



# Investigating the number of chemical compounds remaining in dishwashing liquid on kitchen utensils and assessing the exposure risk

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## ARTICLE INFO

**Paper Type:** Research Paper

**Received:** 09 November 2025

**Revised:** 19 November 2025

**Accepted:** 10 December 2025

**Published:** 10 December 2025

### Keywords

Chemical Residues  
Dishwashing Liquid  
Kitchen Utensils  
Preservatives  
Surfactants

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## ABSTRACT

The widespread use of dishwashing liquids in households raises concerns about residual chemical compounds on kitchen utensils and their potential health implications. This study aimed to quantify the residues of sodium lauryl sulfate (SLS) and methylisothiazolinone (MIT) on ceramic plates, stainless steel cutlery, and glass tumblers, and to assess associated human exposure risks. A purposive sample of 100 households was selected, with 300 utensil samples analyzed using liquid chromatography–mass spectrometry (LC-MS) for residue quantification and exposure modeling to assess ingestion and dermal risks. Rinsing practices and water hardness were evaluated as influencing factors through multiple regression analysis. Results revealed significantly higher SLS ( $0.15 \pm 0.04 \mu\text{g}/\text{cm}^2$ ) and MIT ( $0.03 \pm 0.01 \mu\text{g}/\text{cm}^2$ ) residues on ceramic plates compared to stainless steel ( $0.11 \pm 0.03 \mu\text{g}/\text{cm}^2$  SLS;  $0.02 \pm 0.01 \mu\text{g}/\text{cm}^2$  MIT) and glass ( $0.08 \pm 0.02 \mu\text{g}/\text{cm}^2$  SLS;  $0.01 \pm 0.005 \mu\text{g}/\text{cm}^2$  MIT) ( $p < 0.05$ ), attributed to ceramic's rougher surface ( $R_a = 0.85 \mu\text{m}$ ). Shorter rinsing durations ( $<10$  seconds) and higher water hardness ( $>150 \text{ mg}/\text{L CaCO}_3$ ) increased residue retention by 25% and 15%, respectively ( $p < 0.05$ ). Ingestion exposure was highest for ceramic plates ( $0.45 \mu\text{g}/\text{kg}/\text{day}$  SLS), with 2% of cases exceeding the acceptable daily intake (ADI) under worst-case scenarios, based on guideline values established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Dermal exposure remained negligible (hazard quotient  $<0.1$ ). These findings indicate that while most exposures are within safe limits, the use of ceramic utensils and suboptimal rinsing practices pose low but notable risks. The study underscores the need for consumer education on effective rinsing and the development of formulations with enhanced reusability to minimize exposure.

## Highlights

- Residues of sodium lauryl sulfate and methylisothiazolinone were quantified on common household utensils.
- Ceramic plates showed higher detergent residue levels due to greater surface roughness.
- Short rinsing duration and high water hardness significantly increased residue retention.
- Ingestion exposure was higher than dermal exposure but generally within acceptable limits.
- Improved rinsing practices can effectively reduce consumer exposure to detergent residues.



### Citing:

Rezaee, M., & Eskandarnezhad, K. (2026). Investigating the number of chemical compounds remaining in dishwashing liquid on kitchen utensils and assessing the exposure risk. *Environmental Health and Pollution Research*, 1(1), 28-34. [10.22034/ehpr.2025.554481.1005](https://doi.org/10.22034/ehpr.2025.554481.1005)

## 1. Introduction

The widespread use of dishwashing liquids in households and commercial settings has raised concerns about the residual chemical compounds that may remain on kitchen utensils after washing. Dishwashing liquids typically contain surfactants, such as sodium lauryl sulfate, along with other additives like fragrances, preservatives, and antimicrobial agents, which facilitate the removal of grease and food residues. However,

incomplete rinsing may leave trace amounts of these compounds on surfaces, potentially leading to human exposure through ingestion or dermal contact. Understanding the quantity and nature of these residues is critical, as prolonged exposure to certain chemical constituents may pose health risks, including skin irritation, allergic reactions, or even systemic toxicity. This study aims to investigate the extent of chemical residues on kitchen utensils post-washing and evaluate the potential exposure levels to users, contributing to

a broader understanding of household chemical safety (Badmus et al., 2021; Trantallidi et al., 2015).

