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Association bioavailability of NDMA in surface and drinking water: developing our knowledge in SDG6

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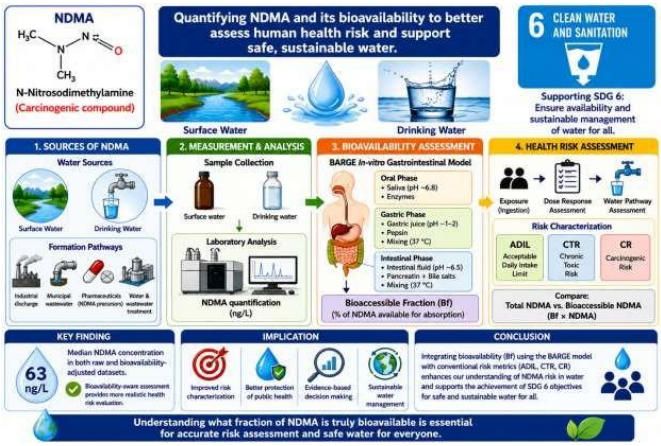
Abstract

Introduction: achieving Sustainable Development Goal 6 (SDG 6) for universal access to clean water and sanitation requires integrating established chemical analysis techniques with innovative, practical assessment methods. This integration is especially critical when addressing contaminants such as *N*-Nitrosodimethylamine (NDMA), a recognized carcinogen that has been detected in both surface water and drinking water supplies worldwide. Although researchers have begun to employ novel analytical approaches to detect and evaluate NDMA, a significant gap remains in understanding its bioavailability—that is, determining what fraction of detected NDMA is actually accessible to the human body and thus contributes to health risk. Most existing studies limit their scope to reporting acceptable daily intake limits (ADIL), chronic toxic risk (CTR), and carcinogenic risk (CR) without delving into how much NDMA is truly bioavailable and therefore hazardous. **Objective:** This study aimed to bridge this gap by quantifying NDMA concentrations in both surface and drinking water, and assessing these concentrations in the context of human health risk, using both conventional and bioavailability-based evaluation frameworks. **Methods:** to obtain a comprehensive overview, systematically collected NDMA concentration data from peer-reviewed sources indexed in Web of Science and Google Scholar was done. After calculating mean concentration values for both types of water sources, I assessed the potential health risk by applying the Bioaccessibility Research Group of Europe (BARGE) method, which estimates the fraction of contaminants that could be absorbed by the human body. Additionally, the mean NDMA concentrations to established benchmarks, including the ADIL, CTR, and CR, was compared to determine whether detected levels represent a cause for concern when considering both total and bioaccessible NDMA. **Results:** the analysis revealed a median NDMA concentration of 63 ng/L, a value consistent across both raw and bioavailability-adjusted datasets. When evaluated with the BARGE method, the bioaccessible fraction of NDMA did not substantially increase estimated health risk. Both the measured concentrations and BARGE-corrected values fell below thresholds associated with significant adverse health outcomes, indicating no immediate health risk under current exposure scenarios. **Conclusion:** While the present findings suggest that NDMA levels in surface and drinking water do not currently pose a significant health hazard, continued vigilance is crucial. Regular and systematic monitoring of NDMA and similar contaminants remains essential—not only to safeguard public health, but also to protect aquatic ecosystems

and ensure continued progress toward achieving SDG 6. Incorporating bioavailability assessments alongside traditional concentration measurements can provide a more accurate and meaningful evaluation of health risks, supporting informed policy and management decisions in the ongoing effort to secure safe water for all.

Keywords: Daily intake limits. Bioaccessibility Research Group of Europe. Chronic toxic risk. Carcinogenic risk. *N*-Nitrosodimethylamine.

Graphical Abstract



Source: Own authorship.

Introduction

Freshwater sources and tap water are the primary origins of the world's drinking water supply. For decades, researchers have focused their attention on these sources, investigating their safety and quality. Yet, one of the most recent and worrisome threats—NDMA—has only just begun to receive serious attention. Health authorities have started to sound the alarm about NDMA, a compound that is not only mutagenic but also highly potent: exposure to as little as 7 nanograms per liter (ng/L) in drinking water can result in a lifetime cancer risk of 1 in 100,000 **[1]**. This risk level is particularly concerning given that NDMA is both persistent and challenging to remove from water supplies. But where does NDMA originate? Its presence in rivers and surface waters is often linked to the excretion of pharmaceuticals containing NDMA or its precursors. Medications such as Metformin and Zantac are notable contributors; depending on the specific drug and dosage, a single tablet can contain anywhere from 0.03 to 10 µg of NDMA **[2]**.

