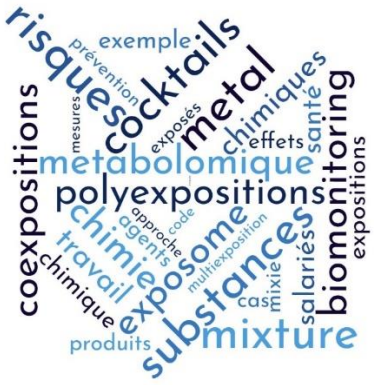

Bulletin de veille
Polyexpositions chimie-chimie
N°9 - juin 2025

Objectif : la polyexposition homogène chimie/chimie est un sujet de plus en plus préconisé pour étudier l'évaluation du risque professionnel et sa prévention. L'objectif est de connaitre les travaux récents qui sont publiés sur le sujet et identifier des moyens d'analyse, et d'interprétation de cette co-exposition à plusieurs composés chimiques.

Ce bulletin a été réalisé à partir d'une surveillance de littérature récente sur les bases Web of Sciences et la base documentaire INRS-Biblio.

La validation des informations fournies (exactitude, fiabilité, pertinence par rapport aux principes de prévention, etc.) est du ressort des auteurs des articles signalés dans la veille. Les informations ne sont pas le reflet de la position de l'INRS. Les éléments issus de cette veille sont fournis sans garantie d'exhaustivité.

Les liens mentionnés dans le bulletin donnent accès aux documents sous réserve d'un abonnement à la ressource.

Actualités web sélectionnées

- 24 avril. Anses. Résultats de l'expertise collective de l'Inserm sur les effets des pesticides sur la santé. https://www.anses.fr/fr/content/analyse-des-resultats-de-lexpertise-collective-inserm

- le CIRC célèbre ses 60 ans et à cette occasion, organise une année de campagne jalonnée par de nombreux évènements. https://circ60.iarc.who.int/fr/home-fr/

- 2 mai. Faut-il s'inquiéter des polluants chimiques dans notre environnement ? Article du Pr Yves Lévy, professeur émérite en santé publique et santé environnementale dans le magazine Harmonie Santé. Lien vers l'article

- la 7ème édition du Patty's Toxicology 2024 comprend un chapitre intitulé « Mixture assessments ». Lien vers la notice INRS-Biblio

- Article d'actualités médicales publié en ligne le 30 mai 2025 dans JAMA. « Au-delà des gènes : un projet d'exposome humain pour s'attaquer aux facteurs externes de la maladie ». Signature de la déclaration sur l'exposome humain. https://jamanetwork.com/journals/jama/fullarticle/2834864

- Rencontre scientifique organisée par Anses et Dares : les (nouveaux) enjeux de la santé au travail. 30 septembre 2025. https://ptolemee.com/sante-travail/index.html

- Libération 10 juin : Pollution, alimentation… Lancement d'une enquête au long cours sur la santé des Français Lire l'article

Sommaire

1. Généralités

Betancur S. ; Bryant A.L. ; Conklin J. ; Walton A.M.
Occupational exposure to chemical substances and health outcomes among hospital environmental services workers : a scoping review of international studies.

Journal of Occupational and Environmental Hygiene 2024 ; 21 (4) : 287-309

Cette revue exploratoire s'intéresse au secteur hospitalier, plus précisément aux agents des services environnementaux (EVS) chargés du nettoyage, de la désinfection et de la gestion des déchets. Elle analyse les risques professionnels liés à l'exposition à diverses substances chimiques, notamment les produits de nettoyage, les désinfectants, les solvants, les agents stérilisants et certains médicaments dangereux comme les antinéoplasiques. L'objectif principal de l'article est de recenser et d'analyser les études internationales portant sur l'exposition professionnelle des agents EVS à ces substances et les effets sanitaires associés. Les risques identifiés concernent principalement des symptômes cutanés (eczéma, dermatite de contact), respiratoires (asthme, essoufflement, irritation nasale), oculaires (irritation, larmoiement), ainsi que des marqueurs biologiques de stress oxydatif et d'inflammation. Deux études mettent en évidence une contamination des mains par des médicaments anticancéreux, bien que les niveaux mesurés restent inférieurs aux seuils réglementaires, ce qui souligne la nécessité d'une vigilance accrue. Les études soulignent également l'importance de la formation, de l'utilisation d'équipements de protection individuelle, et de politiques adaptées pour réduire les expositions. Les auteurs recommandent la mise en place d'études longitudinales, l'amélioration de la surveillance environnementale et le développement d'interventions ciblées pour protéger ce personnel vulnérable. Ce travail met en lumière un manque de données sur l'exposition des EVS et appelle à renforcer la prévention des risques chimiques dans ce secteur. https://doi.org/10.1080/15459624.2024.2311870

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Bouchard, M., Buitrago Cortes, J., El Majidi, N., Côté, J., Dieme, D., Mantha, M., Wingert, L. (2025).

Evaluation et caractérisation de l'exposition aux fumées de soudage et leurs composantes métalliques lors d'activités de soudage au Québec.

Rapport n° RS-1215-fr. 2025. IRSST.

Cette étude porte sur les fumées de soudage, reconnues comme cancérogènes pour l'humain et liées à divers risques sanitaires pour les soudeurs. L'objectif principal était d'évaluer la nature et le niveau d'exposition aux métaux présents dans ces fumées chez des apprentis soudeurs au Québec, en mesurant ces éléments dans plusieurs matrices biologiques et dans l'air, au cours d'un suivi longitudinal. Réalisée dans des écoles de la région de Montréal, où les techniques courantes de soudage sont enseignées, la recherche a suivi 116 apprentis utilisant trois procédés : soudage à l'arc avec électrode enrobée (SMAW), soudage à l'arc sous gaz avec fil plein (GMAW) et soudage à l'arc avec fil fourré (FCAW). Les chercheurs ont effectué des mesures sériées de métaux multiples dans l'urine, les ongles et les cheveux pour identifier les métaux les plus absorbés et les matrices biologiques les plus pertinentes pour le suivi des expositions. L'échantillonnage des fumées a aussi été réalisé dans la zone respiratoire des travailleurs pendant des journées typiques. Les résultats ont montré une augmentation progressive des concentrations de fer, manganèse, nickel et chrome dans les ongles des mains et des pieds ainsi que dans les cheveux tout au long du programme. L'arsenic a augmenté dans les ongles des mains et les cheveux, tandis que le cobalt a augmenté dans les ongles mais pas dans les cheveux. Les niveaux urinaires de manganèse, fer et nickel ont augmenté à la fin du module SMAW, mais pas lors des autres modules. La durée d'exposition était le facteur principal expliquant l'augmentation des métaux absorbés. D'autres facteurs comme l'âge, l'origine ethnique et le revenu ont aussi influencé les niveaux, agissant comme facteurs de confusion. Cette étude, première au Québec et au Canada à utiliser plusieurs matrices biologiques simultanément, démontre que même dans un environnement d'apprentissage contrôlé, l'exposition aux fumées de soudage entraîne une absorption significative de métaux. Les concentrations mesurées dans l'urine, les cheveux et les ongles constituent des biomarqueurs pertinents pour le suivi de cette exposition.

https://doi.org/10.70010/SWBK9077

https://pharesst.irsst.qc.ca/rapports-scientifique/982/

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Handa, S., Isaacs, K. K., Wall, J. T., Larger, A., Burns, S., Koval, L. E.*, et al.*
The Chemical and Products Database v4.0, an updated resource supporting chemical exposure evaluations.
Sci Data 2025, Vol. **12** (1), 950

Since the initial release of the Chemical and Products Database (CPDat) in 2018, the United States Environmental Protection Agency has added a considerable amount of chemical exposure-related information to the database and has expanded its schema to accommodate new types of data. This data descriptor provides information regarding the structure and types of data contained within CPDat (both existing and new), new controlled vocabularies implemented to harmonize terminology across the different data types, application of a rigorous data curation and quality assurance tracking system, and various methods of accessing CPDat.
https://doi.org/10.1038/s41597-025-05240-0

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Chen, D., Lawrence, K. G., Stewart, P. A., Gorman Ng, M., Stenzel, M. R., Cherrie, J. W., et al.
Skin conditions associated with dermal exposure to oil spill chemicals among Deepwater Horizon disaster response and cleanup workers.
Ecotoxicol Environ Saf 2025, Vol. 294, 118076

BACKGROUND : Previous studies have associated oil spill response and cleanup (OSRC) work with skin symptoms, but evidence is lacking on the specific exposure agents that contributed to these skin effects.
OBJECTIVES : We investigated OSRC-related exposures, including dermal exposure to specific chemical agents, in relation to acute and longer-term skin conditions among the 2010 Deepwater Horizon (DWH) OSRC workers.
METHODS : At GuLF Study enrollment, workers reported duration of work, jobs performed, and skin contact with crude oil/tar, dispersants, and decontamination chemicals. Cumulative dermal exposure to polycyclic aromatic hydrocarbons (PAHs) from oil/tar was estimated based on the "GuLF DREAM model". We used Poisson regression with robust standard errors to evaluate associations of exposures with prevalent skin conditions during spill cleanup and at enrollment (1-3 years later) and incident eczema diagnoses after the start of OSRC work. We examined modification

of associations between exposures and prevalent conditions by use of rubber/synthetic gloves.
RESULTS : Duration of OSRC work was positively associated with skin conditions and eczema diagnoses (p-trend<0.01). Workers in operations, response, and decontamination jobs had higher skin condition prevalence (during cleanup: PR range=3.13-4.51; at enrollment: PR range=2.20-2.94) and eczema risk (RR range=1.44-1.89) compared to support workers. After adjusting for co-exposures, we saw associations of skin conditions during cleanup with dermal exposure to oil/tar (PR=3.41, 95 %CI: 3.14, 3.69), decontamination chemicals (PR=1.55, 95 %CI: 1.46, 1.64), dispersants (PR=1.44, 95 %CI: 1.33, 1.57), and PAHs (p-trend<0.01). These associations remained apparent at enrollment. Eczema diagnosis was associated with exposure to oil/tar (RR=1.56, 95 %CI: 1.20, 2.04) and PAHs (Tertile 3 vs. 1: PR=1.33, 95 %CI: 0.86, 2.07). Effect estimates were on average 21 % lower among workers who used rubber/synthetic gloves.
CONCLUSIONS : Duration of work, working in non-support jobs, and dermal exposure to oil/tar, dispersants, decontamination chemicals, and PAHs were associated with acute and longer-term skin effects among the DWH OSRC workers.
https://doi.org/10.1016/j.ecoenv.2025.118076

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Cory-Slechta, D. A., Downs, C., Sobolewski, M.
Cumulative Risk Assessment as the Pathway to Public Health Protection for Behavioral Neurotoxicity.
Neurotoxicology, May 2025, Vol 108 : Pages 400-411

