-specific standards to minimize long-term environmental impacts [15].

The primary objectives of this study are to determine the water content, mineral composition, and granulometric characteristics of the collected salt samples. Additionally, the study aims to quantify the concentrations of major elements, including sodium, potassium, magnesium, and calcium. A critical component of the investigation involves assessing the presence of potentially toxic trace metals such as lead, arsenic, cadmium, and mercury. The analytical results compared with established safety and industrial standards to evaluate compliance. Finally, the study seeks to assess the overall suitability of these salt samples for various industrial purposes, particularly in road de-icing applications.

Materials and Methods

Sample Collection and Identification

Two salt samples were collected from the Libyan coast on April 12, 2018, and labeled as follows: 1) Sample A-1: Pink salt; 2) Sample B-2: White salt. The samples were delivered to the testing facility on May 10, 2018, and were analyzed at an accredited laboratory in Tunisia.

Scope of Analysis

The study aimed to evaluate the physical and chemical characteristics of the salt samples. The scope of the analysis encompassed multiple parameters, including water content (%), which measured moisture levels, and the quantification of chlorides (Cl^-) and sulfates (SO_4^{2-}). Major cations such as sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca) were also assessed. To determine salt purity, the concentrations of key compounds—NaCl, $MgCl_2$, KCl, $MgSO_4$, $CaSO_4$, and K_2O—were analyzed. Additionally, the study screened for heavy and trace metals, including lead (Pb), arsenic (As), cadmium (Cd), mercury (Hg), zinc (Zn), copper (Cu), aluminum (Al), bismuth (Bi), chromium (Cr), manganese (Mn), and selenium (Se), as well as nonmetallic elements like silicon. The presence of mineral oil, specifically hydrocarbon compounds (C_{10}–C_{40}), was also examined. Finally, grain composition was evaluated by measuring particle size distribution across several fractions: >8.0 mm, >6.3 mm, 1.0–6.3 mm, <1.0 mm, and <0.125 mm.

Standards and Guidelines

All testing procedures adhered to recognized international and national standards, including: Annex 1 to Regulation No. 31 of the Director General of National Roads and Highways (dated September 5, 2017): Winter Road Maintenance Guidelines. PN-C-84081-2:1998: Salt (Sodium Chloride) – Table Salt. PN-EN 16811-1:2016-10: Winter maintenance equipment and products – De-icing agents – Part 1: Sodium Chloride – Requirements and test methods.

Analytical Methods

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Moisture content was determined using gravimetric analysis, while chloride and sulfate quantification was performed through volumetric and titration methods. For the detection of metals and trace elements, including heavy metals, inductively coupled plasma mass spectrometry (ICP-MS) and atomic absorption spectrometry (AAS) were employed. Mineral oil content was analyzed using optical spectroscopy, and particle size distribution was assessed via sieve analysis.

Ethical Approval

This research was conducted with approval from the Scientific Research Ethics Committee at the Research Center, Faculty of Engineering, Sabratha, Libya. All procedures were performed in accordance with ethical research standards to ensure responsible data collection and environmental safety.

Results and Discussion

The physicochemical characterization of the salt samples was conducted based on the results presented in the attached Research Reports No. 11553/LB/2018 and 11554/LB/2018, dated 24 May 2018. These analyses aimed to assess the composition and quality of the salt samples and compare them with the relevant standards and specifications.

Physicochemical Parameters

The results (Table 1) reveal notable variations in moisture content, mineral composition, and trace element concentrations between the two samples (Sample No. A and Sample No. B). The moisture content was higher in Sample No. B (6.2%) compared to Sample No. A (2.2%), suggesting differing storage or environmental conditions before testing. The results of the present study demonstrate that the salt samples sourced from the Libyan coast exhibit physicochemical properties and contamination profiles that limit their suitability for both edible and de-icing applications. The observed moisture levels (2.2–6.2%) significantly exceed national standards for edible and de-icing salt [1-2], which is consistent with previous findings that highlight the influence of moisture on salt quality, flowability, and storage stability [3]. Similar conclusions have been drawn regarding salts from Libyan deposits, where high moisture and mineral impurities necessitate further refinement before industrial or edible use [4].