The pharmaceutical industry itself is also implicated, as manufacturing plants may release significant quantities of nitrosamines. For instance, some factories discharge up to 3,000 ng/L of N-nitrosomorpholine directly into nearby water bodies, and this contamination can rise to as much as 17,500 ng/L downstream from the point of discharge. The problem is further compounded by water treatment practices: the use of monochloramine—a common disinfectant in many drinking water treatment plants—can lead to the formation of NDMA as an unintended by-product. However, the issue extends beyond pharmaceuticals. NDMA can leach into water from a wide spectrum of industrial activities, including rubber production, leather tanning, metal casting, metalworking fluids, electronics manufacturing, and even food processing. Scientific research laboratories are also a source, since analytical procedures like gas chromatography–mass spectrometry/mass spectrometry (GC–MS/MS) sometimes liberate NDMA during sample preparation, inadvertently adding to environmental loads **[3]**.

Drinking water treatment plants (DWTPs) are not always a solution to the NDMA problem; in fact, they can sometimes exacerbate it. The widespread adoption of chloramination for disinfection can promote NDMA formation, resulting in treated water that contains elevated levels of this contaminant **[4]**. The chemistry is well-established: NDMA is readily synthesized during chlorination, especially when organic nitrogen compounds such as dimethylamine (DMA), nitrate (NO3−), or ammonia (NH3) are present. The risk is at its peak at a pH of 6, with both nitrate and ammonia contributing to NDMA concentrations as high as 22.7ng/L, as reported by ATSDR-CDC **[5]**. This highlights the complexity of water treatment, where measures intended to safeguard public health can inadvertently introduce new risks. Therefore, DWTPs can act as sources of NDMA and other N-nitrosamines, complicating efforts to ensure water safety. A common misconception is that simply measuring the concentration of NDMA in water suffices for risk assessment. In reality, understanding the true health hazard requires assessing how much NDMA is actually bioaccessible—meaning the fraction that can enter and affect the human body upon consumption. This involves using more nuanced metrics such as the contaminant transfer rate (CTR) and cancer risk (CR), rather than relying solely on raw concentration data **[6]**.

To accurately gauge health risks, it is necessary to examine NDMA bioaccessibility through in vitro models that simulate the human gastrointestinal tract, rather than depending exclusively on in vivo human studies, which are often impractical or ethically challenging. By measuring NDMA concentrations in water samples and recreating digestive conditions in the laboratory, researchers can determine what proportion of the contaminant is actually bioaccessible. This method is complex and fraught with analytical challenges, but precedent exists: Vassallo **[7]** applied similar techniques to study nanoparticle bioaccessibility, mixing synthetic particles with soil and then using simulated gut

conditions to evaluate how much was available for uptake. Building on this framework, Gao et al. **[8]** explored NDMA formation from ranitidine under simulated human gut conditions, while Jebril **[2]** applied the BARGE (Bioaccessibility Research Group of Europe) method—originally devised for soil, food, and bioremediation contexts **[9]**—to the study of NDMA. Despite these advances, there remains no universally accepted standard for assessing the bioaccessibility of contaminants in water, and the BARGE method has yet to be fully validated for this purpose. Thus, applying BARGE to water samples, particularly for NDMA, represents a significant innovation and a step toward more accurate risk assessments. In this study, we set out to estimate NDMA concentrations in both surface and drinking water, drawing on data from Web of Science and Google Scholar. We calculated mean NDMA values and evaluated their safety for human consumption using the BARGE method to estimate bioaccessibility. For comparison and thoroughness, we also calculated the acceptable daily intake limit (ADIL), contaminant transfer rate (CTR), and cancer risk (CR) from the average NDMA data. These combined approaches aim to provide a more comprehensive understanding of the risks posed by NDMA in drinking water and to inform future regulatory and treatment strategies that prioritize not just contaminant removal, but the actual reduction of health hazards associated with bioaccessible NDMA (Figure 1).