The formulation of adverse outcome pathways (AOPs) based on high-throughput in vitro new approach methods linking biochemical/mechanistic data with an apical endpoint considered an adverse outcome (AO), is increasingly proposed to accelerate the process of risk assessment for environmental chemical exposures. While a laudable goal, this approach ignores the extensive evidence demonstrating context-dependence of neurotoxicological consequences, including behavioral toxicity of chemical exposures. Such contextual modifiers can include environmental conditions (poverty, psychosocial stress, behavioral experience/history), physiological conditions (sex, period of exposure, nutritional status, brain region, exposure parameters), and genetic background. Context dependence represents a serious omission for AOP formulation because an environmental context can alter a chemical's molecular targets, or potentially enhance toxicity through interactions with other contextual conditions, thus leading to potential underestimation of neurological risks due to such exposures. The integrative physiological basis of AOs requires cumulative risk assessments that model environmental contexts across scales of biology, i.e., integration and testing in whole-animal models. AOPs contribute to the derivation of cumulative risk considerations regarding factors to incorporate into cumulative risk assessments by defining risk factors with shared biological targets. Epidemiological and animal model studies can provide information to prioritize interactive effects of greatest magnitude. Additionally, a focus on how a single risk factor in different physiological contexts may attribute risk across multiple neurologic conditions, rather than to a single unique condition, would provide broader public health protection. Realistic acknowledgement of context-dependence is requisite to understanding both the etiological basis of neurological diseases and disorders and to human health protection.
https://doi.org/10.1016/j.neuro.2025.04.015

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Ibrahim, B., Le Moual, N., Sit, G., Goldberg, M., Leynaert, B., Ribet, C., et al.
Occupational Exposure Patterns to Disinfectants and Cleaning Products and Its Association With Asthma Among French Healthcare Workers.
Am J Ind Med 2025, Vol. 68 (6), 516-530

BACKGROUND : Disinfectants and cleaning products (DCPs) are important asthma risk factors among healthcare workers. However, healthcare work involves heterogenous cleaning tasks and co-exposure to many chemicals. These multidimensional aspects have rarely been considered. We aimed to identify patterns of occupational exposure to DCPs and study their associations with asthma.
METHODS : CONSTANCES is a French population-based cohort of approximately 220,000 adults. Current asthma and asthma symptom score were defined by questionnaire at inclusion (2012-2021). Healthcare workers completed a supplementary questionnaire on their current/last held occupation, workplace, and cleaning activities that were used in unsupervised learning algorithms to identify occupational exposure patterns. Logistic and negative binomial regression models, adjusted for potential confounders, were used to assess associations with asthma outcomes.
RESULTS : In 5512 healthcare workers, four occupational exposure clusters were identified: Cluster1 (C1, 42%, reference), mainly characterized by low exposed nurses and physicians; C2 (7%), medical laboratory staff moderately exposed to common DCPs (chlorine/bleach, alcohol); C3 (41%), nursing assistants and nurses highly exposed to a few

DCPs (mainly quaternary ammonium compounds); and C4 (10%), nurses and nursing assistants highly exposed to multiple DCPs (e.g., glutaraldehyde, hydrogen peroxide, and acids). Among women (n = 3734), C2 (mean score ratio [95% CI]: 1.31 [1.02; 1.68]) and C3 (1.18 [1.03; 1.36]) were associated with higher asthma symptom score, and an association was suggested between C3 and current asthma (odds ratio 1.22 [0.99; 1.51]).
CONCLUSION : In a large population of healthcare workers, four DCP exposure patterns were identified, reflecting the heterogeneity of healthcare jobs. Two patterns, including one characterized by laboratory workers, were associated with greater asthma symptoms in women.
https://doi.org/10.1002/ajim.23725

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Li, P., Zhu, X., Liu, M., Wang, Y., Huang, C., Sun, J., et al.
Impact of gene-environment interactions on atrial fibrillation and cardiac structure.
Scientific Reports 2025, Vol. 15 (1), 16893.

Environmental pollution is a major burden of cardiovascular disease. The aim of the study was to investigate the interactions between combined environmental factors and genetic susceptibility on atrial fibrillation (AF) and cardiac structures.
The study included 374,495 participants from the UK Biobank, utilizing genetic data and environmental variables (including air pollution, noise, greenspace and water quality). Polygenic risk score (PRS) was calculated to estimate individual genetic risk. Cox proportional hazard model was applied to estimate the impact of exposure factors on the risk of AF occurrence. The mediation analysis was applied to assess the relationship among environmental scores, AF and cardiac structures. Population attributable fraction (PAF) was employed to assess potential influence of mitigating unfavorable environment characteristics on AF.
The results showed that the highest group of four domain scores exhibited 3.38–16.83% higher AF risk than the lowest. Individuals with higher scores in four domains and high PRS had hazard ratio (95%CI) of 2.76 (2.62, 2.91), 2.61 (2.47, 2.75), 2.86 (2.71, 3.02) and 2.84 (2.66, 3.02). Environmental factors could indirectly affect cardiac structures through AF. Up to 7.37% of AF cases could be preventable through environmental interventions. Our findings pointed that gene-environment interaction can increase AF risk, which further affect cardiac structures.
https://doi.org/10.1038/s41598-025-00921-7

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Scarselli, A., Porzio, A., Marinaccio, A.
Evaluation of occupational exposure risk experienced by a cohort of workers exposed to acrylonitrile using a register-based information system.
Annals of Work Exposures and Health 2025 ; wxaf021.

This study aims to explore the extent of exposure to acrylonitrile in workplaces in Italy and its potential implications for workers' health. Exposure measurements data (n = 31,599) on acrylonitrile reported in the period 1996 to 2022 to the Italian national register of occupational exposures, called SIREP, were collected and analysed. Concurrent exposures with other occupational carcinogens were investigated using SPSS 2-step cluster analysis.
A retrospective register-based cohort mortality study was performed, and standardized mortality ratios (SMRs) were calculated linking exposure data to national mortality statistics in the period 2005 to 2020. Most of the exposures occurred in the chemical industry (88%). Exposure to multiple occupational carcinogens was detected frequently (92% of exposed workers). Elevated proportions of deaths from lung and brain cancer, as well as Parkinson's disease, were found among exposed male workers (SMR = 1.3, CI: 1.0 to 1.7; SMR = 1.8, CI: 1.0 to 3.2; and SMR = 2.8, CI: 1.2 to 6.8, respectively). Among other cancers, increased proportions of deaths from multiple myeloma (SMR = 2.9, CI: 1.4 to 5.7), leukemia (SMR = 3.7, CI:1.2 to 11.4), and mesothelioma (SMR = 4.2, CI: 2.2 to 8.1) were also found.
The monitoring of occupational exposures for the prevention of related risks is the main goal of epidemiological surveillance systems such as SIREP. Some acrylonitrile exposure circumstances deserve special attention, especially in the chemical and plastic industries. The excesses mortality from Parkinson's disease, lung cancer, and brain cancer constitute an actual concern for acrylonitrile exposed workers and warrant the implementation of further prevention measures and investigation.
https://doi.org/10.1093/annweh/wxaf021

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Xiong, J., Li, Z., Fantke, P.
Modeling Human Exposure to Chemicals Via Different Freshwater Pathways.
Exposure and Health, 2025, p.

Assessing human health risks from chemicals in freshwater is inherently complex due to the multitude of exposure pathways involved. This study presents a novel aggregate exposure model to provide a comprehensive assessment of human chemical exposure from freshwater sources. Our framework incorporates distinct freshwater types (e.g., surface water, groundwater) and multiple exposure pathways, including aquaculture (fish consumption), aquatic activities (swimming, fishing), and routine household practices (drinking water, bathing). By using chemical concentrations in specific freshwater types as a basis for calculating the lifetime average daily dose, the model improves both precision and practicality in exposure assessment. Our findings reveal significant variation in the contributions of different exposure pathways and routes depending on the chemical analyzed. For example, di (2-ethylhexyl) adipate (DEHP), a chemical with high dermal uptake, accounted for approximately 55% of total exposure via the dermal route during swimming and showering. In contrast, ingestion dominated exposure for chemicals like urea, primarily through contaminated drinking water and fish consumption. These route-specific differences underscore the need to tailor water treatment strategies to chemical types and water sources. For instance, households relying on unfiltered groundwater should closely monitor BDE-209 and urea levels, as conventional water treatment methods are insufficient to mitigate exposure from household water use. This study underscores the importance of considering multiple exposure pathways to effectively assess and mitigate health risks from freshwater contaminants. By providing a pathway-specific understanding of exposure dynamics, our study offers a robust framework for tailoring interventions and mitigating health risks associated with freshwater contaminants.
https://doi.org/10.1007/s12403-025-00702-7

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2. Biomarqueurs, biomonitoring

Peng, B., Liu, M., Zhu, T., Fang, M.
Optimizing Human Exposome Biomonitoring : A Machine Learning Approach to Predict Optimal Biofluid Matrices.
Environmental Science & Technology Letters 2025, Vol. **12** (4) : 383-389.

Biomarker identification is crucial for exposomic studies, yet few have been established relative to the vast number of chemicals human encounter. While biomarkers can be detected in blood or urine, the optimal biological matrix for each chemical remains unclear. We curated data on biomarker identification in urine or blood for 526 chemicals from 4797 biomonitoring entities, sourced from 89 distinct cohorts across 43 countries, and developed a machine learning model named Biomarker Matrix Identifier (BMI) to predict the most suitable biological fluid for biomarker identification. Our model achieves over 94% accuracy using circular fingerprints as the input. Applying this method to the Human Exposomic Metabolome Database (HExPMetDB) containing over 20,000 chemicals revealed that approximately 67% of compounds are predicted to be more effectively monitored using urine as the optimal biomonitoring matrix. This predictive model enhances the accuracy of the exposure assessment in human exposomic analysis, facilitating more efficient biomarker identification strategies. In sum, we have established an effective prediction model in facilitating the prediction of whether the identified chemicals in the biological fluids can represent exposure for human exposomic analysis.
https://doi.org/10.1021/acs.estlett.5c00039

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Hull, S. D., Hougaard, K. S., Toft, G., Petersen, K. K. U., Flachs, E. M., Lindh, C., *et al.*
Fetal exposure to a mixture of endocrine-disrupting chemicals and biomarkers of male fecundity : A population-based cohort study.
Andrology 2025, Vol., First published : 12 April 2025

BACKGROUND : Fetal exposure to endocrine-disrupting chemicals (EDCs) has been associated with reduced male fecundity, but with few studies considering chemical mixtures.
OBJECTIVES : We assessed the association between fetal exposure to a mixture of EDCs and biomarkers of male fecundity in young adulthood.
MATERIALS AND METHODS : The study population comprised 841 young adult males enrolled in the Fetal

Programming of Semen Quality cohort, established as a male offspring sub-cohort within the Danish National Birth Cohort. Maternal blood samples were analyzed for concentrations of per- and polyfluoroalkyl substances (PFAS), phthalate metabolites, and triclosan. We used quantile g-computation to estimate the change in semen characteristics, testicular volume, and reproductive hormone levels with 95% confidence intervals (CI) per one-quartile increase in all chemicals within three chemical mixtures; an overall chemical mixture, a PFAS mixture, and a non-persistent chemical mixture.
RESULTS : Fetal exposure to a one-quartile increase in the overall chemical mixture was associated with 4.0 million/mL lower sperm concentration (95% CI: -9.1, 1.1), 16.1 million lower total sperm count (95% CI: -33.8, 1.6), 0.5 mL smaller testicular volume (95% CI: -1.2, 0.3), 5% higher proportion of non-progressive and immotile spermatozoa (95% CI: 0.99, 1.11), and 7% higher concentration of FSH (95% CI: 0.99, 1.16), but with limited precision. Effect sizes were greatest in magnitude for sperm concentration and total sperm count. We observed somewhat similar associations for the PFAS mixture and no associations for the non-persistent chemical mixture.
DISCUSSION : Results suggest that fetal exposure to an overall mixture of EDCs may be adversely associated with several biomarkers of male fecundity, but findings are also compatible with null associations. These associations, if true, appeared to be driven by PFAS, but misclassification due to a single measurement of the phthalate metabolites and triclosan may have attenuated the results.
https://doi.org/10.1111/andr.70039