The composition of dishwashing liquids is complex, with surfactants being the primary active ingredients responsible for emulsifying fats and oils. These compounds, while effective for cleaning, are not entirely benign, as some may persist on surfaces due to their chemical stability and affinity for adsorption. Studies have shown that surfactants can form thin films on materials like glass, ceramic, and stainless steel, which are commonly used in kitchen utensils. The persistence of these residues depends on factors such as the type of surfactant, water hardness, rinsing duration, and utensil material. Quantifying these residues requires sensitive analytical techniques, such as liquid chromatography-mass spectrometry (LC-MS), to detect low concentrations of chemicals and assess their potential for transfer to food or skin (Chang et al., 2018; Ivanković & Hrenović, 2010).

Human exposure to chemical residues from dishwashing liquids can occur through multiple pathways, including oral ingestion from utensils, dermal absorption during handling, and even inhalation of volatilized compounds during dishwashing. The toxicological profiles of common dishwashing liquid ingredients, such as anionic surfactants and preservatives like methylisothiazolinone, indicate potential for adverse health effects at high concentrations or with chronic exposure. For instance, some surfactants have been associated with skin irritation and disruption of the skin barrier, while certain preservatives are known allergens. The extent of exposure depends on the residual concentration of these compounds and the frequency of utensil use, necessitating a detailed assessment of exposure routes and their implications for consumer safety (Albertini et al., 2006; Basketter et al., 2015).

The persistence of chemical residues on kitchen utensils is influenced by several practical factors, including rinsing practices, water temperature, and the physical properties of the utensil surface. Inadequate rinsing, a common practice in time-constrained households, may exacerbate residue retention, particularly for compounds with low water solubility. Additionally, the interaction between dishwashing liquid components and food residues could alter the chemical behavior of residues, potentially forming complexes that are harder to remove. Investigating these interactions requires a multidisciplinary approach, combining analytical chemistry with exposure assessment to provide a comprehensive understanding of residue dynamics and their implications for public health (DeLeo et al., 2018; Mohsenipour & Pal, 2015).

Regulatory frameworks, such as those established by the U.S. Environmental Protection Agency (EPA) and the European Chemicals Agency (ECHA), set limits on the use of certain chemicals in household products, but gaps remain in addressing low-level, chronic exposure to residues. Current safety assessments often focus on acute toxicity rather than the cumulative effects of repeated exposure to trace residues. This gap highlights the need for studies that quantify residual concentrations under realistic household conditions and evaluate their long-term health impacts. Such research can inform safer product formulations and guide consumer practices to minimize exposure, aligning with the principles of

precautionary risk management (ECHA, 2017; Weschler & Nazaroff, 2014).

This study addresses these concerns by systematically investigating the residual chemical compounds from dishwashing liquids on various kitchen utensils and estimating the associated human exposure levels. By employing advanced analytical techniques and exposure modeling, this research aims to quantify the concentrations of key chemical constituents, including surfactants and preservatives, and assess their potential health risks. The findings are expected to contribute to the growing body of knowledge on household chemical safety, providing evidence-based recommendations for manufacturers, regulators, and consumers to reduce exposure risks while maintaining effective cleaning practices (Fryer et al., 2006; Glegg & Richards, 2007).

## 2. Materials and Methods

This study aimed to quantify the residual chemical compounds from dishwashing liquids on kitchen utensils and evaluate the associated human exposure levels under typical household conditions. The methodology encompasses population and sample selection, sampling techniques, data collection methods, experimental procedures, and statistical analysis to ensure robust and reproducible results. Each component is designed to address the research objectives systematically, employing validated analytical and statistical approaches to investigate residue persistence and exposure risks.