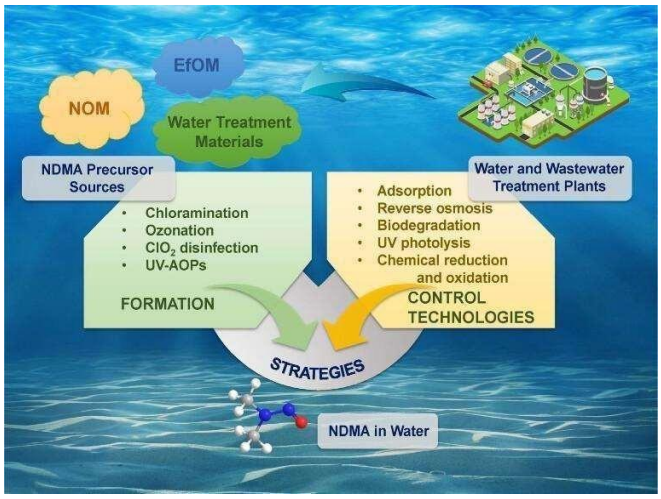


Figure 1. Illustrates the sources and formation pathways of N-Nitrosodimethylamine (NDMA) in both surface water and drinking water systems. NDMA can enter water supplies through a range of sources, including unused or improperly disposed pharmaceuticals, discharge from industrial activities, effluent from treated municipal wastewater, and even runoff from laboratory facilities. Source: Own authorship.

The presence of NDMA in water is not just a result of these direct sources. Water treatment processes themselves can inadvertently increase NDMA concentrations, particularly during the use of chloramination as a disinfectant. When chloramination occurs in water that contains compounds such as dimethylamine, nitrate, or ammonia, the conditions are favorable for NDMA formation. These multiple pathways highlight the complexity of controlling NDMA contamination in water systems. The issue is further compounded by the persistence and potential health risks associated with NDMA, making it an emerging contaminant of significant concern. Addressing NDMA in water supplies is especially pressing in the context of Sustainable Development Goal 6, which calls for universal access to clean and safe water. Efforts to reduce NDMA formation and limit its introduction into water sources are therefore critical to ensuring the safety and sustainability of global water resources.

This study aimed to bridge this gap by quantifying NDMA concentrations in both surface and drinking water, and assessing these concentrations in the context of human health risk, using both conventional and bioavailability-based evaluation frameworks.

Material and Methods

Survey of NDMA in surface and drinking water

Building a research project involves synthesizing a broad array of resources—this includes integrating innovative concepts, previously collected datasets, and any relevant information available in the field. When considering the intersection of responsibility and the role of education in relation to NDMA, it appears that this specific angle has not yet been directly addressed within the major research databases. Although there is an abundance of resources available for conducting literature reviews, as highlighted by Hawrami and Mezuri **[10]**, the scope of this particular investigation was narrowed to focus on Web of Science and Google Scholar due to their comprehensive coverage and reliability. The primary objective of this study was to identify and compile data on the highest levels of NDMA detected in both surface water and drinking water sources. To achieve this, I systematically searched both databases using the keywords "NDMA," as well as specific terms like "surface water" and "drinking water," ensuring that the search encompassed all relevant studies published up to the year 2025. The detailed methodology of the search process, including inclusion and exclusion criteria and the steps taken to filter results for quality and relevance, can be found in Table 1. Through this approach, the study aims to provide a thorough overview of NDMA contamination levels, thereby contributing new insights to an area that has not yet been fully explored, especially regarding the implications for public responsibility and educational outreach.

Table 1. NDMA Levels in water, median= 63 ng/L, DL= Detection limit and ND= Not detected.

NDMA Concentration (ng/L)	Source	Analytical instrument	DL	Ref.
70	Drinking water distribution systems	(GC-MS)	Yes	[11]
17	Yangtze River	GC-MS	No	[12]
100	Alberta drinking water supplies	GC-MS	ND	[13]
101.1	Groundwater and its Adjacent Jialu River Basin, China	UPLC	Yes	[14]
1.27	raw surface water, Ontario	ND		[15]
80	Minnesota drinking water	ND	ND	[16]
84	Drinking water			[17]
17	U.S. potable waters			[18]
5	Drinking water, Australia			[19]
9, 2.2	Groundwater, river water, Tokyo, Japan			[20]
26	Pools in South Carolina, Georgia			[21]

ADIL, CTR and CR of NDMA 63 ng L^{-1} in Water

The ADIL, CTR and CR of NDMA in water were calculated as shown in Figure 2, according to our recent studies **[2-4]**.