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Choi, J. W., Jang, H., Kuiper, J. R., Bennett, D. H., Schmidt, R. J., Shin, H. M.
Gestational exposures to mixtures of multiple chemical classes and autism spectrum disorder in the MARBLES study.
Environ Res August 2025, Volume 278, 121646

BACKGROUND : Previous epidemiologic studies on gestational chemical exposures and autism spectrum disorder (ASD) often lack analysis of chemical mixtures or are limited to investigating certain chemical classes.
OBJECTIVE : We examined the impact of multi-class chemical mixtures on ASD risk, using data from the MARBLES (Markers of Autism Risks in Babies-Learning Early Signs) cohort.
METHODS : Children were clinically assessed at age 3 and classified as ASD, typical development (TD), or non-TD with other neurodevelopmental concerns. In blood or urine from 105 pregnant mothers, we quantified 42 biomarkers across 5 chemical classes : per- and polyfluoroalkyl substances (PFAS), parabens, phenols, phthalates, and organophosphate esters (OPEs). We only analyzed 30 biomarkers detected in >50 % of the sample. After identifying clusters with similar chemical profiles via hierarchical clustering, we applied linear discriminant analysis (LDA) to compute LDA exposure summary scores. In covariate-adjusted models, we used LDA scores to assess co-adjusted, multipollutant associations (relative risk [RR]) with ASD or non-TD, via quasi-Poisson regression. We further examined overall mixture effect and chemical interactions with Bayesian kernel machine regression.
RESULTS : We identified four distinct clusters : PFAS (Cluster 1), OPEs (Cluster 2), parabens and triclosan (Cluster 3), and phthalates and bisphenol A (Cluster 4). Relative to TD, LDA scores for each cluster were associated with increased risk of ASD (RR [95 % CI]: 1.14 [1.03, 1.25], 1.12 [1.01, 1.24], 1.17 [1.07, 1.29], 1.17 [1.07, 1.28] for Cluster 1-4, respectively), whereas clusters 2 and 4 were associated with non-TD (1.07 [1.01, 1.14] and 1.12 [1.05, 1.19], respectively). Cumulative exposure across the four clusters was linked to increased risk of both ASD and non-TD. Potential interactions within and between clusters were observed.
CONCLUSION : This study shows that considering multiple chemical classes resulted in stronger associations with ASD and non-TD risk, compared to when investigated separately in our previous studies.
https://doi.org/10.1016/j.envres.2025.121646

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3. Approche métabolomique/exposomique/dépistage non-ciblé

Nazar, N., Athira, A. S., Nadella, R. K., Panda, S. K., Banerjee, K., Chatterjee, N. S.
Untargeted metabolomics offers insights into the risks of chronic exposure to mixtures of polycyclic aromatic hydrocarbons at environmentally relevant low concentrations.
Environmental Geochemistry and Health 2025, Vol. **47** (6)

Polycyclic aromatic hydrocarbons (PAHs) often occur in mixtures, creating complex interactions in humans and other organisms exposed through food. However, the effects of these PAH mixtures at environmentally relevant low concentrations (ERC) on the metabolome have been underexplored. This research investigated the ERC of PAHs in

Vembanad estuary biota and examined the impact of chronic exposure to these mixtures using an untargeted metabolomics approach. The study observed that 64% of the aquatic samples analysed from India's Ramsar site (VE) had been detected with one or more PAHs (Sigma PAHs5.12-1015.28 ng/g). The non-carcinogenic risk from dietary PAH exposure was low, but cancer risk analysis showed a moderate to high risk for specific areas, particularly Perumbalam. Furthermore, the untargeted metabolomics study revealed that chronic exposure to a PAH mixture at ERC dysregulated metabolites from major classes, including phosphatidylcholines, amino acids, fatty acyls, bile acids, nucleotides, purines, pyrimidines, and vitamins. These metabolites are predominantly associated with key metabolic pathways, including mitochondrial electron transport, pyrimidine metabolism, the citric acid cycle, and butyrate metabolism, all of which play critical roles in cellular energy production, biosynthesis, and regulation. Pathway analysis revealed that long-term exposure to PAH mixtures, even at low doses, significantly affects phenylalanine, tyrosine, and tryptophan metabolism, increasing the likelihood of metabolic and endocrine disorders.
https://doi.org/10.1007/s10653-025-02547-0

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Jagani, R., Chovatiya, J., Patel, H., Andra, S. S.
Exploring the potential of MRM-IDA-EPI method in mass spectrometry for exposomic analysis : a commentary.
Arch Toxicol, 2025, Vol. **99** (4), 1605-1609

Exposomics is a field that studies environmental exposures and their impact on human health. The MRM-IDA-EPI method, which combines targeted and untargeted mass spectrometry methods, is useful for identifying and quantifying biomarkers in various biological matrices. The method's accuracy and precision in forensic toxicological screening suggest potential applications for detecting low-level environmental exposures. It can help detect and understand environmental exposures, explain their metabolic processes, and assess their impact on human health more effectively.
https://doi.org/10.1007/s00204-025-03958-9

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Huang, X., Zhai, W., Su, W., Yang, Z., Liang, W., Wang, P.*, et al.*
Exploration of Chemical Space Covered by Nontarget Screening Based on the Prediction of Chemical Substances Amenable to LC-HRMS Analysis.
Environmental Science & Technology Letters 2025, Vol. **12** (5), 661-667

Le dépistage non ciblé (NTS) est une technique d'analyse prometteuse pour le suivi des polluants émergents. Cependant, l'espace chimique exact qui peut être couvert par la méthode reste à déterminer. Une étude d'exploration de texte dans la littérature a noté que le nombre de composés actuellement signalés par NTS par chromatographie liquide et spectrométrie de masse à haute résolution (LC-HRMS) ne représentait qu'environ 2 % de l'espace chimique approximatif (c.-à-d. base de données NORMAN SusDat). Compte tenu de l'exigence de base relative à la présence d'un parent (États membres)1) et sa fille (MS2) à des concentrations pertinentes pour l'environnement.
Pour l'identification chimique, un modèle de classification binaire des réseaux neuronaux artificiels a été mis au point sur la base des données mesurées du spectre de masse de 1255 substances chimiques uniques. Il a été utilisé pour estimer le pourcentage de composés susceptibles d'être analysés par LC-HRMS à partir d'un large éventail de candidats dans les inventaires de produits chimiques. Les descripteurs moléculaires liés à la taille moléculaire, à la ramification, aux états électroniques des atomes et aux distributions de charge moléculaire ont montré des impacts significatifs sur la sensibilité du modèle. Les composés sensibles prédits dans les modes positif et négatif de l'ionisation par électronébulisation représentaient environ 41 % et 23 % de l'espace chimique approximatif lorsque la même base de données a été utilisée à des fins de comparaison, ce qui suggère un grand potentiel pour le NTS au sein de la plate-forme LC-HRMS.

https://doi.org/10.1021/acs.estlett.5c00293

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Gu, Y., Feuerstein, M. L., Warth, B.
High-Throughput Solid Phase Extraction for Targeted and Nontargeted Exposomics.
Anal Chem 2025, Vol. **97** (11) :6075-6082.

Characterizing the chemical exposome relies on advanced instrumentation including tandem mass spectrometry coupled to liquid chromatography (LC-MS/MS), and nontargeted analysis (NTA) using high-resolution MS. However,

proper sample pretreatment, balancing broad analyte coverage, method robustness, and throughput remain a major bottleneck in exposomics. Here, we developed a robust and scalable solid phase extraction (SPE) protocol for human urine and plasma and optimized it for a panel of 94 highly diverse environmental and food-related contaminants (LogP -0.7 to 6.8). Extraction recoveries (RE) and signal suppression and enhancement (SSE) were determined using targeted LC-MS/MS. Acceptable REs (60-140%) were achieved for >70% of analytes, and acceptable SSE values (60-140%) for 86% and 90% in urine and plasma, respectively. Subsequently, the method was transferred to 96-well plate format, significantly improving throughput to meet the capacity requirements needed for exposome-wide association studies (ExWAS). The established workflow is approximately 10x faster than routinely used metabolomics-based protein precipitation approaches when comparing the estimated total analysis time for 1000 samples. The method's applicability for NTA and suspect screening was tested and compared to a generic protein precipitation protocol using NIST standard reference materials for urine (SRM 3672) and plasma (SRM 1950). Favorable performance was shown for the protein precipitation workflow while the SPE protocol demonstrated promising results. The developed workflow is thus not only superior for future high-throughput targeted exposomics but also offers an option for NTA applications. The presented well-balanced approach is scalable and also applicable to research in the fields of pharmacology, food safety, and systems toxicology.
https://doi.org/10.1021/acs.analchem.4c06177

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4. Modèles, méthodes d'analyses, outils

Mancini, T., Radica, F., Mosesso, L., Paolozzi, M. C., Macis, S., Marcelli, A.*, et al.*
Ultrahigh-sensitive and real-time detection of BTXs for occupational safety via infrared spectroscopy coupled with machine learning technique.
Journal of Environmental Chemical Engineering 2025, Vol. **13** ; (3)

Exposure to Volatile Organic Compounds (VOCs) is one of the major human and occupational safety concern, as possible human carcinogens. Several gold standard methods are used for their detection in the atmosphere ; however, most of them operate ex-situ or do not provide easy discrimination between different molecules with suitable sensitivity.
Here, we introduce an ultrasensitive method based on Fourier Transform Infrared (FTIR) spectroscopy coupled with Machine Learning (ML) algorithms to analyse toxic gaseous substances in working sites down to a concentration of less than 1 ppm. We investigate six selected aromatic compounds (BTXs gases and styrene), building an accurate IR gas-phase database and providing, for the first time at the best of our knowledge, universal IR calibration curves still lacking in literature. Starting from this IR gas-phase database, we design and train a ML automatic and rapid recognition method.
This advantageous combination between IR spectroscopy, including the estimated IR calibration curves, and ML algorithms demonstrates the strong ability of our strategy in discriminating between different gaseous VOCs indoor, with high accuracy and rapidity even when more compounds are present at the same time. The proposed approach responds to the fundamental needs (i) to evaluate low VOCs concentrations up to values less than 1 ppm (under the legislative levels), (ii) to monitor the VOCs presence in real-time for the accurate estimation of long-exposure levels and (iii) to discriminate the coexposure at various compounds.
https://doi.org/10.1016/j.jece.2025.116833

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Ma, X., Wang, Y., Chen, S., Wu, C., Wang, W., Wang, Y.
Impact of mixed benzene site exposure on bioaccessibility in simulated lung fluids and health risk assessment.
J Hazard Mater, 2025 Vol. **494**, 138466 p.