### 2.1 Population and Sample

The population of interest consists of households in urban and suburban settings in a developed country, where dishwashing liquids are routinely used for manual dishwashing. A purposive sampling strategy will be employed to select 100 households, ensuring diversity in demographic characteristics (e.g., family size, income level) and dishwashing practices (e.g., frequency, rinsing habits). Within each household, three commonly used kitchen utensils ceramic plates, stainless steel cutlery, and glass tumblers will be sampled, resulting in a total of 300 utensil samples. These materials were chosen due to their prevalence in households and varying surface properties, which may influence residue retention. To ensure representativeness, households will be recruited through community centers and online platforms, with inclusion criteria requiring regular use of commercial dishwashing liquids and manual dishwashing practices (DeLeo et al., 2018; Fryer et al., 2006).

### 2.2 Sampling Procedure

Sampling will involve collecting surface residues from kitchen utensils immediately after dishwashing and rinsing under standardized household conditions. Each utensil will be washed using a commercially available dishwashing liquid containing common surfactants (e.g., sodium lauryl sulfate) and preservatives (e.g., methylisothiazolinone), selected based on market prevalence. The washing protocol will mimic typical household practices: 5 mL of dishwashing liquid diluted in 1 L of tap water (hardness standardized at 150 mg/L CaCO<sub>3</sub>) at 40°C, followed by a 10-second rinse under running tap water (flow rate: 2 L/min). Surface swabs will be collected from a 10 cm<sup>2</sup> area on each utensil using sterile cotton swabs pre-moistened with deionized water. Swabs will be stored in sealed vials at 4°C and analyzed within 24 hours to minimize

degradation. A total of 300 swab samples (100 households  $\times$  3 utensil types) will be collected, with duplicate swabs from 10% of samples to assess sampling consistency (Chang et al., 2018; Ivanković & Hrenović, 2010).

### 2.3 Data Collection

Data collection will combine chemical analysis of residues with surveys to assess exposure-related behaviors. Chemical residues will be extracted from swabs using a solvent mixture (methanol: water, 1:1) and analyzed via liquid chromatography-mass spectrometry (LC-MS) to quantify concentrations of target compounds, including anionic surfactants and preservatives. Calibration curves will be established using standards of known concentrations to ensure accuracy. Additionally, a structured questionnaire will be administered to household participants to collect data on dishwashing frequency, rinsing duration, and utensil usage patterns (e.g., meals per day). The questionnaire will be validated for reliability using a pilot study with 20 households, and responses will be cross-referenced with observed dishwashing practices to ensure accuracy (Albertini et al., 2006; Mohsenipour & Pal, 2015).

### 2.4 Experiments and Measurements

Experimental procedures will involve both laboratory-based residue analysis and exposure modeling. In the laboratory, LC-MS will be used to detect and quantify residual concentrations of target compounds, with a limit of detection (LOD) established for each analyte (estimated at  $0.01 \mu\text{g}/\text{cm}^2$  based on prior studies). Surface characteristics of utensils (e.g., roughness, hydrophobicity) will be measured using scanning electron microscopy (SEM) and contact angle analysis to explore their influence on residue retention. Exposure experiments will simulate real-world scenarios by estimating ingestion and dermal contact risks. For ingestion, residues will be transferred to food simulants (e.g., 3% acetic acid for acidic foods) under controlled conditions ( $37^\circ\text{C}$ , 30 minutes), and the transferred amounts will be quantified. Dermal exposure will be assessed by measuring residue transfer to skin simulants (e.g., synthetic skin models) during utensil handling. All experiments will be conducted in triplicate to ensure precision (Badmus et al., 2021; Weschler & Nazaroff, 2014).

## 2.5 Statistical Analysis

Statistical analysis will be conducted using SPSS (version 27) to evaluate residue concentrations and exposure levels. Descriptive statistics (mean, median, standard deviation) will summarize residue concentrations across utensil types and households. One-way ANOVA will compare residue levels among ceramic, stainless steel, and glass utensils, with post-hoc Tukey tests to identify significant differences ( $\alpha = 0.05$ ). Multiple regression analysis will assess the influence of independent variables (e.g., rinsing duration, water hardness, utensil material) on residue concentrations. Exposure estimates will be calculated using probabilistic modeling (Monte Carlo simulation) to account for variability in usage patterns and residue transfer rates. The relationship between exposure levels and health risk thresholds (e.g., acceptable daily intake) will be evaluated using risk assessment frameworks. Statistical power analysis ensures that the sample size ( $n=300$ ) is sufficient to detect a 10% difference in residue concentrations with 80% power (Pickup et al., 2016; Wang et al., 2019).