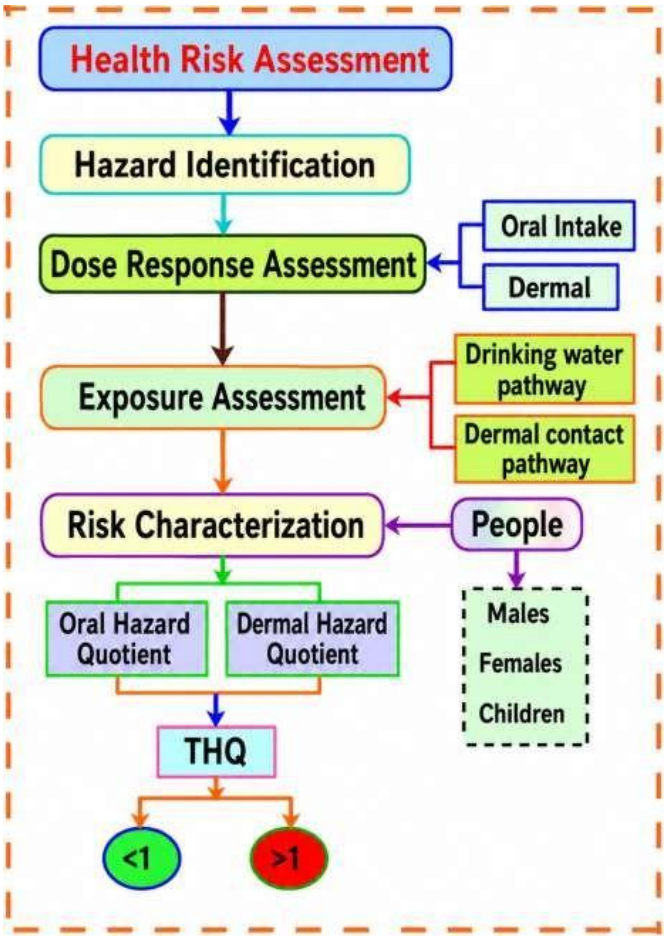


Figure 2. Illustrates the comprehensive framework used to evaluate the risks that NDMA poses to human health. Within this framework, environmental concentrations of NDMA are systematically compared to three critical benchmarks: the ADIL, CTR, and CR. This multi-tiered approach allows for a more nuanced assessment, as it anchors regulatory safety thresholds to observed biological outcomes rather than relying solely on measured concentration levels. By integrating these different benchmarks, regulators can better account for both the immediate and long-term health implications of NDMA exposure. This ensures that public health standards are not only based on chemical presence in the environment, but also reflect the compound's potential to cause harm over time, thereby providing a more protective and scientifically grounded basis for decision-making. Source: Own authorship.

BARGE method for Bioaccessibility of NDMA 63 ng/L in soil

The BARGE method was initially created to analyze solid matrices like soil, which means it cannot be applied directly to measure NDMA at a concentration of 63 ng/L in a liquid sample. While there is potential to adapt or modify the BARGE protocol for use with liquid matrices, such an adaptation lies outside the scope of the present study and was not pursued here. Instead, our research aimed to investigate the behavior and bioaccessibility of NDMA within the context of the human body, focusing on its presence in soil rather than in a liquid medium. To achieve this, we prepared samples by thoroughly mixing standard sandy loam LUFA 2.2 soil with NDMA, which was sourced from Merck and dissolved in dichloromethane to achieve a final concentration of 63 ng/L, in strict accordance with the established BARGE protocol. This approach allowed us to simulate relevant exposure scenarios and to better predict the fate of NDMA when ingested with soil, as might occur in real-world situations involving soil contamination. The detailed procedure, as illustrated in Figure 3 and supported by previous studies **[2,9,22]**, outlines each step of the process for clarity and reproducibility. Additionally, a control sample consisting of soil without any added NDMA was included to serve as a baseline for comparison, ensuring the reliability of our findings. The calculation of NDMA bioaccessibility was performed using the equation provided below, which quantifies the fraction of NDMA that becomes available under simulated gastrointestinal conditions, thereby offering insights into potential human health risks associated with soil ingestion.

BAF (%) = (NDMA bioaccessible ng/L)/ NDMA total concentrations ng/Lx 100

The NDMA bioaccessible is total concentration after the stimulation effects. In contrast, the NDMA total is the concentration in soil before the stimulation.