Benzene series (BTEX) are predominant volatile organic compounds (VOCs) in petroleum production and downstream industrial sites, primarily enter human lungs via inhalation, posing significant health risks. To address the critical limitation of existing risk assessments that focus solely on individual components, this study investigated benzene and ethylbenzene based on contamination characteristics of petroleum refineries in Northwest China.
An innovative in vitro membrane oxygenator system was developed to simulate single and mixed exposure scenarios at three soil concentrations : low (5 mg/kg), medium (10 mg/kg), and high (20 mg/kg), respectively. Health risk indices including inhalation risk (Inh), hazard quotient (HQ), and lifetime cancer risk (LCR) were calculated using bioaccessibility-adjusted parameters to precisely compare risk variations across exposure modes. Results

demonstrated significant synergistic effects in gas-liquid mass transfer kinetics under mixed exposure ($P < 0.05$), the simulated lung fluid bioaccessibility of benzene and ethylbenzene was also significantly higher ($P < 0.05$), likely due to their intermolecular cosolvency. Risk assessment results indicated that Inh, HQ, and LCR indices in mixed exposure were significantly higher ($P < 0.05$) than in single exposure, with a concentration-dependent contribution to health risks. At low concentrations, benzene's health risk indices increased by 185 %-284 %, while ethylbenzene's increased by approximately 63 %-68 %, indicating a synergistic effect in mixed exposure scenarios.
This study offers a new methodological basis for health risk assessment of BTEX mixed exposure at petrochemical sites.
https://doi.org/10.1016/j.jhazmat.2025.138466

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Jagani, R., Chovatiya, J., Patel, H., Andra, S. S.
Exploring the potential of MRM-IDA-EPI method in mass spectrometry for exposomic analysis : a commentary.
Arch Toxicol 2025, Vol. **99** n°(4) : 1605-1609.

Exposomics is a field that studies environmental exposures and their impact on human health. The MRM-IDA-EPI method, which combines targeted and untargeted mass spectrometry methods, is useful for identifying and quantifying biomarkers in various biological matrices. The method's accuracy and precision in forensic toxicological screening suggest potential applications for detecting low-level environmental exposures. It can help detect and understand environmental exposures, explain their metabolic processes, and assess their impact on human health more effectively.
https://doi.org/10.1007/s00204-025-03958-9

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Huang, Y., Li, Z.
Deriving exposure route-specific cancer slope factors of carcinogenic chemicals via PBK modeling.
Environ Int 2025, Vol. **199**, 109483 p.

Carcinogenic chemicals entering the body via different exposure routes result in varying internal doses and thus influence the tumors development. The internal doses can be quantified using biotransfer factors (BTF) simulated by the physiologically based kinetic (PBK) model.
This study proposed a modeling method to analyze the quantitative relationships between BTF and cancer slope factors (CSFs). When the CSF for one exposure route is known, the CSF values for the other two routes can be derived using the relationships. A total of 45 carcinogenic chemicals were selected, and their oral CSF (CSF(oral)) and BTF values were collected for analysis. The results demonstrated that route-specific CSFs of chemicals can be different due to their physicochemical properties. In addition, the derived route-specific CSFs are further utilized to conduct a comprehensive cancer risk assessment.
The results revealed that cancer risk caused by most environmental chemical exposure exceeded 1 x 10(-6), suggesting that long-term exposure to chemicals would pose certain human cancer risks. These findings highlight the importance of exposure route-specific CSFs for accurate cancer risk assessment and provide a scientific reference for environmental agencies to refine the risk assessment system.
https://doi.org/10.1016/j.envint.2025.109483

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5. Co-expositions métaux lourds

Chen., Z. W. W. Y. Z. Z.
Association between exposure to blood heavy metal mixtures and overactive bladder risk among U.S. adults : A cross-sectional study.
Front. Public Health 2025, Vol. **13**.

Background : Increasing evidence has demonstrated that exposure to environmental heavy metals harms human health. However, information regarding the impact of co-exposure to metal mixtures on the risk of overactive bladder (OAB) was limited. Our study aimed to explore the joint effects of blood heavy metal mixtures on OAB risk.

Methods : Data for this study were obtained from four National Health and Nutrition Examination Survey cycles (2011) (2012) (2013) (2014) (2015) (2016) (2017) (2018). The effects of single metals on OAB risk were explored using multivariate logistic regression. Additionally, we used weighted quantile sum (WQS), quantile-based g computation (qgcomp), and Bayesian kernel machine regression (BKMR) models to explore the combined effect of metal mixtures on OAB risk. Age-stratified subgroup analyses were conducted, and restricted cubic splines (RCS) were utilized to investigate the non-linear relationship between metals and OAB.
Results : A total of 4183 individuals aged 20-80 years were included for further study. Among them, 866 (20.7%) participants had OAB. OAB patients had significantly higher blood concentrations of cadmium (Cd) and lead and lower blood concentrations of selenium and manganese than those without OAB (all $P < 0.05$). In the single-metal analyses, Cd significantly increased OAB risk. In the mixed-exposure analyses, the WQS and BKMR models consistently revealed a significant positive association between co-exposure to heavy metal mixtures and OAB risk, identifying Cd as the main positive driver. The young/middle-aged group exhibited similar significant associations. In the metal mixtures, Cd was the top-weighted metal for the entire population and young/middle-aged individuals, whereas mercury (Hg) held the highest weight among elderly individuals. Furthermore, we observed an underlying interaction between Cd and Hg in the BKMR model. In the sensitivity analyses, the findings from the qgcomp model validated the toxic effect of blood metal mixtures on OAB. According to the RCS regression, we identified a positive linear dose-response relationship between Cd and OAB risk.
Our study identified that co-exposure to heavy metal mixtures was significantly related to OAB risk. Further research prioritizing low-dose, real-world exposure to metal mixtures in vulnerable populations (e.g., elderly, high-risk occupations) is essential to translate our findings into preventive strategies and regulatory policies.
https://doi.org/doi:10.3389/fpubh.2025.1597321

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Ding, S., Gu, Q., Zhao, Z., Xie, Y., Wang, F., Liu, J.*, et al.*
Role of Glucose Metabolism in the Effects of Serum Metals on Telomere Length : Findings in Chinese Diabetic Population.
Biol Trace Elem Res, 2025.

The effects of metal exposure on telomere length have attracted considerable attention, but definitive evidence is still lacking in the diabetic population. Thus, this study was conducted to explore the associations of metal mixture with telomere length and the mediated effects of glucose metabolism among the Chinese diabetic population.
Eleven metals in serum and relative telomere length of leucocyte were quantified among 1516 diabetic population based on a large-scale diabetic retinopathy screening program in southern China. Multiple statistical models were used to evaluate the single and joint effects of metal mixture on telomere length. Moreover, to assess the mediating roles of glucose metabolism in the associations between metals and telomere length, mediation analyses were performed. In single-exposure models, serum levels of nickel and thallium were identified to be negatively associated with telomere length, while magnesium showed an inverted U-shaped association with telomere length.
Consistent findings from three mixed-exposure analyses indicated that increased serum level of metal mixture was associated with decreased telomere length, with nickel playing a major role in the joint effects of the metals. Mediation analyses further revealed that the associations of nickel and metal mixture with telomere length were partially mediated by glycated hemoglobin, and the mediated proportions were 4.26% and 4.38%, respectively.
Moreover, the associations between metals exposure and telomere length were observed to be more prominent in males. Our results indicated that exposure to metal mixture was associated with shortened telomere length, which may be partially mediated by glycated hemoglobin.
https://doi.org/10.1007/s12011-025-04585-2

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Huang, X., Wu, Y., Lu, Y.
Single and mixed effects of seven heavy metals on stroke risk : 11,803 adults from National Health and Nutrition Examination Survey (NHANES).
Front Nutr, 2025. Vol. **12**, 1524099 p.

BACKGROUND : The accumulation of heavy metals in soil and plants poses risks to food safety. Human exposure to heavy metals has been linked to stroke risk, though research on this connection is limited and findings are inconsistent.
METHODS : We estimated the associations of 7 blood metals [cadmium (Cd), lead (Pb), mercury (Hg), manganese (Mn), copper (Cu), selenium (Se), and zinc (Zn)] with the risk of stroke among 11,803 U.S. adults. Logistic regression account for the intricate sampling design and restricted cubic spline (RCS) was used to explore the associations between single heavy metal and stroke risk. The weighted quantile sum (WQS) and quantile g-computation (qgcomp)

were employed to explore the joint effects of seven metals on stroke. Potential confounders were adjusted.
RESULTS : After adjusting for the potential confounders, the logistic regression analysis showed the log-transformed Cd and Zn level was associated with stroke (All $p < 0.05$). After adjusting for the potential confounders, the logistic regression analysis showed the log-transformed Cd and Zn level was associated with stroke (All $p < 0.05$). WQS and qgcomp analyses consistently demonstrated a positive correlation between metals-mixed exposure and stroke risk, identifying Cd and Cu as key contributors to the outcomes, while Zn may serve as a protective factor.
CONCLUSION : These findings indicated that heavy metal exposure is associated with stroke risk, and the protective effect of Zn on stroke risk deserves further research to verify.
https://doi.org/10.3389/fnut.2025.1524099

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Li, Z., Lin, Y., Wang, W., Xie, M., Jiang, Y., Wang, Z.*, et al.*
Association between mixture exposure to metals in urine and cognitive function in older adults in the United States : NHANES 2011-2014.
J Trace Elem Med Biol, 2025 Vol. **89**, 127643 p.

AIMS : The effects of exposure to individual metals on cognitive function have been widely reported, but research on the effects of metal mixtures is rare. This study aims to investigate the association of exposure to both individual metals and multiple metals in urine on cognitive function in US elderly.
METHODS : Data derived from the National Health and Nutrition Examination Survey 2011-2014 were utilized in this cross-sectional study. A total of 13 urinary metals were determined using inductively coupled plasma mass spectrometry. Cognitive function assessments included the Consortium to Establish a Registry for Alzheimer's Disease (CERAD) word learning test, the CERAD word recall test, the animal fluency test, and the Digit Symbol Substitution test (DSST). To assess the relationships between multiple metal exposures and cognitive performance, linear regression and Bayesian kernel machine regression (BKMR) and the weighted quantile sum (WQS) regression models were employed.
RESULTS : A total of 1018 older adults were included. The participants' mean scores on the CERAD word learning test, the CERAD word recall test, the animal fluency test, and the DSST were 19.04 +/- 4.62, 5.96 +/- 2.30, 16.71 +/- 5.57 and 45.56 +/- 17.07, respectively. There were 10 metals with detection rates higher than 80 %. The linear regression model revealed that higher levels of barium (Ba), cadmium (Cd), lead (Pb), and tungsten (W) were associated with a decline in cognitive function scores. Conversely, increased levels of molybdenum (Mo), cobalt (Co), strontium (Sr), and thallium (Tl) were associated with improved cognitive function scores. Furthermore, BKMR model demonstrated that the slope of the dose-response curve between Mo and animal fluency test score decreased with increasing concentrations of Cd, suggesting an interaction effect of Mo and Cd exposure on cognitive function. WQS regression model demonstrated a significant negative association between exposure to metal mixtures and DSST score (beta=-2.42, $p < 0.001$).
CONCLUSIONS : Our study suggests significant associations between several metals, such as Ba, Cd, Pb, W, Mo, Co, Sr and Tl, and cognitive function in older adults. Moreover, there is an interaction between Mo and Cd on cognitive function under metal co-exposure conditions. Prospective studies are needed to confirm the potential causal relationship.
https://doi.org/10.1016/j.jtemb.2025.127643

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Liu, S., Wang, H., Cao, Y., Lu, L., Wu, Y., Lian, F.*, et al.*
The association between low-concentration heavy metal exposure and chronic kidney disease risk through alpha-klotho.
Sci Rep 2025, Vol. **15** (1), 11320 p.

