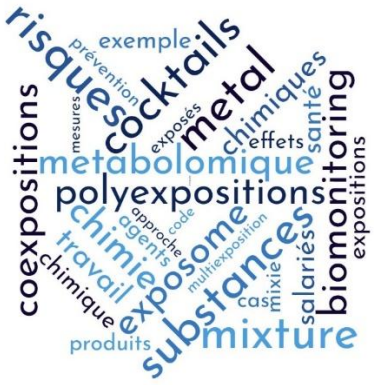

Bulletin de veille
Polyexpositions chimie-chimie
N°14 - avril 2026

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

- 26 février 2026. Les objets connectés seront un élément clé de la recherche en exposomique à l'avenir. Exemple des échantillonneurs d'air portables, comme les bracelets portables à base de silicone sont de plus en plus utilisés pour mesurer les expositions chimiques, notamment après des incendies de forêt. https://www.jmir.org/2026/1/e93193

- 4 mars 2026. eNews du NIOSH. Les chercheurs du NIOSH étudient les bonnes pratiques en milieu professionnel pour permettre de recycler en toute sécurité les plastiques afin que ces matériaux transformés en filaments, puissent être utilisés dans des produits de fabrication additive. Les résultats préliminaires montrent que le polyéthylène haute densité (HDPE) contenu dans les plastiques peut être recyclé en filament d'impression 3D utilisable sept fois. Les résultats indiquent également que le nombre de particules potentiellement toxiques libérées lors de la fabrication du filament diminue à mesure qu'il est recyclé.
  Plus d'info

- 3 mars 2026. Dossier NIOSH 3D printing.
  https://www.cdc.gov/niosh/manufacturing/additive/index.html

- 12 mars 2026. ATSDR updates chemical mixtures interaction profiles : Why They Matter for Risk Assessment and Regulation. https://www.lawbc.com/atsdr-updates-chemical-mixtures-interaction-profiles-why-they-matter-for-risk-assessment-and-regulation/
  Pour en savoir plus : https://www.atsdr.cdc.gov/interaction-profiles/about/

- 18 mars 2026. France Exposome et ses partenaires lancent une première cartographie (**iChemAtlas**) de l'exposome chimique humain réalisée à partir d'échantillons représentatifs provenant de 800 individus (hommes, femmes, enfants de 6 à 17 ans). Lire le communiqué de presse
  Ces travaux font l'objet d'une publication : https://www.nature.com/articles/s41591-026-04289-7

  Sur le même thème, annonce de l'École des hautes études en santé publique (EHESP) : Cartographier l'exposome chimique humain : une initiative européenne inédite pour la santé publique
  24 mars : Annonce de l'INRAE

- 18 mars 2026. La recherche sur l'« exposome » menée par une équipe américaine a démontré que les expositions individuelles n'avaient qu'un impact modéré sur les résultats de santé ; mais que cet impact augmentait lorsqu'on considérait plusieurs expositions simultanément : https://hms.harvard.edu/news/large-scale-look-exposome
  Résultats publiés dans Nature Medicine https://doi.org/10.1038/s41591-026-04266-0

- 27 mars 2026. Mis à jour le 1er avril. L'ANR s'engage à la recherche sur les expositions environnementales et des modes de vie sur la santé, afin d'identifier les facteurs associés au développement ou à la prévention des maladies chroniques. La cohorte familiale E3N-Générations, dans le cadre de l'approche One Health, intègre l'exposome de près de 200 000 personnes issues de trois générations successives.
  https://anr.fr/fr/actus/details/news/comprendre-lorigine-des-maladies-chroniques-et-le-role-de-lexposome-a-lechelle-de-trois-generatio/

- 2 avril 2026. Bioengineering.org
  Les schémas d'exposome chimique varient selon l'urbanisation en Europe.
  https://bioengineer.org/chemical-exposome-patterns-vary-by-urbanization-in-europe/

Sommaire

1. Généralités.

1.1. Polyexpositions chimiques en milieu professionnel

Antonios Tsimpidakis, M., Phd, Katerina Tsaoutou, Md, Electra Nicolaidou, Md, Phd, et coll.
Patterns of Sensitization and Cross-Reactivity in Hair Dye Allergy : An 18-Year Tertiary-Center Experience from Greece.
Dermatitis, Vol. 0, first published online February 6, 2026.