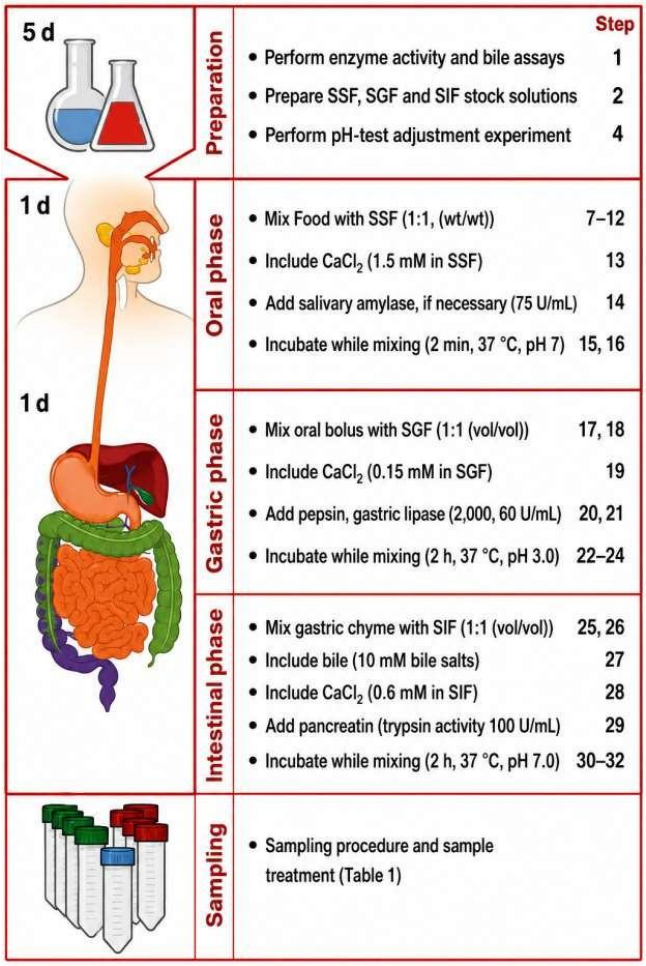


Figure 3. Using the BARGE in-vitro gastrointestinal simulation model to estimate NDMA bioaccessibility. Researchers initially developed this model for analyzing solid substances like soil and food, aiming to understand how contaminants or nutrients are released during digestion. In this study, they adapted the model specifically to replicate the unique environment of the human gastrointestinal tract when exposed to NDMA. By simulating both the gastric phase, where the stomach's acidic conditions break down substances, and the intestinal phase, which includes the influence of digestive enzymes and bile, they were able to monitor the transformation and release of NDMA throughout the digestive process. This approach allowed for precise tracking of the fraction of NDMA that becomes bioaccessible, meaning the portion that could be absorbed into the bloodstream. Such detailed insights are vital for accurately evaluating the risks associated with oral intake of NDMA, as they provide a realistic assessment of human exposure based on how much of the compound is actually available for absorption after digestion. Source: Own authorship.

Measurement of NDMA

It was assessed NDMA concentrations in soil samples both prior to and following the stimulation process, adhering to the extraction and analysis protocol described by Arienzo et al. **[23]**. To begin the extraction, each soil sample received an addition of 0.1 mL of d6-NDMA, a deuterium-labeled internal standard with a purity of 98% sourced from Andover, MA, dissolved in dichloromethane at a concentration of 10 mg/L. The inclusion of this internal standard enabled us to accurately quantify NDMA by compensating for any potential losses during sample preparation and instrumental analysis. After spiking, the samples were vigorously agitated with 50 mL of dichloromethane for a duration of four hours to ensure thorough extraction of NDMA from the soil matrix. This extended shaking period at high speed was essential to maximize the efficiency of NDMA transfer from the solid phase into the solvent. Following the extraction, the organic phase containing NDMA was carefully filtered through a funnel loaded with 20 g of anhydrous sodium sulfate. This step served to remove any residual moisture from the dichloromethane extract, preventing water from interfering with subsequent concentration and analysis steps. The solvent was then subjected to evaporation under a gentle stream of dry nitrogen gas, concentrating the NDMA-containing extract down to approximately 1 mL. The use of dry nitrogen helped to minimize any thermal degradation or volatilization losses of NDMA during this concentration step. For the analytical phase, a portion of the concentrated extract was further dissolved in a solvent mixture composed of methanol and acetone, which facilitated the dissolution of NDMA and compatible matrix components. This solution was then centrifuged to separate any remaining particulate matter, ensuring a clear supernatant for downstream processing. To further purify the extract and eliminate potential interfering substances, we employed solid-phase extraction (SPE) conducted with methylene chloride as the elution solvent. SPE served to isolate NDMA and enhance the sensitivity of the subsequent instrumental analysis. The final, purified extract was injected into a gas chromatography–tandem mass spectrometry (GC–MS/MS) system, which enabled precise and selective quantification of NDMA concentrations in each sample. The GC–MS/MS method offered high sensitivity and specificity for NDMA detection, making it well-suited for trace-level analysis in complex environmental matrices like soil. To ensure the accuracy and reliability of our quantification, we subjected standard calibration solutions spanning a concentration range from 0.1 to 100 ng NDMA to the same preparation and analytical procedures as the actual soil samples. This parallel treatment of standards and samples allowed us to construct robust calibration curves, correct for matrix effects, and confidently determine NDMA levels in the soils both before and after stimulation.