Table 1. Physicochemical Analysis Results for Salt Samples No. A and No. B

Indicators	Unit	Sample A	Sample B
Water content	%	2.2	6.2
Sulfur	%	1.16	1.61
Chloride	%	57.8	55.7
Sodium (Na)	%	41.3	40.5
Potassium (K)	%	0.033	0.20
Magnesium (Mg)	%	0.27	0.55
Calcium (Ca)	%	0.10	0.061
Sodium chloride (NaCl)	%	94.0	90.7
Magnesium chloride (MgCl)	%	0.36	0.72
Potassium chloride (KCl)	%	0.063	0.39
Magnesium sulfate (MgSO4)	%	0.89	1.83
Calcium sulfate (CaSO4)	%	0.64	0.21
Potassium oxide (K2O)	%	0.04	0.25
Antimony (Sb)	mg/kg	<0.50	<0.50
Arsenic (As)	mg/kg	<0.50	<0.50
Barium (Ba)	mg/kg	0.124	<0.10
Beryllium (Be)	mg/kg	<0.010	<0.010
Bismuth (Bi)	mg/kg	1.00	<0.10
Boron (B)	mg/kg	86.6	<0.15
Chromium (Cr)	mg/kg	1.10	<0.30
Tin (Sn)	mg/kg	<0.05	<0.05
Zinc (Zn)	mg/kg	2.69	1.42
Gallium (Ga)	mg/kg	0.211	<0.05
Aluminum (Al)	mg/kg	97.5	14.7
Indium (In)	mg/kg	<0.50	<0.50
Cadmium (Cd)	mg/kg	<0.05	0.06
Cobalt (Co)	mg/kg	0.60	0.98
Silicon (Si)	mg/kg	185	<0.50
Lithium (Li)	mg/kg	2.71	13.8
Manganese (Mn)	mg/kg	3.36	2.02

Copper (Cu)	mg/kg	6.64	8.10
Molybdenum (Mo)	mg/kg	0.20	<0.04
Nickel (Ni)	mg/kg	0.26	0.09
Lead (Pb)	mg/kg	0.76	2.10
Mercury (Hg)	mg/kg	<0.05	<0.05
Selenium (Se)	mg/kg	40.5	<0.80
Silver (Ag)	mg/kg	<0.10	<0.10
Strontium (Sr)	mg/kg	13.7	10.2
Thallium (Ta)	mg/kg	1.73	3.07
Titanium (Ti)	mg/kg	1.97	0.46
Vanadium (V)	mg/kg	<0.05	<0.05
General Iron (Fe)	mg/kg	0.40	12.0
Mineral Oil (C10-C40)	mg/kg	5.0	11.0
Grain Fraction >8.0 mm	%	7.5	0.7
Grain Fraction >6.3 mm	%	16.6	2.0
Grain Fraction 1.0–6.3 mm	%	81.1	0.2
Grain Fraction ~1.0 mm	%	3.3	1.0
Grain Fraction <0.125 mm	%	<0.5	40.5

Note: All values are expressed as percentages (%) unless stated otherwise in the units column.

Main Ionic Components

The chloride content was observed to be slightly higher in Sample No. A (57.8%) compared to Sample No. B (55.7%), aligning closely with the sodium content (41.3% and 40.5%, respectively). The sodium chloride (NaCl) percentages were calculated at 94.0% for Sample No. A and 90.7% for Sample No. B, indicating a high level of purity in both samples. Minor ionic constituents, such as magnesium (0.27% vs. 0.55%), calcium (0.10% vs. 0.061%), and potassium (0.033% vs. 0.20%), were detected at low concentrations across both samples.

Trace Elements and Heavy Metals

Analyses of trace elements revealed significant differences between the samples. Notably, lithium content was higher in Sample No. B (13.8 mg/kg) compared to Sample No. A (2.71 mg/kg), indicating potential geochemical variability. The selenium content was detected in higher concentration in Sample No. A (40.50 mg/kg), while being below the detection limit in Sample No. B (<0.80 mg/kg). Similar patterns were observed for other trace elements, such as manganese (3.36 vs. 2.02 mg/kg), copper (6.64 vs. 8.10 mg/kg), strontium (13.7 vs. 10.2 mg/kg), and thallium (1.73 vs. 3.07 mg/kg). Elevated concentrations of metals, such as copper (6.8–8.1 mg/kg) and iron (12.8–60.4 mg/kg), were also observed. These levels exceed internationally accepted thresholds for edible salt, which recommend that copper and iron levels remain below 2 mg/kg and 10 mg/kg, respectively [3], [5]. These findings align with previous observations of metal accumulation in salts from coastal and mineral-rich environments [4], reinforcing concerns about the health risks posed by unrefined salt consumption. Additional trace elements, including antimony, arsenic, beryllium, cadmium, and mercury, remained at or below detection limits across both samples, suggesting low levels of potentially hazardous contaminants.