Hair dye-related allergic contact dermatitis (ACD) is a common problem among both consumers and professionals. The main sensitizers are aromatic amines such as para-phenylenediamine (PPD) and toluene-2,5-diamine (TDA), which can also cross-react with chemically related compounds.
Objective : To analyze patch-test results from patients with suspected hair dye-related ACD, focusing on the prevalence of sensitization to hair dye allergens, cross-reactivity patterns, and occupational differences.
Methods : We retrospectively reviewed 666 patients patch-tested between 2005 and 2023 at the Patch Test Clinic of Andreas Sygros Hospital, Athens, Greece. All patients were tested with the European baseline and extended hairdresser series. Results were evaluated according to the International Contact Dermatitis Research Group and European Society of Contact Dermatitis criteria. Logistic regression was used to calculate odds ratios for co-sensitization, adjusted for sex and age.
Results : Overall, 82.4% of patients reacted to at least 1 allergen, with a median of 3 positive reactions. PPD was the most frequent allergen (47.9%), followed by TDA (35.9%) and nickel (41.1%). Significant co-sensitization was observed between PPD and several chemically related compounds, including 4-aminophenol, 3-aminophenol, benzocaine, textile dyes, hydroquinone, and pyrogallol ($P < 0.001$). Similar associations were observed for TDA. Hairdressers were younger (mean 32.2 vs 40.7 years, $P < 0.001$) and had predominantly hand dermatitis (62.9%). Patients reacting to multiple hair dye components were significantly more likely to be sensitized to PPD. Co-sensitization between PPD and cocamidopropyl betaine likely reflected cosmetic co-exposure rather than structural cross-reactivity.
Conclusions : PPD and TDA remain the dominant sensitizers in hair dye-related ACD, with strong cross-reactivity to aminophenols, benzocaine, and textile dyes. Extended patch testing is essential for accurate diagnosis, as 7% of para-amino–compound–sensitized patients would be missed by PPD testing alone. Occupational exposure and multi-allergen sensitization highlight the need for safer formulations and preventive strategies in hair dye use.
https://doi.org/10.1177/17103568251408797

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Baraketi, E., Khouja, N., Tebourbi, Y., Taleb, F., Bechrifa, E., Hsinet, J.*, et al.*
Eczéma de contact aéroporté en milieu textile : formaldéhyde et méthylisothiazolinones comme allergènes professionnels.
Revue Française d'Allergologie, Vol. 66, (2026)

Les eczémas de contact allergiques (ECA) aéroportés sont rarement rapportés dans l'industrie textile. Leur diagnostic est souvent difficile en raison de la complexité et diversité des traitements appliqués aux tissus.
Objectifs : Décrire un cas d'ECA aéroporté chez une ouvrière du textile, ayant un retentissement sur l'aptitude médicale au travail.
Méthodes : Cas clinique.
Résultats/Discussions : Il s'agissait d'une patiente de 39 ans, aux antécédents de lupus érythémateux systémique, ouvrière piqueuse sur machine dans une usine de confection textile. Elle était exposée aux poussières textiles végétales et synthétiques, aux colorants et apprêts textiles, avec un poste de repassage avoisinant. Depuis deux ans, elle présentait des lésions érythémato-vésiculeuses prurigineuses évoluant vers la desquamation, touchant le visage, le cou et le décolleté, avec des épisodes d'œdème des paupières. Les tests épicutanés à la batterie standard européenne ont montré une sensibilisation au formaldéhyde et

aux méthylisothiazolinones. Le diagnostic d'un ECA aéroporté a été retenu. L'origine professionnelle a été évoquée devant la rythmicité de la symptomatologie avec son activité professionnelle, la concordance du siège des lésions avec l'exposition à des agents aéroportés ainsi que la pertinence des résultats des tests épicutanés. En effet, le formaldéhyde peut être présent dans certains tissus en tant qu'agent conservateur, ainsi que dans les résines libératrices de formaldéhyde utilisées comme agents anti-froissement. Il est alors libéré dans les poussières textiles dégagées lors de la coupe et de la confection, ainsi que dans les vapeurs émises lors du repassage des tissus synthétiques traités. De même, les méthylisothiazolinones peuvent se retrouver dans ces tissus en tant que conservateurs. Compte tenu de l'ubiquité de ces allergènes dans l'usine, l'aptitude au travail de la patiente était compromise.
Conclusion : Ce cas illustre la complexité du diagnostic des ECA aéroportés en milieu textile. Il souligne l'importance d'une enquête professionnelle ciblée et d'une meilleure traçabilité des substances utilisées dans le traitement des tissus pour prévenir et gérer ces allergies.
https://doi.org/10.1016/j.reval.2026.104803