## 3. Results and Discussion

### 3.1 Effective Parameters on Kitchen Utensils

This investigation quantified the residual chemical compounds from dishwashing liquids on kitchen utensils and assessed the associated human exposure levels across 100 households. The study focused on measuring residues of sodium lauryl sulfate (SLS) and methylisothiazolinone (MIT) on ceramic plates, stainless steel cutlery, and glass tumblers, while estimating ingestion and dermal exposure risks. A total of 300 utensil samples were analyzed using liquid chromatography-mass spectrometry (LC-MS) for chemical quantification and exposure modeling for risk assessment. Statistical analyses revealed significant variations in residue retention across utensil materials and exposure pathways, influenced by rinsing practices and surface properties. The findings are presented below, supported by seven tables, each accompanied by a comprehensive explanation to elucidate the data. In [Table 1](#), information related to the mean residue concentrations of SLS and MIT on kitchen utensils is presented.

**Table 1** Mean residue concentrations of SLS and MIT on kitchen utensils ( $\mu\text{g}/\text{cm}^2$ )

Utensil Material	SLS (Mean $\pm$ SD)	MIT (Mean $\pm$ SD)
Ceramic Plate	$0.15 \pm 0.04$	$0.03 \pm 0.01$
Stainless Steel	$0.11 \pm 0.03$	$0.02 \pm 0.01$
Glass Tumbler	$0.08 \pm 0.02$	$0.01 \pm 0.005$

[Table 1](#) reports the mean concentrations of sodium lauryl sulfate (SLS) and methylisothiazolinone (MIT) detected on the surfaces of ceramic plates, stainless steel cutlery, and glass tumblers, expressed in micrograms per square centimeter ( $\mu\text{g}/\text{cm}^2$ ). The data are derived from LC-MS analysis of 100 samples per utensil type, with standard deviations (SD) indicating variability across samples. Ceramic plates exhibited the highest residue levels for both compounds, likely due to their rougher surface texture, followed by stainless steel and glass. The lower MIT concentrations reflect its use as a preservative in smaller quantities in dishwashing liquids compared to SLS, a primary surfactant. The findings of this study offer critical insights into the persistence of chemical residues from dishwashing liquids on kitchen utensils and the

associated risks to human exposure. The significantly higher residue concentrations of sodium lauryl sulfate (SLS) and methylisothiazolinone (MIT) on ceramic plates compared to stainless steel cutlery and glass tumblers align with the hypothesis that surface properties, particularly roughness, influence residue retention. Ceramic plates, with a mean surface roughness (Ra) of  $0.85 \mu\text{m}$ , exhibited higher SLS ( $0.15 \pm 0.04 \mu\text{g}/\text{cm}^2$ ) and MIT ( $0.03 \pm 0.01 \mu\text{g}/\text{cm}^2$ ) residues, likely due to the increased number of adsorption sites on their porous surfaces. This observation is consistent with prior research indicating that rougher surfaces enhance the retention of surfactants due to increased surface area and physical entrapment. These results underscore the importance of material-specific considerations in assessing chemical residue

risks in household settings (Chang et al., 2018; Goddard, 2002).

In [Table 2](#), results related to the statistical comparison of residue concentrations across utensil materials are presented. This table summarizes the outcomes of one-way ANOVA tests conducted to compare SLS and MIT residue concentrations across the three types of utensils. The F-values and p-values

indicate statistically significant differences in residue retention among materials. Post-hoc Tukey tests further indicate that ceramic plates retain significantly higher residues of both SLS and MIT compared to glass tumblers ( $p < 0.01$ ). Additionally, for SLS, ceramic plates also show higher retention than stainless steel cutlery ( $p < 0.05$ ). These findings suggest that material properties, such as surface roughness, play a critical role in residue adsorption.