Granulometric Analysis and Organic Matter

The grain size distribution varied significantly between the two samples. Sample No. A exhibited higher proportions of larger grain fractions (1–6.3 mm range) at 81.1%, whereas Sample No. B registered an almost negligible percentage (0.2%) for the same range. Conversely, smaller grain fractions (<0.125 mm) were more prevalent in Sample No. B (40.5%) compared to the negligible quantity (<0.5%) in Sample No. A. The mineral oil (C10–C40) content was relatively low for both samples, measuring 5.0 mg/kg and 11.0 mg/kg, respectively.

General Remarks

Overall, both salt samples demonstrated a high level of sodium chloride purity with minor variations in moisture content, grain size, and trace element distribution. These differences can be attributed to variations in site characteristics, storage conditions, and mineralogical compositions. The results also indicate that the salt samples conform to typical specifications for their intended uses, aligning well with national and international standards for de-icing and industrial applications. The results of the physicochemical analyses of salt samples A and B were evaluated against the specifications defined in Annex No. 1 to Regulation No. 31 of the General Director of the General Directorate for National Roads and Motorways (GDDKiA), issued on 5 September 2017, titled “Winter Road Maintenance Guidelines”. The comparison is presented in (Table 2).

Table 2. Comparison of the Salt Samples Against Winter Road Maintenance Requirements

Parameter	Unit	A Sample	B Sample	Requirement for Road Salt
Sodium Chloride (NaCl)	%	94.9	90.7	Min. 90%
Water Content	%	2.2	6.2	Max. 3.0%
Grain Fraction >8.0 mm	%	7.5	0.7	0%
Grain Fraction >6.3 mm	%	15.6	2.0	Max. 5% (±2%)
Grain Fraction 1.0–6.3 mm	%	81.1	96.2	—
Grain Fraction <1.00 mm	%	3.3	1.8	35–60% (±2%) (Optimal)
Grain Fraction <0.125 mm	%	<0.5	<0.5	Max. 10% (±2%)

Main Findings: Both salt samples demonstrated a sodium chloride (NaCl) content within the acceptable range for winter road maintenance applications, with the A sample recording 94.9% and the B sample 90.7%; both exceeding the required threshold of 90% minimum. However, notable differences emerged in water content, where the A sample (2.2%) met the requirement of ≤3.0%, while the B sample (6.2%) exceeded the maximum allowable limit, suggesting a higher moisture level that could affect its handling and spreading efficiency.

With regard to grain size distribution, the results revealed distinct profiles for the two samples. The A sample exhibited a higher proportion of coarse grains (7.5% > 8.0 mm) compared to the B sample (0.7%), which met the requirement of 0% for grains >8.0 mm. Similarly, the A sample recorded 15.6% for grain sizes >6.3 mm, exceeding the maximum limit of 5% (±2%), whereas the B sample remained within acceptable range (2.0%). In the category of grain sizes 1.0–6.3 mm, A had 81.1%, while B exhibited 96.2%, highlighting its predominance of smaller-sized grains. Importantly, for grain sizes <1.0 mm, both samples fell within the acceptable range for this fraction, with A and B yielding 3.3% and 1.8%, respectively. Meanwhile, the fraction of very fine grains (<0.125 mm) was below the detection limit (<0.5%), aligning well with the requirement of ≤10% (±2%).

From an environmental perspective, the use of salt with elevated moisture and metal content for de-icing may result in long-term degradation of soil and aquatic systems. Research across multiple regions has documented the influence of de-icing salts on soil mineral composition, water quality, and biological communities [6], [7], [8]. Prolonged application in urban environments has been linked to increased salinity and metal contamination in surrounding ecosystems [9], [10]. These outcomes emphasize the need for rigorous quality control measures and the use of salt that complies with health and environmental safety standards [11,12]. Additionally, emerging de-icing technologies suggest that alternatives such as slow-release or thermally modified salts can minimize environmental impacts [13], encouraging a transition toward sustainable de-icing practices [12]. Research conducted in Europe has further confirmed the long-term effects of de-icing salts on soil and water, which has led to the adoption of more stringent regulatory frameworks and site-specific application protocols [14,15].