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Knott, P. G., Nolan, E., Oldmeadow, C., Attia, J., Schofield, P. W., Benke, G.*, et al.*
Cognitive performance and lifetime occupational exposures in a regional Australian population : a distributed lag mixtures approach.
International Journal of Environmental Health Research, Vol. 36 n°(3), (2026), 357-368.

Examination of exposures over a lifetime of employment and work-related disease has largely focused on the effects of single agents. In reality, workers are exposed to mixtures of agents.
In a community cohort of 1621 older participants (Hunter Community Study) with a mean age of 68.0 years (SD 6.8 yr), cognitive performance was assessed using the Audio Recorded Cognitive Screen, and lifetime occupational histories used to retrospectively estimate yearly exposures to a range of chemicals from the Finnish job-exposure matrix. This study utilised Bayesian Kernel Machine Regression - Distributed Lag Models to investigate potential time windows of increased susceptibility to cognitive effects following retirement.
Furthermore, the research explored exposure-response relationships between multiple chemicals, with adjustments for covariates identified from a directed acyclic graph. Analysis identified a window of susceptibility from welding fume exposures 17 years after commencement of work at age 18.
The negative effects from lead (Pb) at levels below current exposure standards were identified. Bivariate interactions from co-exposure of carbon monoxide to lead, toluene and trichloroethylene were identified, the magnitude of which may not be statistically meaningful.
This study identified effects on cognition post-retirement associated with occupational exposures to a mixture of chemicals encountered throughout the participants' working life.
https://doi.org/10.1080/09603123.2025.2520897

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RIZZA A. ; PESTRE T. ; CHEZE O. ; DUFAUD O.

Influence of seasonal, technical, and lithological parameters on exposure to dust and crystalline silica in the French natural stone industry.

(Influence des paramètres saisonniers techniques et lithologiques sur l'exposition aux poussières et à la silice cristalline dans l'industrie française de la pierre naturelle).

Annals of Work Exposures and Health, n° 2, mars 2026, 12 p., ill., bibliogr. (En anglais)

Cet article présente une étude de terrain menée dans huit entreprises représentatives de l'industrie française de la pierre naturelle, visant à caractériser l'exposition des travailleurs aux poussières inhalables, respirables et à la silice cristalline alvéolaire, dans le contexte de l'abaissement récent des valeurs limites d'exposition professionnelles. Les auteurs réalisent des prélèvements individuels et des mesures en temps réel sur plusieurs procédés (finition, éclatement, sciage au disque, guillotine,

flambage), en conditions sèches ou humides, l'hiver et l'été. Les résultats mettent en évidence des dépassements fréquents des VLEP, notamment lors des travaux de finition à sec du granit et de certaines opérations sur calcaire dur, avec des concentrations pouvant atteindre jusqu'à 120 fois la VLEP pour la fraction inhalable et des indices d'exposition à la silice très supérieurs à l'unité. L'analyse statistique montre l'influence majeure du type de procédé, du recours au travail humide et de facteurs saisonniers. L'étude conclut à la nécessité de combiner procédés humides, dispositifs de captage efficaces et appareils de protection respiratoire de type FFP3, associés à une formation des opérateurs, pour ramener l'exposition en dessous des valeurs limites et améliorer la prévention du risque silice dans ce secteur.

Référence INRS-Bilio : 768715

Lien vers l'article : https://doi.org/10.1093/annweh/wxaf086

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1.2. Exposome humain chimique

David, A., Lennon, S., Mercier, F., Bouhlel, J., Chaker, J., Appenzeller, B. M. R., *et al.*
Mapping the human chemical exposome for public health.
Nature Medicine, 18 March 2026.
No abstract available
https ://doi.org/10.1038/s41591-026-04289-7

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Gaba, S., Lefeuvre, S., Ouedraogo, F., Mougard, C., Brillard, E., Delva, F., *et al.*
Territory health : A transdisciplinary approach of environmental, plant, animal, and human health interdependencies in a rural landscape in France.
Iscience, Vol. 29 (3), (2026).