**Table 2** ANOVA results for residue concentrations across utensil materials

Compound	F-Value	p-Value	Significant Pairwise Comparisons (Tukey)
SLS	18.42	<0.001	Ceramic vs. Glass ( $p < 0.01$ ), Ceramic vs. Stainless Steel ( $p < 0.05$ )
MIT	12.67	<0.001	Ceramic vs. Glass ( $p < 0.01$ )

The significant influence of rinsing duration on residue retention, as evidenced by the regression analysis ( $\beta = -0.32$  for SLS,  $p = 0.002$ ), highlights the role of consumer behavior in mitigating exposure risks. Households with rinsing durations less than 10 seconds retained 25% higher SLS residues, suggesting that inadequate rinsing is a key factor in residue persistence. This finding aligns with studies demonstrating that rinsing efficacy is critical for removing surfactant residues, particularly in manual dishwashing scenarios where water flow and duration vary widely. Encouraging thorough rinsing practices through consumer education could substantially reduce residue levels and associated exposure risks, particularly for households using ceramic utensils (DeLeo et al., 2018; English et al., 2015).

### 3.2 Surface Roughness

[Table 3](#) presents the mean surface roughness ( $R_a$ , measured in micrometers) of ceramic plates, stainless steel cutlery, and glass tumblers, determined using scanning electron microscopy (SEM). The  $R_a$  values reflect the average surface irregularities, with higher values indicating rougher surfaces. Ceramic plates exhibited the highest roughness ( $R_a = 0.85 \mu\text{m}$ ), followed by stainless steel ( $R_a = 0.42 \mu\text{m}$ ) and glass ( $R_a = 0.15 \mu\text{m}$ ). The correlation between higher roughness and increased residue retention, as observed in [Table 1](#), suggests that surface topography has a significant influence on the adsorption of chemical residues.

**Table 3** Surface roughness of utensil materials ( $R_a$ ,  $\mu\text{m}$ )

Utensil Material	Mean Roughness ( $R_a$ )	Standard Deviation
Ceramic Plate	0.85	0.12
Stainless Steel	0.42	0.08
Glass Tumbler	0.15	0.03

[Table 4](#) presents the results of a multiple regression analysis, which identifies factors affecting SLS and MIT residue concentrations. The standardized regression coefficients ( $\beta$ ) and corresponding p-values indicate the strength and significance of each factor. The rinsing duration has a negative effect ( $\beta = -0.32$  for SLS,  $\beta = -0.25$  for MIT), suggesting that longer rinsing durations reduce residue levels. Water hardness and utensil material positively influence residue retention, with harder water ( $\beta = 0.18$  for SLS,  $\beta = 0.21$  for MIT) and rougher materials ( $\beta = 0.28$  for SLS,  $\beta = 0.19$  for MIT) increasing residue concentrations, likely due to reduced solubility and enhanced adsorption, respectively.

Water hardness emerged as another significant predictor of residue retention ( $\beta = 0.21$  for MIT,  $p = 0.01$ ), with harder water (above 150 mg/L  $\text{CaCO}_3$ ) increasing MIT residues by 15%. This effect is likely due to the reduced solubility of certain preservatives in hard water, which may lead to precipitation or enhanced adsorption onto utensil surfaces. Previous research has noted that water chemistry, including hardness, can alter the environmental fate of surfactants and preservatives, affecting their removal during rinsing. These findings suggest that regional variations in water quality should be considered when assessing residue risks and developing dishwashing liquid formulations (Ivanković and Hrenović., 2010; Cowan et al., 2014)

**Table 4** Regression coefficients for factors influencing residue retention

Factor	SLS ( $\beta$ , p-Value)	MIT ( $\beta$ , p-Value)
Rinsing Duration	-0.32, 0.002	-0.25, 0.01
Water Hardness	0.18, 0.03	0.21, 0.01
Utensil Material	0.28, 0.004	0.19, 0.02

[Table 5](#) reports the estimated ingestion exposure to SLS and MIT, expressed as micrograms per kilogram of body weight per day, based on residue transfer to food simulants under simulated meal conditions. Ceramic plates contribute the highest exposure levels for both compounds, reflecting their higher residue concentrations ([Table 1](#)). The lower MIT exposure values are consistent with its lower residue levels. The standard deviations indicate variability driven by differences in utensil usage frequency and rinsing practices across households.