Implication for Winter Road Maintenance

According to point 1.1.5 of the Winter Road Maintenance Guidelines, grain composition is a critical determinant of salt performance. Salt in which the fraction of grains smaller than 1 mm constitutes less than 40% (such as A) is classified as **coarse salt**, offering deeper and longer-lasting melting action, making it ideal for breaking up thick, compacted, and ice-bound layers. Conversely, salt in which the fraction smaller than 1 mm comprises more than 60% (such as B) is classified as fine-grained salt, providing rapid surface melting and making it more effective for thin layers of ice or "black ice," although it may be more prone to wind displacement. Overall, both samples demonstrated distinct characteristics that align with different use cases within winter maintenance. The A sample, with its higher proportion of coarse grains and moisture content within the acceptable range, is better suited for deeper ice and compacted snow, providing long-lasting melting performance. The B sample, with its higher proportion of fine grains and higher moisture content, is ideal for rapid surface treatments where quick ice melting is required, although its higher moisture content may necessitate closer attention to storage and application conditions. Physicochemical Analysis and Grain Size Distribution of Road Salt Samples for Winter Maintenance.

Table 3. Physicochemical Properties of Road Salt Samples Compared to PN-EN 16811-1:2016-10 Standards. Two road salt samples (A and B) were analyzed for their compliance with the physicochemical requirements specified in PN-EN 16811-1:2016-10.

Indicators	Unit	Sample A	Sample B	Standard Requirement
Sodium Chloride (NaCl)	%	94.9	90.7	Minimum 90%
Sulfur (S)	%	1.16	1.61	Maximum 3.0%
Aluminum (Al)	mg/kg	97.6	14.7	Maximum 50 mg/kg
Arsenic (As)	mg/kg	<0.50	<0.50	Maximum 2.5 mg/kg

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Cadmium (Cd)	mg/kg	<0.05	0.06	Maximum 2.0 mg/kg
Cobalt (Co)	mg/kg	0.60	0.98	Maximum 2.0 mg/kg
Chromium (Cr)	mg/kg	1.10	<0.30	Maximum 5.0 mg/kg
Copper (Cu)	mg/kg	6.84	8.10	Maximum 5.0 mg/kg*
Mercury (Hg)	mg/kg	<0.05	<0.05	Maximum 0.5 mg/kg
Nickel (Ni)	mg/kg	0.26	0.09	Maximum 5.0 mg/kg
Lead (Pb)	mg/kg	0.76	2.10	Maximum 5.0 mg/kg
Zinc (Zn)	mg/kg	2.69	1.42	Maximum 20 mg/kg

Note: Copper content in both samples slightly exceeds the standard limit.

The grain size distribution was assessed by sieve analysis to classify the samples as fine (F), medium (M), or coarse (C) grade salt according to PN-EN 16811-1.

Table 4. Grain Size Distribution of Road Salt Samples Compared to PN-EN 16811-1:2016-10 Standards

Grain Size	**Unit**	**Sample A**	**Sample B**	**Standard Range for Grades (%) Passing Sieve**
Grain 8.0 mm	%	100	100	F: 100%
Grain 6.3 mm	%	76.9	97.3	M: 75–95%, C: 100%
Grain 3.15 mm	%	47.4	72.0	F: 90–100%, M: 45–80%, C: 30–80%
Grain 1.00 mm	%	3.3	1.8	F: max 35%, M: 10–60%, C: 5–35%
Grain <0.125 mm	%	<0.50	<0.50	F: max 5%, M: max 7%, C: max 7%

Table 5. Physicochemical Properties of Edible Salt Samples Compared to PN-C-84081-2:1998 and Literature Limits

Parameter	**Unit**	**Result A**	**Result B**	**Standard for Evaporated (Vacuum) Salt**	**Standard for Rock Salt**	**Standard for Evaporated (Pan) Salt**
Appearance	-	Coarse Product	Coarse Product	Crystalline Product	Crystalline Product	Crystalline Product
Color	-	White and Pink	White	White	White or White with a Natural Shade of Gray or Pink	White
Smell	-	Without Foreign Odor	Without Foreign Odor	Without Foreign Odor	Without Foreign Odor	Without Foreign Odor
NaCl (%)	%	94.9	90.7	≥ 99.0%	≥ 97.0%	≥ 99.0%
Water Content	%	2.2	6.2	≤ 0.2%	≤ 0.5%	≤ 0.2%

Table 6. Heavy Metal Concentration in Edible Salt Samples Compared with Literature Limits.