Health is increasingly understood as an integrated property of human, animal, plant, and environmental systems, as articulated by the One Health and EcoHealth concepts. The Territory Health project applies these perspectives within an agricultural landscape to examine interdependencies between environmental, nonhuman organisms, and human health. Using in a participatory and experimental approach, the project brings together researchers, local residents, farmers, decision-makers, and NGOs to investigate the relationships between pesticide use, in situ exposure to pesticide mixtures, and health effects on non-target organisms.
A key objective is to establish a « partner cohort » to examine how changes in food production, dietary practices, and the human-nature relationship shape health of the territory under study. By situating the food biodiversity-environment-health nexus within a socio-ecosystem perspective, this work supports agrifood system transformations toward long-term territorial health.
https ://doi.org/10.1016/j.isci.2026.114956

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Yang, Q.-S., Xu, J.-Q., Liu, R.-L., Zheng, J., Bao, M.-H., Zhong, Z.-H., *et al.*
Environmental toxicant exposure and diabetes risk : An exposome-wide association study integrating mixture effects and molecular mechanisms.
Ecotoxicology and Environmental Safety, Vol. 312, (2026)

Environmental toxicant exposure has emerged as a potential contributor to diabetes, yet systematic investigations integrating multiple chemicals and biological mechanisms remain limited. This study employed a hypothesis-generating, exposome-toxicogenomic framework to examine the associations

between diverse environmental toxicants and diabetes risk and to explore underlying biological pathways. Data from 2689 NHANES 2013-2016 participants (366 with diabetes and 2323 without) were analyzed. Forty-six toxicants across seven chemical classes were evaluated using exposure-wide association studies, deletion/substitution/addition modeling, restricted cubic splines, Bayesian kernel machine regression, and quantile-based g-computation. Integrative bioinformatics analyses, including Comparative Toxicogenomics Database annotations, transcriptomic profiling, pathway enrichment, protein-protein interaction networks, and machine learning, were conducted to explore potential biological pathways and support biological plausibility.
Five toxicants glycidamide, ethylene oxide, antimony, uranium, and NAC-3HPM-were consistently associated with higher odds of diabetes (OR range : 1.22-1.34). Mixture analyses revealed cumulative risk amplification (qgcomp OR 1.39, 95 % CI 1.21-1.60), with ethylene oxide showing the highest posterior inclusion probability (>0.5). Stronger associations were observed among obese individuals. Bioinformatics analyses identified 87 overlapping toxicant-diabetes-related genes enriched in pathways related to oxidative stress, apoptosis, AGE-RAGE signaling, and atherosclerosis. Machine learning across 113 models (optimal : Elastic Net ; training AUC 0.956, test AUC 0.867) highlighted 14 key genes, of which five (MAPK8, SIRT1, PIK3R1, KRAS, MAPK1) overlapped as hub genes in protein-protein interaction networks.
These findings suggest that background-level exposure to environmental toxicants is associated with increased diabetes risk, potentially involving biologically relevant pathways related to mitochondrial function, insulin signaling, and inflammatory processes, with obesity acting as a potential susceptibility factor.
https ://doi.org/10.1016/j.ecoenv.2026.119923

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Zhou, Z. L., Li, J. Y., Wang, W., Wang, X. Q., Yin, L., Li, N. N.*, et al.*
Exposome-wide association study of environmental toxicant exposure and insulin resistance : Findings from US National Health and Nutrition Examination Survey.
Ecotoxicol Environ Saf, Vol. 309, (2025), 119594 p.