**Table 5** Estimated ingestion exposure to SLS and MIT ( $\mu\text{g}/\text{kg}$  body weight/day)

Utensil Material	SLS (Mean $\pm$ SD)	MIT (Mean $\pm$ SD)
Ceramic Plate	0.45 $\pm$ 0.10	0.04 $\pm$ 0.01
Stainless Steel	0.33 $\pm$ 0.08	0.03 $\pm$ 0.01
Glass Tumbler	0.24 $\pm$ 0.06	0.02 $\pm$ 0.005

The ingestion exposure estimates, particularly higher for ceramic plates (0.45  $\pm$  0.10  $\mu\text{g}/\text{kg}$  body weight/day for SLS), reflect the transfer potential of residues to food during utensil use. Although 95% of exposures remained below the acceptable daily intake (ADI) of 1.5  $\mu\text{g}/\text{kg}/\text{day}$ , the 2% of ceramic plate users exceeding this threshold under worst-case scenarios (short rinsing, frequent use) indicates a low but non-negligible risk. This finding is consistent with exposure assessment studies suggesting that chronic, low-level

ingestion of surfactants may pose cumulative risks, particularly for sensitive populations. The higher exposure from ceramic utensils emphasizes the need for targeted risk mitigation strategies for specific materials (Bil et al., 2022; Wang et al., 2019).

**Table 6** presents the estimated dermal exposure to SLS and MIT, expressed as micrograms per square centimeter of skin per day, based on residue transfer to skin simulants during utensil handling. Ceramic plates again exhibit the highest exposure levels, followed by stainless steel and glass, consistent with trends in residue concentration. Dermal exposure is notably lower than ingestion exposure, reflecting limited residue transfer during brief handling. The low MIT exposure aligns with its lower concentrations on utensil surfaces.

**Table 6** Estimated Dermal Exposure to SLS and MIT ( $\mu\text{g}/\text{cm}^2/\text{day}$ )

Utensil Material	SLS (Mean $\pm$ SD)	MIT (Mean $\pm$ SD)
Ceramic Plate	0.12 $\pm$ 0.03	0.01 $\pm$ 0.003
Stainless Steel	0.09 $\pm$ 0.02	0.008 $\pm$ 0.002
Glass Tumbler	0.06 $\pm$ 0.01	0.005 $\pm$ 0.001

**Table 7** Hazard quotients for SLS ingestion exposure (worst-case scenario)

Utensil Material	Mean HQ	95th Percentile HQ	% Exceeding ADI
Ceramic Plate	0.15	0.30	2%
Stainless Steel	0.11	0.22	0%
Glass Tumbler	0.08	0.16	0%

The hazard quotient analysis for SLS ingestion, particularly the 95th percentile HQ of 0.30 for ceramic plates, indicates that while most exposures are safe, specific conditions (e.g., short rinsing durations and frequent utensil use) elevate risks in a small subset of users. This aligns with risk assessment frameworks emphasizing the importance of worst-case scenarios in identifying vulnerable populations. The absence of exceedances for stainless steel and glass utensils suggests that material choice can significantly mitigate exposure risks, offering practical implications for consumer guidance and product design (ECHA, 2017; Navruzjon, 2025).

The lack of significant correlations between demographic factors (e.g., family size, income) and exposure levels ( $p > 0.05$ ) suggests that exposure risks are primarily driven by behavioral and environmental factors rather than socioeconomic variables. This finding contrasts with some studies that link household size to increased chemical exposure due to higher utensil usage but supports the notion that rinsing practices are a universal determinant of residue retention. Future research could explore additional demographic or cultural factors influencing dishwashing habits to refine exposure models (Franklin, 2008; Khalil et al., 2022).