Although the association between pollution exposure and chronic kidney disease (CKD) has been explored, previous studies have focused on specific effects observed via in vitro or animal experiments. We first conducted a priority screening of pollutants for population CKD risk by using machine learning approaches. We then used the National Health and Nutrition Examination Survey (NHANES) 2007-2016 data from 2415 adults aged 40 years and over to study the joint effects of low-concentration metal exposure and the mediating effects of alpha-klotho by using Bayesian kernel machine regression (BKMR) and mediation analyses. Priority screening revealed that cadmium (Cd), mercury (Hg), lead (Pb), and thallium (Tl) were associated with the highest risk of developing CKD. The BKMR model revealed a negative joint effect of mixed-metal exposure on CKD risk. Tl presented the highest posterior inclusion probability (PIP) of 1.0000, followed by Pb, with a PIP of 0.6080. Significant mediating effects of alpha-klotho on Hg-CKD associations were observed. Mendelian randomization demonstrated that a high level of alpha-klotho is associated

with a decreased risk of developing CKD.
This is the first study to reveal the risk prioritization of various pollutants in CKD patients, as well as the coexposure effects of metals. Our study also provides insight into the potential mechanisms underlying the association between metal exposure and CKD risk.
https://doi.org/10.1038/s41598-025-96016-4

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Liu, T. Z., Qiao, Z. H., Gong, K. L., Yang, Y. H., Han, Y. N., Tan, J. Q.*, et al.*
Synergistic toxicity of DBDPE and Cd in a microcosm agrosystem : Insights into physiological, biochemical, nutrient elements and amino acid metabolic responses.
Journal of Hazardous Materials 2025, Vol. **493**, p.

Agricultural soil contamination by flame retardants and heavy metals has become an environmental concern, with decabromodiphenyl ethane (DBDPE) and cadmium (Cd) being frequently detected in e-waste dismantling areas. While previous studies mostly focused on single-organism system or individual toxicity, the combined effects of DBDPE and Cd on agricultural ecosystems remain largely unknown.
This study aimed to reveal the joint toxicity mechanisms of DBDPE and Cd by examining physiological responses, amino acid metabolism, nutrient element distribution, and DBDPE degradation pathways in this integrated system. Results demonstrated that co-exposure to DBDPE and Cd intensified toxicity compared to single exposure. In lettuce, DBDPE amplified the inhibitory effects of Cd on plant growth (height and fresh weight of the aerial part decreased by 3.8 % and 5.8 %). Co-exposure inhibited chlorophyll synthesis (particularly carotenoid production, decreased by 53.33 %), disrupted amino acid metabolism, and impaired nutrient elements uptake, ultimately leading to reduced plant growth. In earthworms, co-exposure altered amino acid profiles, disrupted nutrient elements absorption and transport, thereby reducing their antioxidant defense capacity. Both organisms showed limited ability to detoxify DBDPE through similar debromination pathways.
This study reveals the synergistic toxicological impacts of DBDPE and Cd in agricultural systems, highlighting the elevated ecological risks of their co-occurrence and emphasizing the need for comprehensive pollution control strategies in contaminated agricultural soils.
https://doi.org/10.1016/j.jhazmat.2025.138421

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Njale, E., Shilla, D. J., Dharsee, N., Mahugija, J. a. M., Mbare, N. S.
Association between single and mixed exposure to potentially toxic trace metals and the risk of prostate cancer : a case-control study in Tanzania.
Environ Geochem Health 2025, Vol. **47** (6), 194.

Metal contamination is a major environmental concern in Tanzania, where it has been linked to an increased risk of prostate cancer. However, there have been no epidemiological studies addressing this association. The aim of this study was to investigate the association between urinary toxic trace metals and prostate cancer. Inductively coupled plasma atomic emission spectrophotometer (ICP-AES) was employed to measure the concentrations of Pb, As, Ni, Al, and Cd in urine samples from histologically confirmed100 prostate cancer patients (n = 100) and 80 healthy controls (n = 80). The associations between individual metals and prostate cancer were assessed using unconditional logistic regression, while Bayesian kernel machine regression (BKMR) was employed to investigate the combined effects of multiple metals with adjustments of potential covariates. Cancer patients had significantly higher mean levels of Ni, Pb, and As in their urine compared to controls. In multivariable logistic models, the findings suggested that quartiles increase of As and Cd were positively associated with prostate cancer with ORs of 5.25 (1.33, 20.72) in Q3 for As and ORs of 2.87 (1.72, 11.52) in Q4 for Cd.
The BKMR results revealed that the combined effect of five urinary metals exhibited a negative association with prostate cancer risk. In conclusion, this study offers preliminary evidence suggesting that exposure to trace metals particularly Cd and As may potentially be associated with prostate cancer. Pb and Al were found to have an inverse relationship with prostate cancer and overall metal mixture had no impact on prostate cancer. Since the study was preliminary, these results remain to be confirmed by further large-scale studies.
https://doi.org/10.1007/s10653-025-02497-7

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Scardino, B., Dicharry, D., Agrawal, A., Xing, D., Bhuiyan, M. M. R., Bhuiyan, M. S.*, et al.*
Cumulative environmental exposures and metabolic syndrome : A study of heavy metals and volatile organic compounds.
Ecotoxicol Environ Saf, 2025 Vol. **297**, 118238.

BACKGROUND : Metabolic Syndrome (MetS), a condition affecting over one-third of the U.S. population, heightens the risk of cardiovascular disease, Type 2 diabetes, and premature mortality. While individual links between heavy metals (HM), volatile organic compounds (VOC), and MetS have been established, the impact when these environmental toxins are combined remains unclear and unexplored. This study investigates how simultaneous exposure to HMs and VOCs influences the risk of MetS.
METHODS : Weighted Quantile Sum regression and Bayesian kernel Machine Regression were performed on data from 6603 participants in the National Health and Nutrition Examination Survey (2011-2020) to determine the impact of HMs and VOCs detected in urine on MetS. Further analyses were performed for individuals placed in subgroups based on age, sex, race/ethnicity, and monthly poverty level index.
RESULTS : The analyses reveal that combined exposure to HMs and VOCs is associated with an increased risk of MetS; in particular, exposure to cadmium, tin, N-acetyl-S-(N-methyl carbamoyl)-L-cysteine, and N-acetyl-S-(2-carboxyethyl)-L-cysteine significantly elevates the risk of developing MetS. Younger adults (18-50 years), men, Hispanics and non-Hispanic whites, and those with a monthly poverty index > 1.3 (higher socioeconomic status) emerged as the most vulnerable groups.
CONCLUSION : These findings emphasize an urgent need to address and tackle the cumulative impact of environmental toxins through a shift in public health efforts to go beyond investigating isolated exposures to address real-world chemical exposures. By understanding these cumulative risks, we can begin to mitigate them and pave the way for more effective interventions, especially for at-risk populations.
https://doi.org/10.1016/j.ecoenv.2025.118238

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Shin, S., Kim, Y., Choe, Y., Kim, S. H., Cho, J., Kim, C.*, et al.*
Exposure to polycyclic aromatic hydrocarbons, heavy metals, and per- and polyfluoroalkyl substances and their associations with serum lipid profiles in the general Korean adult population.
Environmental Health 2025, Vol. **24** (1), 30 p.

Previous studies on associations between polycyclic aromatic hydrocarbons (PAHs) and lipid profiles are limited. We investigated the associations between urinary PAH metabolites and serum lipid profiles using a representative sample of Korean adults.
https://doi.org/10.1186/s12940-025-01185-4

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Thiel, A., Heider, S., Bieck, K., Michaelis, V., Schwerdtle, T., Ebert, F.*, et al.*
Genotoxicity Assessment of Co(II) and Ni(II) in HepG2 Cells: Insights into Combined Metal Exposure.
Chem Res Toxicol 2025, Vol. **38** (4), 695-704 p.

The usage of cobalt (Co) and nickel (Ni) in numerous commercial, industrial, and military applications causes widespread exposure nowadays, and concerns are rising about adverse impacts on human health. Emphasis is on the respiratory system, with both metals classified as (possibly) carcinogenic upon inhalation by the International Agency for Research on Cancer (IARC), but limited data are available upon oral exposure.
Therefore, this study aims to evaluate the in vitro genotoxicity of Co(II) and Ni(II) and their combination in HepG2 cells, since exposure of those environmental pollutants occurs realistically in concert. Here, Co(II) exposure led to the induction of single-strand breaks and oxidative DNA damage detected by the Comet assay as FPG-sensitive sites, while Ni(II) increased the abundance of gamma-H2AX, an indicator for double-strand breaks. Notably, combined exposure to Co(II) and Ni(II) resulted in enhanced DNA damage, especially at the chromosomal level, with increased formation of micronuclei as well as polynucleated cells, indicating a stronger effect compared to single exposure. Furthermore, both metals induced the DNA damage response pathway PARylation. As this process involves the consumption of large amounts of cellular NAD(+) after DNA damage, the energy state was assessed upon exposure with Co(II) and Ni(II). Current data indicate that especially Co(II) altered the cellular energy state.
This study reveals distinct mechanisms of DNA damage exhibited by Co(II) and Ni(II), which were enhanced after a combined treatment. This highlights the need for further research to estimate the genotoxic potential of targeting cells upon oral intake with increasing environmental entry.
https://doi.org/10.1021/acs.chemrestox.4c00518

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Udom, G. J., Iyaye, D., Oritsemuelebi, B., Nwanaforo, E., Bede-Ojimadu, O., Abdulai, P. M.*, et al.*
Public health concerns of multifaceted exposures to metal and metalloid mixtures : a systematic review.
Environ Monit Assess 2025, Vol. **197** (5), 502.