Prior epidemiological evidence regarding the associations between environmental toxicant and insulin resistance (IR) focused exclusively on single or limited exposure classes, failing to capture the interactions and mixed effects of multiple toxicants with grouping structures.
Furthermore, there is a knowledge gap in addressing whether oxidative stress may mediate the relationships in the context of high-dimensional exposure. Based on data from the 2013-2014 and 2015-2016 circles of National Health and Nutrition Examination Survey, we examined the associations of IR with 53 toxicants in 10 categories. IR status was assessed using HOMA-IR, with the highest quartile defined as severe IR. The effects of mixtures were determined using principal component pursuit in combination with multi-pollutant exposure models. Mediation analysis was conducted to examine the mediating effects of oxidative stress indicated by gamma-glutamyl transferase.
This study identified 15 environmental toxicants in 5 classes were significantly associated with severe IR risk, including the metabolites of volatile organic compounds (VOCs), CEMA (OR, 1.57 ; 95 % CI, 1.30-1.91), as well as total nicotine (OR, 1.05 ; 95 % CI, 1.01-1.09). In co-exposure scenarios, VOCs mixtures dominated the associations and elevated severe IR risk (beta, 0.54 ; 95 % CI, 0.27-0.81), with MHBMA2, 3-HPMA, MA, and CEMA holding the major weights. Individual younger than 60 years and females had greater vulnerability to environmental toxicants compared to their counterparts. Oxidative stress mediated 11.54 %-37.61 % of the total effects.
Our findings offer crucial implications on IR management by tailoring interventions to key environmental targets and individuals at high risks.
https ://doi.org/10.1016/j.ecoenv.2025.119594

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Rizk, N., Chaix, B., Annesi-Maesano, I., Bista, S., Fancello, G.
Evaluation of the effects of air pollutants on lung function using ambulatory air pollution monitor data from the Mobilisense Project.
BMC Environmental Health (2026) : This is a preprint ; it has not been peer reviewed by a journal.

Background : Exposure to air pollution negatively impacts respiratory health, but limited research exists on its short-term effects while simultaneously considering several pollutants measured with sensors.
Objective : This study investigated the impact of air pollutants on lung function among 199 participants in Paris, France. Participants' exposure to black carbon (BC), nitrogen dioxide (NO2), nitrogen monoxide (NO), carbon monoxide (CO), ozone (O3), and particulate matter (PM2.5) was recorded continuously. Lung function was assessed using spirometry tests conducted twice per day in the morning and evening over three days (N = 2504), measuring forced expiratory volume in 1 second (FEV1), forced vital capacity (FVC), and the FEV1/FVC ratio.
Methods : Air pollution levels were averaged over time windows from 15 minutes to 6 hours before the spirometry tests. Mixed-effect linear models were used to estimate the pollutants' associations with lung function.
Results : Results showed that increased exposure to BC and PM2.5 was associated with a reduced lung function. A 1 µg/m3 increase in BC within 1 or 2 hours prior to testing was associated with a decrease in FEV1 by 0.016 (95% CI -0.024, -0.008) and 0.021 (95% CI -0.034, -0.007) respectively. Similarly, increases in BC exposure over 2 hours to 4 hours were associated with a decrease in the FEV1/FVC ratio. Additionally, PM2.5 exposure 15 or 30 minutes or 1 hour before testing was linked to a 0.60 (95% CI -1.30, -0.03), 0.70 (95% CI -1.39, -0.09) and 0.50 (95% CI -1.10,-0.01) percentage points reduction in the FEV1/FVC ratio. Ozone (O3) was positively associated with FEV1 and FVC. No associations were found for other pollutants or time windows.
Significance : This study highlights the detrimental short-term effects of air pollution, particularly BC and PM2.5, on lung function during daily mobility.
https ://doi.org/10.21203/rs.3.rs-9022657/v1

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2. Biomonitoring, biomarqueurs

Alharbi, K. S.
Multi-omics biomarkers in cadmium-related lung toxicity and carcinogenesis.
Clinica chimica acta ; 15 April 2026, 120933.

Cadmium exposure through smoking, occupational exposure, and pollution is linked to lung damage and cancer risk ; however, most mechanistic studies remain limited to in vitro transformation and animal studies rather than large human cohorts. However, there are few clinically applicable biomarkers for early detection, risk assessment, and therapeutic monitoring.
This review, centered on mechanisms, provides a summary and critical analysis of multi-omics biomarker evidence related to cadmium (Cd)-induced lung toxicity and carcinogenesis, with a particular focus on diagnostic laboratory medicine. We combine genomic and epigenomic signals (mutational signatures, cfDNA/ctDNA, methylation, and miRNA profiles) with proteomic and metabolomic readouts that represent inflammation, oxidative stress, extracellular matrix remodeling, and altered energy metabolism. In matrices (blood, urine, sputum, bronchoalveolar lavage, and extracellular vesicles), we emphasize key pre-analytical variables affecting measurements (collection tubes, processing delays, hemolysis, storage temperature, freeze-thaw cycles, and batch effects) rather than providing comprehensive experimental validation of the assays.
Where appropriate, we comment on representative requirements for analytical performance and common pitfalls (limit of detection, precision, interference, calibration/traceability, and external quality assessment)