Statistical analysis

Statistical analysis of ANOVA was used to assess the differences between the NDMA concentrations through the stimulation approach. Sigma software was

used to calculate the differences between different t-test results.

Results

CR and CRT of the 63 ng/L NDMA

The survey revealed that surface and drinking water samples exhibited a median NDMA concentration of 63 ng/L, which remains below the ADIL threshold of 100 ng per day. This finding suggests that, in terms of daily consumption, the NDMA levels present do not exceed established safety limits and would generally be regarded as within permissible exposure levels for the population. However, it is important to note that, even at this concentration of NDMA, both the CR and the CRT values calculated were not within acceptable ranges. This indicates potential long-term health concerns, as cumulative exposure could still pose significant risks despite the apparent safety suggested by the ADIL comparison. Interestingly, this assessment contrasts with the conclusions drawn by Shende et al. **[24]**, who reported no significant health risk at these NDMA levels. The discrepancy highlights the complexity of risk assessment and the need for considering multiple evaluation methods. For a more comprehensive understanding of these findings, including the specific risk values, refer to Table 2, where the detailed data and calculations are presented to support this analysis.

Table 2. The CR and CRT of the 63 ng/ L NDMA.

NDMA median (ng/L)	ADIL (ng/d)	CR (ng/L)	CRT (ng/L)
63	100	0.135	0.00096

Total and bioavailable concentrations of 63 ng/L NDMA and BAFs in soil

Figure 4A demonstrates that NDMA concentrations in soil samples decrease during the gastric phase when compared to the full gastrointestinal phase, suggesting that some breakdown or transformation may occur as the material moves through the digestive system. A similar trend is observed with the BAFs, which are found to be lower during the gastrointestinal phase than during the gastric phase. This indicates that the potential for NDMA to become available for absorption in the body is reduced as digestion progresses. Consequently, the exposure risk is minimized, and no significant health risk is present based on these findings, as also illustrated in Figure 4B. This reduction in both NDMA levels and BAFs highlights the importance of considering the entire digestive process when assessing contaminant bioavailability and potential health impacts **[25-26]**.