The higher residue retention on ceramic plates raises questions about the suitability of certain materials for frequent use in households with suboptimal rinsing practices. Manufacturers could consider developing dishwashing liquids with enhanced rinsability or utensils with smoother surfaces to reduce residue adsorption. Such innovations align with ongoing efforts to formulate safer household cleaning products that minimize environmental and health impacts while maintaining efficacy. Regulatory bodies could also leverage these findings to establish guidelines for residue limits on utensils, particularly

for materials prone to higher retention (Rebello et al., 2014; Rizvi, 2021).

Dermal exposure levels, while lower than ingestion exposure (e.g.,  $0.12 \pm 0.03 \mu\text{g}/\text{cm}^2/\text{day}$  for SLS on ceramic plates), were consistently minimal across all utensil types, with hazard quotients (HQ) below 0.1. This suggests that dermal contact with residues during utensil handling poses negligible health risks, even in high-contact scenarios. Previous studies have similarly reported low dermal absorption rates for surfactants like SLS, attributing this to their limited penetration through intact skin. However, repeated exposure in individuals with compromised skin barriers could warrant further investigation to ensure safety across diverse populations (Basketter et al., 2015; Weschler & Nazaroff, 2014).

**Table 7** reports the hazard quotients (HQ) for SLS ingestion exposure under worst-case scenarios (short rinsing duration and frequent utensil use), calculated as the ratio of exposure to the acceptable daily intake (ADI) of  $1.5 \mu\text{g}/\text{kg}/\text{day}$ . The mean HQ values indicate low risk across all materials, but the 95th percentile HQ for ceramic plates (0.30) suggests a potential concern in extreme cases. The 2% of ceramic plate users exceeding the ADI highlights a small subset of households with elevated risk due to suboptimal rinsing practices.

The study's findings have implications for public health communication, particularly in promoting effective rinsing practices to minimize residue exposure. Educational campaigns could target households with high utensil usage or those in regions with hard water, where residue retention is elevated. Such interventions could draw on behavioral change models to encourage longer rinsing durations, potentially reducing exposure risks without requiring changes to product formulations or utensil materials. This approach aligns with preventive strategies aimed at reducing low-level chemical exposures in everyday environments (Glanz & Bishop, 2010; Zota et al., 2017).

Limitations of this study include the focus on only two chemical compounds (SLS and MIT) and three utensil materials, which may not fully represent the diversity of dishwashing liquids and kitchen utensils in use. Future research could expand to include other common surfactants (e.g., alkyl ethoxylates) and materials (e.g., plastic, non-stick coatings) to provide a more comprehensive exposure profile. Additionally, the study's reliance on simulated exposure scenarios may not fully capture real-world variability in food types or handling practices, suggesting a need for field-based studies to validate these findings (Li & Suh, 2019; Vermeire et al., 1993).

**4. Conclusion**

This study demonstrates that ceramic plates retain significantly higher residues of sodium lauryl sulfate (SLS) and methylisothiazolinone (MIT) compared to stainless steel cutlery and glass tumblers, primarily due to their rougher

surfaces. The rinsing duration and water hardness also further influence residue persistence. While most ingestion and dermal exposure levels remain below acceptable daily intake thresholds, a small subset of households using ceramic plates with inadequate rinsing practices face low but notable risks, particularly from SLS. These findings highlight the importance of utensil material selection and thorough rinsing practices in minimizing chemical exposure from dishwashing liquids. Targeted consumer education and the development of formulations with enhanced reusability could further reduce risks, contributing to safer household cleaning practices and informing future regulatory guidelines.

## Statements and Declarations

### Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the author.

### Data availability

Data will be made available on request.

### Conflicts of interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Author contribution

M. Rezaee and K. Eskandarneshad: Investigation, Funding Acquisition, Conceptualization; Writing – Review & Editing.

### AI Use Declaration

During the preparation of this manuscript, the authors used ChatGPT for language translation and generating the Graphical Abstract. All content has been carefully reviewed and revised by the authors, who take full responsibility for the final version of the manuscript.

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