Exposure to metals and metalloids presents a significant global public health threat due to their widespread presence in natural, industrial, and occupational environments. These substances, such as arsenic, lead, cadmium, and mercury, accumulate in biological systems, leading to chronic and acute health conditions.
The review focuses on investigating the health risks, pathways of exposure, and the associated regulatory frameworks. A review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines. Two main databases (PubMed and Toxline) and a search engine (Google Scholar) were searched in September 2024, and 23 articles met the eligibility criteria and were included in the review. The quality of all the articles that met the inclusion criteria was assessed using the Newcastle-Ottawa scale. The review examined exposure pathways in different settings (natural, industrial, and occupational), health outcomes, mechanisms of toxicity, and vulnerable populations. The synthesis highlights the current gaps in regulatory frameworks and identifies areas for future research. Exposure to metals and metalloids occurs through contaminated water, soil, and air in natural settings, and through industrial activities and occupational hazards in sectors like manufacturing, construction, and agriculture. Adverse health outcomes include neurological disorders, cardiovascular diseases, renal dysfunction, and cancers. Vulnerable populations, such as children, pregnant women, and workers in high-risk industries, face elevated risks, with socioeconomic factors and inadequate regulatory protections exacerbating these health disparities. To mitigate the public health risks posed by metal and metalloid exposure, a multifaceted approach is necessary. This includes enhanced environmental monitoring, public awareness campaigns, stricter occupational safety regulations, and international cooperation in pollution control. Future research should prioritize understanding the synergistic effects of metal mixtures and developing innovative strategies for detection and intervention. Safeguarding public health and promoting environmental justice requires urgent action to address the multifaceted impacts of metal exposures.
https://doi.org/10.1007/s10661-025-13963-1

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Wen, X., Deng, F., Qiao, L., Li, M., Wang, X., Li, H.*, et al.*
The association between metal element levels and thyroid nodules in oilfield workers : a cross-sectional study.
Frontiers in Endocrinology 2025, Vol. **16**

Background : Metal elements affect the physiological processes of the thyroid gland and are associated with the formation of thyroid nodules (TNs). This study aimed to investigate the relationship between metal element levels and TNs in oilfield workers and to provide a preliminary scientific basis.
Methods : The study used a cross-sectional study to collect relevant data in 2022. Spearman's rank correlation was used to analyze the correlation between multiple metal elements. The Logistic regression model and Weighted Quantile Sum (WQS) regression model were used to analyze the association between metal elements and the prevalence of TNs.
Results : A total of 517 oilfield workers were included in this study and the prevalence of TNs was 40.62%. Sex, age, and uric acid levels differed between the two groups ($P < 0.05$). The correlation analysis showed that most of the metals were correlated with each other to varying degrees. The WQS regression model showed that mixed exposure to seven metal elements was positively associated with the risk of developing TNs. In the total population and males, iron (Fe) and copper (Cu) levels were positively related to the risk of TNs prevalence ($P < 0.05$).
Conclusions : TNs was found to be very prevalent among oilfield workers. Mixed exposure to metal elements may be associated with an elevated risk of TNs, with Fe and Cu emerging as potential contributors to this association.
https://doi.org/10.3389/fendo.2025.1590821

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Yan, F., Huang, L., Jiang, Y., Jiang, C., Huang, Y., He, J.*, et al.*
Impact of multi-metal exposure on blood pressure : a mediation analysis through oxidative stress markers in China's Southern Jiangxi Province.
BMC Public Health, 2025, Vol. **25** (1).

Hypertension is a prevalent condition that contributes significantly to the global disease burden. Recent research endeavors have been investigating the potential causal link between metal exposure and the development of

hypertension, yet consensus remains elusive. Nevertheless, studies examining the interplay among metal exposure, hypertension, and oxidative stress are relatively limited.
This study utilized data from a cross-sectional survey conducted in southern Jiangxi Province, China. We evaluated urinary concentrations of 19 metals, including aluminum and manganese, in conjunction with measurements of systolic and diastolic blood pressures, as well as three oxidative stress biomarkers : glutathione peroxidase (GSH), superoxide dismutase (SOD), and malondialdehyde (MDA). In the monometallic model, chromium, iron, manganese, and molybdenum exhibited positive correlations with blood pressure.
These findings were consistent in the mixed exposure model. Conversely, all the afore mentioned metals exhibited a negative correlation with GSH and SOD, while demonstrating a positive correlation with MDA. Mediation effect analysis revealed that GSH and SOD mediated the relationships between urinary concentrations of aluminum, iron, manganese, and antimony and blood pressure. In contrast, MDA mediated the associations between urinary silver and antimony and blood pressure. Furthermore, GSH and SOD were identified as mediators in part of the relationship between mixed metal exposure and blood pressure, with mediation rates of 19.09% for GSH and 27.36% for SOD.
The results of this study suggest that exposure to both individual and combined metals effects blood pressure levels, which are further associated with changes in oxidative stress levels. Moreover, oxidative stress levels may modulate the changes in blood pressure related to metal exposure, providing a basis for further investigation into the health risks associated with these metal exposures.
https://doi.org/10.1186/s12889-025-23078-4

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Yang, B., Chen, Y., Zhang, H., Liu, Y., Liu, C., Coll., E.
Association between parental exposure to metal mixture and preterm birth : A prospective birth cohort study.
Ecotoxicol Environ Saf 2025, Vol. **299**, 118375.

Accumulating evidence suggests that maternal prenatal exposure to metals is associated with preterm birth. However, the relationship between paternal metals exposure and preterm birth remains unclear. In current study, we assessed the association of paternal exposure, maternal exposure and parental co-exposure to metals with the risk of preterm birth, using data from the Jiangsu Birth Cohort (JBC) study.
Urine samples collected from 1680 couples during the first trimester were measured for 25 metals concentrations. In the multivariable logistic regression models, paternal and maternal urinary antimony (Sb) concentrations were associated with 45 % (paternal : Odds Ratio (OR), 1.45; 95 % Confidence Interval (95 %CI), 1.01-2.09) and 43 % (maternal : OR, 1.43; 95 % CI, 1.01-2.03) higher risk of preterm birth per ln-unit increase, respectively. Also, maternal urinary cobalt (Co) concentrations (OR, 1.45; 95 % CI, 1.02-2.06) and copper (Cu) concentrations (OR, 2.16; 95 % CI, 1.15-4.03) were significantly associated with an increased risk of preterm birth. In addition, maternal exposure to Cu and paternal exposure to Sb demonstrated a significant dose-response relationship, with trend test P-values of 0.037 and 0.015, respectively. These findings suggested that higher concentrations of Cu and Sb are associated with an increased risk of preterm birth. The Bayesian Kernel Machine Regression (BKMR) models revealed a positive joint effect on preterm birth that intensified across increasing quantiles of parental mixture concentrations.
Our findings emphasize that metals influence the onset of preterm birth through both maternal and paternal exposure. These results lay a theoretical foundation for developing risk assessment models based on parental exposure characteristics, offering deeper insights into the etiology of preterm birth. Furthermore, they provide essential scientific evidence to support its prevention and control strategies.
https://doi.org/10.1016/j.ecoenv.2025.118375

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Yang, T., Zhang, Y., Zhong, J., Zhang, R., Xu, Z., Xiao, F.*, et al.*
Analysis of the association between mixed exposure to multiple metals and comorbidity of hypertension and abnormal bone mass : Baseline data from the Chinese multi-ethnic cohort study (CMEC).
Ecotoxicol Environ Saf 2025, Vol. **296**, 118212.

Comorbidity represents an increasingly significant public health challenge. While numerous studies have confirmed the association between metals and both hypertension and osteopenia, the relationship between the multi-faceted effects of mixed metal exposure and the comorbidity of hypertension with abnormal bone mass, as well as age-specific associations, remains unclear.
This study utilized baseline data from the China Multi-Ethnic Cohort Study, investigating 9870 Chinese ethnic minorities (Dong and Miao) aged 30-79 years. We measured 17 urinary metal levels using inductively coupled plasma mass spectrometry. The study employed Least Absolute Shrinkage and Selection Operator (LASSO) penalized regression and Bayesian Kernel Machine Regression (BKMR) models to explore the association between urinary metals

and comorbidity of hypertension and abnormal bone mass risk. In single-metal models, urinary nickel and zinc levels showed positive correlations with hypertension-related bone mass reduction risk, with ORs and 95 % CIs of 1.23 (1.01, 1.50) and 1.56 (1.27, 1.90), respectively. LASSO regression identified 11 urinary metals (aluminum, cobalt, chromium, copper, iron, manganese, lithium, lead, strontium, vanadium, and zinc) associated with hypertension and abnormal bone mass comorbidity. These selected metals were incorporated into subsequent analyses. BKMR analysis revealed an overall negative effect of metal mixtures on hypertension and abnormal bone mass comorbidity when all metals were fixed at their 50th percentiles. Vanadium and lithium showed negative correlations with the comorbidity. In subgroup analyses, age-stratified groups demonstrated consistent overall negative effects of metal mixtures on the comorbidity. Notably, in individuals over 60 years old, aluminum additionally exhibited a negative association alongside vanadium.
Interactions were observed among metals in mixed exposures. Increasing urinary aluminum concentrations attenuated the negative correlation between manganese and hypertension-bone mass abnormality comorbidity. Similarly, increasing manganese concentrations weakened the positive association between urinary zinc and the comorbidity. In individuals under 60 years old, consistent with the general population, increasing urinary aluminum concentrations at P(50) levels of other metals diminished the protective effect of manganese against hypertension-bone mass abnormality comorbidity. Interactions were identified between aluminum and lithium, and between manganese and zinc. This study provides substantial evidence linking mixed urinary metal exposure to hypertension and bone mass comorbidity, exploring the multifaceted effects of mixed metal exposure.
These findings contribute to a deeper understanding of the role of metal exposure in chronic disease comorbidity, offering a scientific foundation and new directions for preventing and controlling hypertension and bone mass comorbidity, as well as informing public health policy formulation from an environmental metal perspective.
https://doi.org/10.1016/j.ecoenv.2025.118212

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Yu, M., Xun, J., Ge, Y., Li, X., Chen, X., Cui, L.*, et al.*
Relationship between internal metal exposure and thyroid cancer incidence : a case-control study simultaneously validated by BKMR and WQS models.
Food Chem Toxicol 2025, Vol. **201**, 115443.

The global incidence of thyroid cancer is increasing, attracting great attention. Heavy metals affect human health and cause different diseases through various mechanisms. Several studies have identified heavy metals as risk factors for thyroid cancer and examined the association between heavy metals and the development of thyroid cancer. However, the mixed effects of multiple heavy metals on thyroid cancer are still unknown.
In this study, twelve heavy metals including iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), strontium (Sr), cadmium (Cd), cesium (Cs), palladium (Ba), mercury (Hg), and lead (Pb), in urine from thyroid cancer patients and healthy adults, were measured.
The results revealed that the levels of Fe, Ni, and Cu were significantly higher in the case group than in the control group. Weighted quantile sum (WQS) and Bayesian kernel-machine regression (BKMR) analyses consistently showed that heavy metal mixtures in urine were positively associated with the risk of thyroid cancer, with metals such as Fe and Ni being the main contributors. Further epidemiological surveys are needed in the future to investigate the effects of individual or multiple heavy metals on thyroid disease.
https://doi.org/10.1016/j.fct.2025.115443

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Zhao, J., Yang, M., Xing, X., Mei, Y., Zhou, Q., Zhao, M.*, et al.*
Metals and polycyclic aromatic hydrocarbons co-exposure : Amino acid omics insights on blood glucose homeostasis.
Journal of Environmental Sciences, Vol. **157**, (2025), 35-51 p.

Previous studies have reported a relationship between exposure to metals and polycyclic aromatic hydrocarbons (PAHs) and blood glucose levels, but whether the mechanisms are mediated by amino acids remains to be elucidated. We conducted a three-wave repeated measurement study involving 201 elderly individuals (aged ≥ 50 years) from five communities in Beijing, China. We simultaneously measured eight metals in both blood and urine, six monohydroxy PAHs in urine, and 23 amino acids in blood. Linear mixed-effects and sparse partial least squares models were used to evaluate the individual effects, and Bayesian kernel machine regression was employed to mixture effects. Mediation analysis was further used to explore whether amino acids mediators mediate the association. We observed significant associations of selenium and strontium with increased blood glucose. Additionally, blood copper, urinary nickel, as well as urinary 1 + 9 hydroxyphenanthrene, were associated with irregular blood glucose regulation.