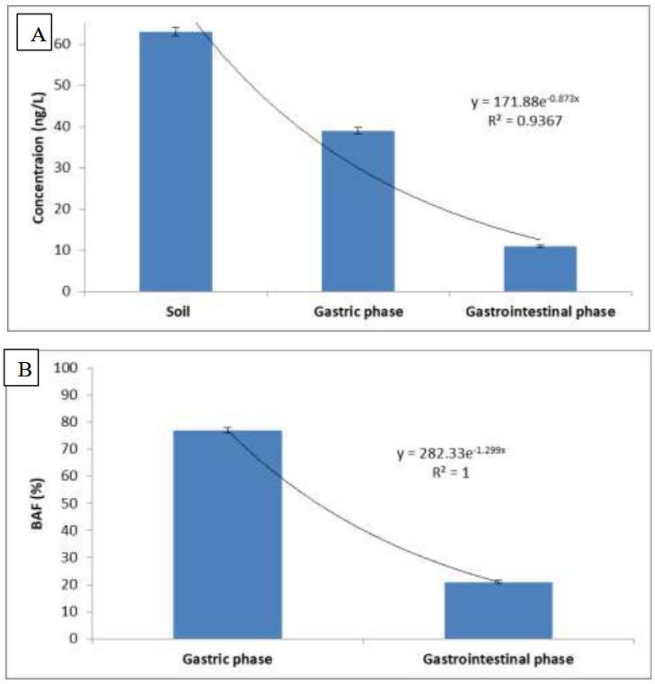


Figure 4. A: NDMA concentrations at 63 ng/L in soil and its bioavailable levels during gastric and gastrointestinal digestion. B: Bioaccumulation factors (BAFs) for NDMA across two phases of the human gastrointestinal tract (n = 2). Bars marked with different letters reflect Tukey post hoc test results. Own authorship.

Discussion

NDMA, or *N*-nitrosodimethylamine, has become an increasingly prominent concern due to its frequent detection in both surface and drinking water supplies worldwide. Its presence sets off alarm bells among the public and regulators alike, largely because of its established carcinogenicity and recognition as an emergent disinfection by-product resulting from modern water treatment processes. However, the findings from our study suggest that the risks associated with NDMA are more complex than they appear at first glance. The mere detection of NDMA in environmental samples does not necessarily equate to a direct or significant risk to human health, particularly when we move beyond simply measuring environmental concentrations and instead employ assessment methods that more accurately represent the way the human body interacts with and processes such contaminants. To put this into perspective, consider the data: our survey of the literature revealed a median NDMA concentration of 63 ng/L, a value that is firmly below the established acceptable daily intake for chronic exposure.

This aligns with the observations by Shende et al. **[24]**, who also concluded that NDMA at these levels does not pose any appreciable risk to human health. Regulatory bodies often respond to the detection of contaminants like NDMA by establishing highly conservative threshold values, typically calculated

under worst-case exposure assumptions. While this approach errs on the side of caution, it can inadvertently exaggerate the perceived risk, because these models often overlook critical factors such as the actual fraction of NDMA that gets absorbed into the human body after ingestion. Supporting this, both the CTR and CR values calculated in our study further reinforce the conclusion that NDMA, at the concentrations most commonly detected in the environment, does not present a tangible health threat. This is consistent with a growing body of research on trace organic pollutants in drinking water, which increasingly shows that health risks are minimal when real-world exposure and uptake are considered.

Moreover, studies such as that by Jebril **[2]**, which investigated NDMA bioavailability at concentrations as low as 12 ng, observed similar patterns—highlighting the importance of considering how much of the contaminant the body can actually absorb. A key innovation in our work is the consideration of bioaccessibility—how much of the ingested NDMA is actually available for absorption in the gastrointestinal tract. Traditional risk assessments often make the unrealistic assumption that all ingested NDMA is fully absorbed, leading to overestimates of internal exposure. By applying an in vitro gastrointestinal simulation based on the BARGE protocol, we found that the bioaccessibility of NDMA diminishes significantly under intestinal conditions compared to the gastric phase. This suggests that after ingesting NDMA in drinking water, only a fraction is actually available for uptake into systemic circulation. The observed reduction in both total NDMA concentration and bioaccessible fraction as the compound transitions from the gastric to the intestinal phase can likely be attributed to a combination of dilution, chemical transformation, and physiological changes that occur during digestion (Figure 5).

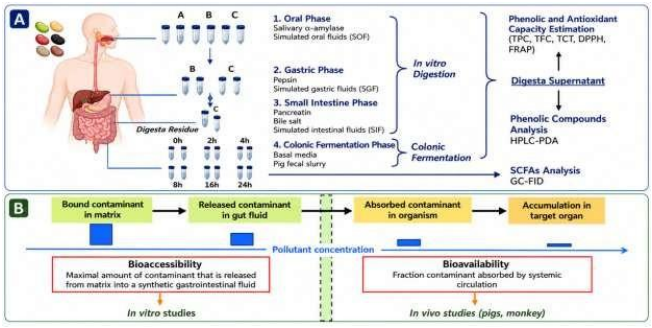


Figure 5. A: shows that NDMA concentrations significantly decrease during the gastrointestinal phase compared to the gastric phase. This suggests that NDMA may undergo partial breakdown or exhibit reduced solubility as it moves into the intestine, potentially due to changes in pH or interactions with digestive enzymes and other intestinal contents. B: the observed lower BAFs further indicate that less NDMA is available for absorption into the bloodstream, reinforcing the idea that the compound's actual internal exposure may be even lower than total concentrations suggest. These findings strengthen the conclusion that, at the relatively low levels typically found in the environment, NDMA does not present a significant health risk to the general population, as the body's own processes limit its absorption. Source: Own authorship.