of candidate biomarker classes ; however, a comprehensive discussion of quantitative clinical performance measures (sensitivity, specificity, AUC, prospective validation) for most markers is lacking. Finally, we suggest a practical, stepwise translation pathway that emphasizes mechanistically informed multi-analyte panels, documented differences between exposure and effect biomarkers, future validation in exposed cohorts, and clinically relevant endpoints (reduction in lung function, incidence of malignancy, and response to treatment) to facilitate routine laboratory implementation. To demonstrate the clinical relevance and economic viability of controlling confounders and establishing decision limits, standard reporting of methods, rigorous control of confounders (particularly smoking and co-exposures), and explicit derivation of decision limits based on specific targeted applications (such as screening, surveillance, or monitoring of responses) should be prioritized over current evidence base achievements.
https ://doi.org/10.1016/j.cca.2026.120933

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Howe, M. E., Wiley, A. S., Essandoh, Y. E., Venier, M.
Silicone Wristbands for Measuring Human Exposure to Organic Chemicals : Uses and Benefits for Human Biological Research.
American journal of human biology : the official journal of the Human Biology Council, Vol. 38 (2), (2026), e70187.

Increasing human exposure to environmental contaminants is a growing concern and has become an important factor within human biological variation and health outcomes. Yet, traditional exposure assessment methods are often limited in their ability to capture the complexity and variation of chemical exposure, or are invasive, costly, and challenging to apply in field-based research.
Here, we introduce silicone wristbands as an innovative and noninvasive tool for measuring personal passive chemical exposure and highlight opportunities for their use in human biological research. The wristbands sequester organic chemicals across multiple media (e.g., air, water, dust) and capture both inhalation and dermal absorption. We describe how they work, how to deploy them in the field, how to extract and analyze the chemical composition, and their methodological advantages for human biological research. A case study assessing exposure to flame retardants and the relationship to body size among girls in Costa Rica demonstrates the application for human biological research in a tropical and remote setting.
We argue that wristbands provide a noninvasive method for assessing individual exposomes and understanding how environments are embodied and become a meaningful axis of human biological variation. Additionally, they motivate interdisciplinary, ethical, and community-engaged research in diverse and hard-to-reach populations, aligning with future directions of the field of human biology.
https ://doi.org/10.1002/ajhb.70187

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Narayanan, M.
Heavy metal exposure among industrial workers mechanisms of toxicity biomonitoring strategies and public health risk assessment.
Discover Public Health, 2026, Vol. 23, (146).

Exposure to heavy metals is still a significant occupational health issue in the manufacturing industry and millions of workers globally are exposed to heavy metal substances. Many industrial processes, such as mining, smelting, welding, electroplating, battery manufacturing, and electronic waste recycling, result in exposure to airborne fumes, dust, and contaminated surfaces, leading to inhalation, ingestion, and dermal absorption of metals such as lead, cadmium, mercury, arsenic, chromium, nickel, and manganese.
Chronic exposure results in oxidative stress, inhibition of enzymes, DNA damage, mitochondrial dysfunction, and epigenetic alterations, culminating in detrimental health effects on the nervous system, kidneys, liver, and cardiovascular system. A biomonitoring assay that tests blood, urine, hair, and nails can fully check for internal exposure in addition to environmental monitoring and provides the opportunity to

detect subclinical toxicity early. Guidance is given by established reference values and occupational exposure limits, while biomarkers of effect, either renal or neurobehavioral indicators, serve as the basis for risk assessment on the basis of exposure.
This review highlights current research on sources and pathways of occupational heavy metal exposure, elucidates the molecular and systemic mechanisms of toxicity, and identifies biomonitoring strategies for risk assessment. Focus is on co-exposure scenarios, vulnerable worker populations, and the application of biomarker-based surveillance in prevention with occupational health in the workplace as part of occupational health prevention programs. In conclusion, combining ecological surveillance with biomarker-based biomonitoring is a strong way to find and stop heavy metal–related occupational diseases promptly, especially when people are exposed to more than one substance at a time. To safeguard vulnerable workers and lower long-term health risks, it is important to strengthen this kind of monitoring in occupational health initiatives.
https ://doi.org/10.1186/s12982-026-01431-1

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Perez-Diaz, C., Raux, A., Massias, J., Le Bizec, B., Philippe-Antignac, J., Guitton, Y.*, et al.*
Serum biomarkers of phthalate exposure, adipose tissue metabolites and 20-years incidence of elevated LDL levels : An exploratory exposome study in the GraMo cohort.
Environmental Toxicology and Pharmacology, Vol. 122, March 2026, 104956.