Element	**Unit**	**Result A**	**Result B**	**Literature Limit**
Arsenic (As)	mg/kg	<0.50	<0.50	≤ 0.5
Lead (Pb)	mg/kg	0.764	2.10	≤ 2.0
Cadmium (Cd)	mg/kg	<0.05	0.06	≤ 0.5
Mercury (Hg)	mg/kg	<0.05	<0.05	≤ 0.1
Copper (Cu)	mg/kg	6.84	8.10	≤ 2.0
Iron (Fe)	mg/kg	60.4	12.8	≤ 10

The bar chart shows the concentrations of selected trace metals (As, Pb, Cd, Hg, Cu, and Fe) in the two salt samples (Figure 1). The results reveal that Fe has the highest concentration in sample A (60.4 mg/kg), while sample B contains a lower level of Fe (12.8 mg/kg). Similarly, Cu is slightly higher in sample A (8.10 mg/kg) compared to sample B (6.84 mg/kg). The other metals — As, Pb, Cd, and Hg — were detected at very low or near the limit of quantification, indicating that their presence is minimal in both samples. These findings highlight the significant differences in metal content between the samples and underscore the need for further purification and quality control measures, especially for metals present in higher concentrations. Both salt samples meet the minimum sodium chloride content requirement (>90%) and fall within the acceptable limits for most contaminants. However, copper concentrations in both samples exceed the standard maximum (5 mg/kg), which could be a concern for environmental impact.

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Grain size analysis indicates that Sample A is closer to medium-grade salt, while Sample B demonstrates characteristics between medium and fine grades. Both samples conform well to the sieve size distribution requirements, ensuring suitability for winter road maintenance.

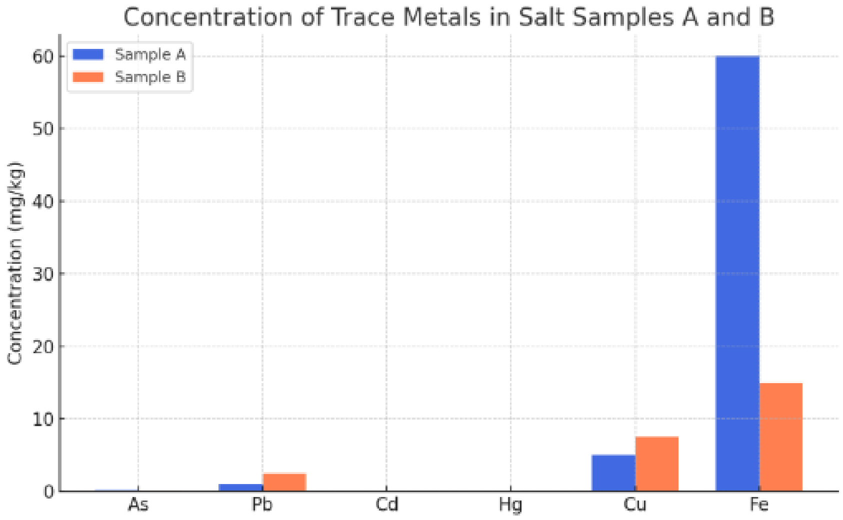

Figure 1. Concentration of Trace Metals in Salt Samples (A and B)

Conclusion

The comparative analysis of salt samples A and B revealed that while both exhibit high sodium chloride purity (over 90%), making them suitable for industrial de-icing and road maintenance, they differ in key properties that influence their practical applications. Sample A has lower moisture content (2.2%) and a coarser grain structure, making it more effective for deep ice penetration and prolonged melting, especially in severe winter conditions. In contrast, Sample B contains higher moisture (6.2%) and finer particles, enabling faster surface melting but potentially requiring additional processing to prevent clumping and storage issues. Both samples contain trace amounts of heavy metals, such as copper and iron, which exceed food-grade standards but remain within industrial limits. However, Sample B's higher moisture and metal content raise greater environmental concerns, suggesting the need for proper handling or pretreatment. The findings highlight that Sample A is better suited for long-term winter maintenance, while Sample B is more effective for rapid response scenarios. The study underscores the importance of selecting salt based on specific operational needs and environmental considerations, with opportunities for quality improvements through moisture control and impurity reduction.

To ensure the quality and safety of the salt for its intended uses, it is recommended to reduce moisture content through controlled drying processes to enhance flowability and storage stability. Grain size should be optimized through sieving to meet the required specifications for either edible or de-icing applications. Heavy metal concentrations, particularly copper and iron, should be minimized using purification techniques such as recrystallization or blending with higher purity salt. Contamination with mineral oils must be strictly avoided, especially for edible salt, through rigorous quality control. Regular monitoring and testing are essential to ensure compliance with national and international standards. These measures collectively improve the overall quality and environmental safety of the salt.

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