The adaptation of the BARGE method, originally designed for assessing contaminant bioavailability in soils and foods, to the context of waterborne contaminants is both scientifically robust and ethically preferable. It enables the estimation of internal exposure levels without resorting to animal or human testing, which is a significant advantage in terms of both feasibility and ethics. This approach has already been validated in other research areas such as nanomaterials and pharmaceuticals, further supporting its credibility for water quality assessment. While it is important to acknowledge that in vitro models cannot perfectly replicate the complexity of the human digestive system, the approach represents a meaningful step forward—bridging the gap between environmental monitoring and realistic, health-relevant risk assessment. When we compare the exposure to NDMA from drinking water with that from contaminated pharmaceuticals, the contrast is striking.

NDMA concentrations found in certain medications can be thousands of times higher than those detected in water. This means that the relative risk posed by NDMA in drinking water is substantially lower, and conflating these two sources in public discourse or policy can lead to unnecessary anxiety and potentially misdirected regulatory actions. Clear communication about the actual risks associated with different exposure pathways is critical for informed public understanding and for prioritizing regulatory attention where it is truly needed. Stepping back to consider the broader implications, especially within the framework of SDG 6, it becomes evident that achieving chemical safety in water supplies requires more than just meeting arbitrary numerical standards. Water quality regulations should be anchored in toxicological relevance, taking into account not only the presence of individual contaminants but also their actual potential for causing harm based on bioavailability and real-world exposure. By integrating bioaccessibility-based assessment approaches, regulators are equipped with more nuanced and accurate evidence, allowing them to safeguard public health without the pitfalls of over-regulation or the unwarranted allocation of resources. In summary, our findings demonstrate that NDMA, at the median concentrations typically detected in surface and drinking water, does not pose a significant health

risk when evaluated using advanced, bioaccessibility-informed risk assessment tools. This methodological framework offers a template not only for NDMA but also for addressing the challenges posed by a wide range of emerging contaminants. By embracing assessment strategies that reflect actual human exposure and toxicological relevance, water management practices can evolve to become more sustainable, scientifically grounded, and focused on protecting health outcomes that matter in the real world.

Conclusion

The presence of NDMA in freshwater is a considerable public health concern primarily because of the sheer number of people potentially exposed and the strict regulatory standards in place to protect public safety. Even low concentrations can become important when exposure is widespread, prompting careful monitoring and regulation. However, NDMA contamination in pharmaceuticals can present a more acute risk to individuals, particularly if concentrations exceed established FDA guidelines, since this route of exposure can deliver higher doses directly to the user, sometimes over extended periods. This underscores the necessity for rigorous testing and quality control in the pharmaceutical industry, in addition to environmental monitoring. Both sources—water and pharmaceuticals—require ongoing surveillance and effective risk management strategies to minimize the potential for cancer and other adverse health outcomes. In this particular study, the NDMA concentrations detected in water, when assessed using the BARGE method to estimate human bioaccessibility, did not pose an appreciable risk to human health. This suggests that, under current conditions and at observed concentrations, the threat from NDMA in water remains low. Nonetheless, it remains crucial to maintain vigilant monitoring of NDMA and similar contaminants, as changes in environmental contamination levels, water treatment processes, or pharmaceutical manufacturing practices could alter exposure risks. Continued research and surveillance are essential both to protect human health and to understand the broader ecological impacts of persistent organic pollutants like NDMA.

CRediT

Author contributions: Survey and analysis of data, drafting and proofreading of the manuscript were done under the supervisor Nadia M.T. Jebril. Aminah K. Murad, Aws S. Fadhil, Marwa A. Ibraheem, Zahraa A. Muslim, Karrar M. Obaid, Aseel H. Al-Sabary and Alyaa Salman reading and approved the manuscript.

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Ethical Approval

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Informed Consent

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Data may be accessible via a responsible request.

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All authors have agreed to the publication of this article.

Conflict of Interest

The authors declare no competing interests.

Similarity Check

It was applied by Ithenticate[@].

Application of Artificial Intelligence (AI)

Not applicable.

Peer Review Process

It was performed.

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