Several phthalates are considered metabolic-disrupting chemicals since they may alter adipose tissue and lipid metabolism, although human evidence remains limited. This study explored metabolic signatures in adipose tissue associated with phthalate exposure, and their relationship with the 20-year incidence of elevated low-density lipoprotein (LDL) levels in adults from the GraMo cohort. 72 adipose tissue and serum samples were collected from patients in two public hospitals in Granada, Spain. Adipose tissue was analysed using targeted and non-targeted metabolomic and lipidomic approaches. 32 phthalate biomarkers were measured in serum. A meet-in-the-middle approach identified metabolites associated with both exposure and outcome, with pathway analysis conducted using Mummichog. Phthalates were inversely associated with unsaturated phosphatidylcholines and fatty acids, and positively associated with saturated lipids. These lipid changes were, in turn, linked to elevated LDL incidence. Our findings suggest an impact of phthalates on lipid metabolism, but warrant further confirmation.
https ://doi.org/10.1016/j.etap.2026.104956

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Zhang, D., Tang, X., Liu, X., He, Z., Wang, S.
Health hazards of occupational exposure to benzene, toluene and xylene (BTX) and the role of Vanin-1 : a populational-based study.
Int Arch Occup Environ Health, 2026, Vol. 99 (4)

Purpose : Despite most enterprises adhering to regulatory limits for benzene, toluene and xylene (BTX) exposure, growing evidence suggests that chronic, low-level exposure to these chemicals is associated with compromised antioxidant defenses. Vascular non-inflammatory molecule 1 (Vanin-1) plays a pivotal role in modulating oxidative stress. This study investigates the effect on hematological parameters and oxidative stress markers among occupationally exposed workers, focusing on Vanin-1 as a potential early oxidative damage biomarker.
Methods : A total of 300 participants (exposure group = 100, control group = 200) were recruited from three enterprises located in Henan Province, China. Demographic, occupational, and lifestyle data were collected through structured questionnaires, followed by comprehensive statistical analyses.
Results : The exposed group exhibited significantly lower white blood cell/neutrophil counts, along with higher mean corpuscular hemoglobin concentration compared to the control group. Urinary metabolite S-phenylmercapturic acid (S-PMA) levels were significantly higher in the exposure group, and these levels

exhibited a positive linear relationship with eosinophil percentage. Additionally, the exposed group had significantly reduced glutathione (GSH) levels, while oxidized glutathione (GSSG) levels were significantly elevated. Both Vanin-1 protein and mRNA expression levels were significantly lower in the exposed group. Generalized linear model analysis indicated a significant positive correlation between S-PMA and malondialdehyde (MDA), while S-PMA was negatively correlated with Vanin-1 expression. Bootstrapping mediation showed Vanin-1 explained 10.6% of S-PMA on MDA.
Conclusion : Vanin-1 appears to be a potential biomarker for detecting early oxidative damage resulting from low-level BTX exposure. These findings provide a scientific basis for safeguarding worker health.
https ://doi.org/10.1007/s00420-025-02190-3

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3. Approches métabolomiques

Sunyer-Caldu, A., Xie, H., Bonnefille, B., Raptopoulou, F., Pesquet, E., Rian, M. B.*, et al.*
Silicone-Foam Passive Air Samplers for Combined Target and Nontarget Chemical Profiling and Toxicity Assessment of Airborne Exposomes.
Environmental science & technology, Vol., (2026), p.