Moreover, we found that amino acids such as leucine, proline, and alanine may mediate the associations. This study is the first to investigate the effect of metals and PAHs on blood glucose homeostasis, while also exploring the mediating role of amino acids, offering new insights into the impact of metals and PAHs on blood glucose regulation.
https://doi.org/10.1016/j.jes.2024.12.007

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Zhao, S., Lu, W., Yuan, G., Liu, Y., Yang, C., Lu, S.*, et al.*
Associations between seminal plasma metal mixture and semen quality : A metabolome-mediated case-control study.
Ecotoxicol Environ Saf 2025, Vol. **297**, 118257.

Metal exposure constitutes a global public health concern associated with male infertility. This matched case-control study advances mechanistic understanding of how environmental pollutants interact with biological systems to impair human reproduction by investigating multi-metal exposure and seminal plasma metabolic responses.
Based on this matched case-control study among 522 males, we assessed the role of untargeted metabolomic profiling of 265 seminal plasma metabolites in the relationship between seminal metals and abnormal semen quality (ASQ). The relationship between metals and ASQ was analyzed using single-exposure models (single-metal and multi-metal logistic regression) and mixed-exposure models including Quantile Gaps-Cumulated (QG-C), weighted quantile sum (WQS) regression, and Bayesian kernel machine regression (BKMR).
The findings revealed that metal mixture exposure collectively increased ASQ risk, with seminal plasma Cu demonstrating a significant risk-enhancing effect in both single- and mixed-exposure models, while Fe and Se consistently exhibited protective trends. These associations were robustly supported by sensitivity analyses. In addition, orthogonal partial least squares discriminant analysis (OPLS-DA) identified 74 significant differential metabolites out of a total of 265 metabolites. Among these, 22, 21, and 12 differential metabolites were found to mediate the association between iron, selenium, copper, and the risk of ASQ, respectively. Moreover, 16-glucuronide-estriol, Aspartyl-Valine, Dihydrocoumarin, L-(-)-3-Phenyllactic acid, and trans-cinnamate were significant mediators in the association between iron, selenium, copper and ASQ.
This study provides the evidence that seminal plasma metals disrupt male fertility through metabolite-specific pathways, with copper driving damage while iron and selenium exert protection. These findings highlight candidate biomarkers warranting validation in environmental reproductive epidemiology, while suggesting biologically plausible pathways for future intervention studies.
https://doi.org/10.1016/j.ecoenv.2025.118257

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Zhou, Y., Wang, Y., Qiu, C., Man, Y., Zhu, X., Tan, S.*, et al.*
Associations among blood heavy metals, neurofilament light chains and cognition function in US adults : NHANES 2013-2014.
Ecotoxicol Environ Saf 2025, Vol. **299**, 118369.

BACKGROUND : Heavy metals could induce neurotoxicity, leading to cognitive function and motor deficiencies. Serum neurofilament light chain (sNfL) is a promising biomarker for neurological injury, and it may indicate nerve damage from heavy metals exposure. However, there's limited research exploring the associations among heavy metals, sNfL, and cognitive function in adults, and the existing findings are inconsistent.
OBJECTIVE : 959 participants were enrolled from the National Health and Nutrition Examination Surveys (NHANES) 2013-2014. This study was aimed to investigate the possible associations among heavy metals, sNfL, and cognitive function in adults.
METHODS : We utilized data from the National Health and Nutrition Examination Survey (NHANES) 2013-2014, comprising 959 participants. Heavy metals were detected in blood samples including lead (Pb), cadmium (Cd), mercury (Hg), manganese (Mn), and selenium (Se), with measurements taken using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) technology. The level of sNfL was quantified via an innovative high-throughput immunoassay technology developed by Siemens Healthineers. Cognitive function were assessed using the Animal Fluency Test (AFT), the Consortium to Establish a Registry for Alzheimer's Disease (CERAD), and the Digit Number Symbol Substitution Test (DSST). Additionally, generalized linear models (GLMs), weighted quantile sum regression (WQS), Bayesian kernel machine regression (BKMR), quantile-based g computation (qgcomp), and restricted cubic splines (RCS) analyses were employed to examine the associations between heavy metals exposure and sNfL level. Finally, a mediation analysis to explore the interaction among heavy metals, sNfL, and cognitive function in adults aged 60 and above.
RESULTS : The generalized linear models exhibited a positive correlation between blood Pb or Cd levels and sNfL (beta = 0.14, 95 % CI: 0.08-0.20; beta = 0.14, 95 % CI: 0.07-0.20), in total population. Both WQS and BKMR analysis

consistently showed a strong correlation between higher levels of the blood heavy metals mixture and increased sNfL (OR=0.051, 95 %CI: 0.025-0.090). The qgcomp model indicated that Cd had a significant positive correlation with sNfL, while Mn and Se showed a significant negative correlation with sNfL. Moreover, we have identified a significant relationship between sNfL or Cd and cognitive function scores (AFT, DSST) in adults aged 60 and above. The mediation analysis further revealed that sNfL partially mediated the relationship between Cd and AFT or DSST scores, with interpretive efficiencies of 23.35 % and 32.7 %, respectively.
CONCLUSION : This study is the first to utilize sNfL data to establish a link between heavy metals exposure and cognitive function. The finding highlight the the positive correlation between Pb or Cd and sNfL, the negative correlation between Se and sNfL. The impact of Cd exposure on cognitive function in individuals older than 60 was partially explained by sNfL. Further investigations are required to validate these findings, considering the constraints of the NHANES study.
https://doi.org/10.1016/j.ecoenv.2025.118369

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6. Co-expositions substances organiques, pesticides, VOCs

Rigal, S., Perrot, T.
Pesticides in France : ten years of combined exposure to active substances in land, air and surface water.
Sci Data 2025, Vol. **12** (1), 512.

Des données spatiales et temporelles à petite échelle sur l'exposition aux pesticides dans l'environnement sont d'un grand besoin pour la recherche sur l'environnement et la santé. L'omniprésence des pesticides dans l'environnement est attestée par de nombreuses analyses, mais la disponibilité des données reste insuffisante, empêchant les analyses temporelles à de grandes échelles spatiales comme au niveau national, où les politiques agricoles sont mises en œuvre ou adoptées.
Nous avons compilé des données sur l'achat de plus d'une centaine de substances actives avec des mesures de pollution de ces substances dans l'air et les eaux de surface pour proposer une cartographie de l'exposition aux substances actives les plus dangereuses entre 2013 et 2022 en France métropolitaine. Nous fournissons une validation technique de l'indice d'exposition à l'aide d'un ensemble de données construit à partir d'enquêtes sur le terrain.
L'indice d'exposition combiné est conçu pour être mis à jour chaque année, et nous prévoyons que cet ensemble de données fournira des informations de premier ordre pour la recherche en conservation et en santé.

https://doi.org/10.1038/s41597-025-04864-6

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Zhang, Y., Xiang, Y., Cao, Z., Dai, K., Gui, S., Liu, Y., *et al.*
Oxidative stress biomarkers for assessing the synergistic toxicity of emamectin benzoate and cyantraniliprole on liver function.
Sci Rep 2025, Vol. **15** (1), 17051.

Multiple pesticide residues in agricultural products and environments, especially those with synergistic toxicity, pose a potential risk to human health. We observed a remarkable increase in serum biochemical parameters related to rat liver function when rat liver was exposed to the binary mixture of emamectin benzoate and cyantraniliprole. The present study aimed to investigate the toxicity interactions and underlying mechanisms of the binary mixture by using an L-02 cell model and metabolomics analysis.
Cytotoxicity tests have shown that binary mixtures of emamectin benzoate and cyantraniliprole produced either additive or synergistic toxic effect on the cell viability of the human hepatic epithelial cell line L-02. The interaction within the binary mixtures resulted in the production of excessive reactive oxygen species (ROS) and malondialdehyde, as well as overexpression of antioxidant enzyme activities. The synergism was driven by aggravated production of ROS, leading to an imbalance in mitochondrial oxidation and energy metabolism, suggesting the possible use of ROS as an effective toxicity endpoint. Based on the benchmark dose calculated to determine the combined toxicity threshold, the model-averaged estimates of the benchmark dose lower confidence limits (4.74-9.58 mmol/L) of the binary mixtures at concentration ratios of 3:15, 3:45, 4:15, and 4:45 were 20% more toxic than their individual active ingredients.

These findings have important implications for risk assessments of pesticide residue in food and highlight the need to consider concentration ratios and oxidative stress endpoints in such assessments.
https://doi.org/10.1038/s41598-025-02429-6

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Yu, H., Ma, J., Chen, D., Gao, Y., Li, G., An, T.
Associations between inhalation of typical volatile and semi-volatile organic compounds in e-waste dismantling workers with liver function damage.
J Hazard Mater 2024, Vol. **464**, 133004.

Studies in cell culture and animal models suggest hepatotoxicity of some volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs), however, their effects in human populations under real exposure conditions have never been clarified. In this cross-sectional study, 224 participants, 38 e-waste dismantling workers and 186 subjects residing near to the dismantling sites in southern China, were evaluated for personal inhalational exposure to 72 VOCs and 91 SVOCs according to site-specific atmospheric chemical concentrations and personal exposure time. Additionally, their serum samples were subjected to liver function tests (LFTs), including total protein (TP), albumin (ALB), globulin (GLB), aspartate aminotransferase (AST), alanine aminotransferase (ALT), gamma-glutamyl transpeptidase (GGT), and bilirubin. Linear regression analysis of the VOC/SVOC levels against the LFTs results indicated that VOC exposure was negatively associated with the TP, ALB, GLB levels (indicating liver-specific protein synthesis functions), while positively associated with AST, ALT, GGT activities (marking liver damage). Somehow, SVOC exposure appeared to be positively associated with not only AST and ALT but also TP and ALB. These findings were supported by the quantile g-computation analysis and confirmed in the Bayesian kernel machine regression model. This study indicates that simultaneous inhalation of VOCs and SVOCs may impair human liver functions.
https://doi.org/10.1016/j.jhazmat.2023.133004

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Wei, Y. F., Chen, H. W., Liu, K., Wang, S. A., Fan, W. D., Shao, Z. H.*, et al.*
Independent and joint effects of volatile organic compounds on pulmonary function in U.S. adults from NHANES : the mediating role of platelet-to-lymphocyte ratio.
Environ Pollut 2025, Vol., 126473.

Volatile organic compounds (VOCs) are known to impair pulmonary function. However, the specific VOC with the main significant impact on pulmonary function and the joint effect of combined VOC exposure on pulmonary health, and the underlying mechanisms remain unclear.
We used the of data 1,697 participants aged >/= 18 years old from the National Health and Nutrition Examination Survey 2007-2012. Forced expiratory volume in the first 1.0 second (FEV1), pre-bronchodilator forced vital capacity (FVC), peak expiratory flow rate (PEF) and FEV1/FVC % were used to evaluate pulmonary function. A covariate-adjusted multiple linear regression model evaluated associations between pulmonary function and blood concentrations of seven selected VOCs. Additionally, Bayesian kernel machine regression (BKMR) and weighted quantile sum (WQS) regression were employed to assess combined VOC effects, interactions, and nonlinear dose-response relationships. Parallel mediation analyses explored the mediating role of platelet-to-lymphocyte ratio (PLR) in the associations between VOC mixtures and pulmonary function, utilizing a WQS-derived VOC index. In an analytical sample of 1,697 general adults, the concentrations of blood 1,4-dichlorobenzene, m-/p-xylene, bromodichloromethane, and nitromethane were significantly negatively correlated with pulmonary function, whilst dibromochloromethane was significantly positively correlated with pulmonary function. The joint effect of the seven blood VOCs was also negatively associated with pulmonary function. Particularly, 1,4-dichlorobenzene (PIP = 0.992 for FEV1; 0.998 for FVC) and nitromethane (PIP = 0.990 for FEV1; 1.000 for FVC; 0.845 for PEF) as the most influential VOCs contributing to the overall mixture effect. PLR partially mediated the association between VOC mixtures and pulmonary function, particularly impacting FEV1, FVC, and PEF.
This study demonstrated that in addition to chloroform, dibromochloromethane and toluene, the other four blood VOCs were associated with pulmonary function impairment. Their combined exposure effects reflect realistic environmental scenarios. Further research is needed to elucidate the underlying biological mechanisms of these associations.
https://doi.org/10.1016/j.envpol.2025.126473

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Suljevic, D., Karlsson, P., Focak, M., Brulic, M. M., Sulejmanovic, J., Sehovic, E.*, et al.*
Microplastics and nanoplastics co-exposure modulates chromium bioaccumulation and physiological responses in rats.
Environ Int, 2025 Vol. **198**, 109421.

The environmental fragmentation of plastics generates a mixture of plastic particles of various sizes, which frequently co-occur with other mobile and persistent environmental pollutants. Despite the prevalence of such scenarios, the interaction between micro- and nanoplastics (MNPs) and their combined effects with environmental pollutants, such as highly toxic hexavalent chromium (Cr(VI)), remain almost entirely unexplored in mammalian species. This study demonstrated that nanoplastic and microplastic particles co-aggregate and together influence Cr bioaccumulation patterns and related physiological alterations in rats. Following a four-week repeated intragastric exposure of Wistar rats to MNPs and Cr(VI), either alone or in combination, MNPs significantly enhanced Cr bioaccumulation in the liver, heart, brain, and skin. Under co-exposure conditions, Cr(VI) was the primary driver of cellular effects observed in the blood, including shifts in immune cell subpopulations (e.g., neutrophils, lymphocytes) and alterations in red blood cell indices, while serum biochemistry reflected limited physiological stress. MNPs per se decreased creatine kinase activity and increased cholesterol levels. In summary, polystyrene MNPs increase Cr(VI) distribution and bioavailability, but co-exposure does not uniformly exacerbate toxicity. Instead, their interaction may selectively alter physiological responses, emphasizing the need for a deeper understanding of their combined effects and potential health risks.
https://doi.org/10.1016/j.envint.2025.109421

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Seo, J. H., Kim, P.-G., Choi, Y.-H., Shin, W., Sochichiu, S., Khoshakhlagh, A. H.*, et al.*
Evaluation of personal exposure to volatile organic chemicals (VOCs) in small-scale dry-cleaning facilities using passive sampling.
Atmospheric Environment 2025, Vol. **353**, p.

This study evaluates personal exposure to volatile organic compounds (VOCs) in 50 workers from small-scale dry-cleaning facilities using optimized ePTFE passive samplers, analyzing 13 VOCs. At mean exposure levels, significant non-carcinogenic risks were identified for trichloroethylene (TCE), while carcinogenic risks were confirmed for five compounds: styrene, benzene, ethylbenzene, dichloroethene (DCE), and perchloroethylene (PCE). Workers most frequently reported health changes (48 %), followed by specific symptoms such as dry skin (24 %), fatigue (22 %), skin irritation (20 %), and eye fatigue (20 %), all of which were associated with exposure to different VOCs in the workplace. These findings highlight the need for continuous monitoring and guidelines regarding working hours, particularly in small-scale workplaces. The VOC emissions from dry-cleaning facilities not only pose direct health risks to workers but also contribute to environmental pollution, highlighting the importance of proactive management and control measures in these businesses.
https://doi.org/10.1016/j.atmosenv.2025.121235

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Ottenbros, I. B., Vermeulen, R. C. H., Krop, E. J. M., Beeltje, H., Fuhrimann, S., Figueiredo, D. M.
Characterization of aggregated exposure to multiple pesticides near agricultural fields : an application of silicone wristbands.
Environmental Research Communications 2025, Vol. **7** (4), p.

Public health concerns exist regarding pesticide exposure of workers and residents living near agricultural fields. Still, knowledge is limited in part due to the difficulties of assessing cumulative personal exposure to pesticides over time, as well as the total aggregate exposure. Silicone wristbands are a low-cost and non-invasive passive sampling tool to assess exposure to multiple pesticides.
In this study, 19 residents living close to flower bulb fields in the Netherlands wore wristbands for an average of 60 days (range : 38–155). 31 different pesticides were quantified in the wristbands via liquid chromatography with tandem mass spectrometry (LC-MS/MS). For interpretation purposes of potential patterns of exposure the pesticides were categorized by their application status : 1) applied during the study period, 2) registered for usage on flower bulbs but not applied during the study period, 3) not applied and not registered. Measured concentrations reflected highly individualized exposure profiles over a long-term measurement period. The minimum number of pesticides that were detected in a wristband was 6, with an average of 19 (maximum : 31). Azoxystrobin, carbendazim and pymetrozine were detected in all wristbands. While carbendazim was not applied during the study period, it was authorized for spraying on bulb fields. No distinction could be made between wristbands with days of wearing, vapor

pressure or soil half-life of the pesticides. Using wristbands, we efficiently assessed pesticide mixture exposure profiles. The co-occurrence of pesticides in the wristbands allowed the identification of realistic chemical mixtures in residents living near agricultural fields.
This study demonstrates the potential of wristbands to assess a large number of pesticides over an extended period of time independent of the source of exposure. Due to their low-cost and non-invasive nature, wristbands could be applied in larger populations, combined with the ability to detect a large number of pesticides over time, this methodology could be informative for future environmental health, toxicology, and exposome studies, as well as regulators.
https://doi.org/10.1088/2515-7620/adc547

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Mancini, T., Radica, F., Mosesso, L., Paolozzi, M. C., Macis, S., Marcelli, A.*, et al.*
Ultrahigh-sensitive and real-time detection of BTXs for occupational safety via infrared spectroscopy coupled with machine learning technique.
Journal of Environmental Chemical Engineering 2025 Vol. **13** (3)

Exposure to Volatile Organic Compounds (VOCs) is one of the major human and occupational safety concern, as possible human carcinogens. Several gold standard methods are used for their detection in the atmosphere ; however, most of them operate ex-situ or do not provide easy discrimination between different molecules with suitable sensitivity. Here, we introduce an ultrasensitive method based on Fourier Transform Infrared (FTIR) spectroscopy coupled with Machine Learning (ML) algorithms to analyse toxic gaseous substances in working sites down to a concentration of less than 1 ppm. We investigate six selected aromatic compounds (BTXs gases and styrene), building an accurate IR gas-phase database and providing, for the first time at the best of our knowledge, universal IR calibration curves still lacking in literature. Starting from this IR gas-phase database, we design and train a ML automatic and rapid recognition method. This advantageous combination between IR spectroscopy, including the estimated IR calibration curves, and ML algorithms demonstrates the strong ability of our strategy in discriminating between different gaseous VOCs indoor, with high accuracy and rapidity even when more compounds are present at the same time. The proposed approach responds to the fundamental needs (i) to evaluate low VOCs concentrations up to values less than 1 ppm (under the legislative levels), (ii) to monitor the VOCs presence in real-time for the accurate estimation of long-exposure levels and (iii) to discriminate the coexposure at various compounds.
https://doi.org/10.1016/j.jece.2025.116833

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Chiger, A. A., Gigot, C., Robinson, E. S., Tehrani, M. W., Claflin, M., Fortner, E.*, et al.*
Improving Methodologies for Cumulative Risk Assessment : A Case Study of Noncarcinogenic Health Risks from Volatile Organic Compounds in Fenceline Communities in Southeastern Pennsylvania.
Environ Health Perspect 2025, Vol. **133** (5), 57004 p.

BACKGROUND : Cumulative risk assessment (CRA) is key to characterizing health risks in fenceline and disadvantaged communities, which face environmental pollution and challenging socioeconomic conditions. Traditional approaches for inclusion of mixtures in CRA are limited and only assess the most sensitive target organ system for each chemical.
METHODS : We developed an expanded approach to cumulative risk assessment that considers all known target organ systems associated with a chemical. Specifically, we created a multi-effects toxicity database by a) compiling toxicological and epidemiological data from the Agency for Toxic Substances and Disease Registry's (ATSDR) Toxicological Profiles and the Environmental Protection Agency (US EPA) CompTox Chemicals Dashboard ; b) developing a tiering system to prioritize identified data for use in developing toxicity values; and c) accounting for uncertainty to create toxicity values for additional target organ systems. We demonstrated differences between the traditional approach and our expanded approach by using state-of-the-art mobile monitoring data from our Southeastern Pennsylvania Hazardous Air Pollutant Monitoring and Assessment Project (SEPA HAP-MAP) to conduct a cumulative risk assessment.
RESULTS : Of the 32 chemicals quantified in SEPA HAP-MAP, 28 were represented in our multi-effects toxicity database, whereas only 16 were included using a traditional approach. In total, we derived toxicity values for 172 chemical-target organ system combinations. Our expanded approach found neurological, renal, respiratory, endocrine, and systemic risks (hazard index > 1) in SEPA HAP-MAP fenceline communities, whereas no risks were identified using a traditional approach limited to the most sensitive target organ systems only.
CONCLUSION : Our results suggest that traditional approaches to CRA underestimate health risks in fenceline and other highly exposed communities and highlight the need for improved methods to inform health-protective and just risk management decisions.

https://doi.org/10.1289/EHP14696

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Alijagic, A., Särndahl, E., Kotlyar, O., Karlsson, P., Duberg, D., Scherbak, N*., et al.*
Nanoplastics drive toxicity under co-exposure with perfluorooctanesulfonic acid in human intestinal cells.
Environmental Chemistry Letters 2025,

Per- and polyfluoroalkyl substances and nanoplastics frequently co-occur in environmental matrices, yet the effects of co-exposure on cellular responses upon ingestion are poorly understood. Here, we exposed human intestinal Caco-2 cells to perfluorooctanesulfonic acid, nanoplastics, and their combination. Cell painting-based phenomics was used to map phenotypic alterations across subcellular structures, and untargeted metabolomics using ultra-high-performance liquid chromatography coupled to quadrupole time-of-flight mass spectrometry was employed to assess metabolic changes. Results show that perfluorooctanesulfonic acid predominantly affected the actin cytoskeleton, Golgi apparatus, and plasma membrane, while nanoplastics primarily targeted mitochondria. Combined exposure disrupted the endoplasmic reticulum, RNA, and mitochondria. Perfluorooctanesulfonic acid reduced levels of carnitines, free fatty acids, nucleotides, and sugars, whereas nanoplastics inhibited ceramides, triglycerides, sphingomyelins, and additional free fatty acids. Combined exposure produced a metabolic profile resembling that of nanoplastics, with specific differences attributed to perfluorooctanesulfonic acid. Overall, nanoplastics appear as the main drivers of the co-exposure effects.
https://doi.org/10.1007/s10311-025-01847-2

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