Polluted air is a major global health risk factor, yet the chemical composition and toxicity of airborne gases and particles remain underexplored due to their complexity and difficulties in sampling.
We recently introduced how polydimethylsiloxane (PDMS) foam–or silicone foam–can be synthesized for passive air sampling, enabling simple and cost-effective nontarget chemical profiling of indoor air. Here, we demonstrate expanded applications, indoors and outdoors, with commercial PDMS-foam, including for :
(i) wide-scope target analysis of >220 priority substances by quantitative liquid- and gas chromatography-high-resolution mass spectrometry,
(ii) microscopic characterization and nontarget profiling of accumulated fine particles, and
(iii) effect-guided discovery of harmful substances, combining toxicological data with nontarget analysis in silico. Median method quantification limits were 0.12 ng/mL, 90% of target analytes had absolute recoveries between 70 and 130%, and hazardous substances were discovered, including ethylene glycols, insecticides, and UV filters. Microscopy revealed the accumulation of abundant fine particles, and the automated characterization of the fluorescent fraction revealed that most were <4 mum. Extracts from outdoor samples reduced human lung cell viability, and multivariate modeling flagged families of potentially toxic substances in a virtual effect-directed analysis. PDMS-foam disks require field calibration to determine their linear sampling rate(s), but current results and applications establish PDMS-foam as a multimodal passive sampler, enabling integrated chemical quantitation, toxicological analysis, and molecular discovery in air.
https://doi.org/10.1021/acs.est.5c16613

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Perez-Diaz, C., Raux, A., Massias, J., Le Bizec, B., Philippe-Antignac, J., Guitton, Y.*, et al.*
Serum biomarkers of phthalate exposure, adipose tissue metabolites and 20-years incidence of elevated LDL levels : An exploratory exposome study in the GraMo cohort.
Environmental Toxicology and Pharmacology, Vol. **122**, (2026), p.

Several phthalates are considered metabolic-disrupting chemicals since they may alter adipose tissue and lipid metabolism, although human evidence remains limited. This study explored metabolic signatures in adipose tissue associated with phthalate exposure, and their relationship with the 20-year incidence of elevated low-density lipoprotein (LDL) levels in adults from the GraMo cohort.
72 adipose tissue and serum samples were collected from patients in two public hospitals in Granada, Spain. Adipose tissue was analysed using targeted and non-targeted metabolomic and lipidomic approaches. 32

phthalate biomarkers were measured in serum. A meet-in-the-middle approach identified metabolites associated with both exposure and outcome, with pathway analysis conducted using Mummichog.
Phthalates were inversely associated with unsaturated phosphatidylcholines and fatty acids, and positively associated with saturated lipids. These lipid changes were, in turn, linked to elevated LDL incidence. Our findings suggest an impact of phthalates on lipid metabolism, but warrant further confirmation.
https://doi.org/10.1016/j.etap.2026.104956

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Pedersen, A. F., Petrick, L. M., Roth, K., Yang, Z., Sitarik, A. R., Maroli, A.*, et al.*
Nontargeted screening identifies mixtures of environmental pollutants that are associated with perturbations to amino acid and fatty acid metabolic pathways during early pregnancy.
Environment international, Vol. 209, (2026), 110172.

"One-chemical-at-a-time" approaches are typically used to investigate adverse health outcomes associated with exposure to environmental chemicals during pregnancy. However, nontargeted high-resolution mass spectrometry (HRMS) approaches can instead measure complex, real-world mixtures of xenobiotics and metabolic products and may better explain mechanisms of toxicity and identify biomarkers of exposure than single-chemical approaches during pregnancy, a particularly sensitive exposure window.
Here, our objective was to use a nontargeted, HRMS approach that monitors endogenous and xenobiotic compounds to identify associations of pollutant mixtures with metabolic pathways in serum of 100 pregnant women from the MARCH cohort (Michigan Archive for Research on Child Health). Xenobiotic mixtures were identified based on in-house libraries as well as a discovery-based approach, FluoroMatch 3.0, to identify nonlegacy/emerging fluorinated chemicals in these same samples. Metabolic pathways of interest were determined using MetaboAnalyst software and effect estimates on metabolic profiles were estimated for both individual contaminants and mixtures of all identified chemicals. 415 endogenous metabolites and 21 individual chemical pollutants were detected with high identification confidence and included per- and poly-fluoroalkyl substances (PFAS), phthalates, bisphenols, organophosphate esters (OPEs), and parabens. An additional 105 tentative fluorinated compounds were identified via FluoroMatch. As classes of toxicants, bisphenol and PFAS mixtures showed the greatest number of associations with metabolic pathways related to arginine, proline, glycine, serine, and threonine metabolism. When the total mixture of all 21 contaminants was modeled after covariate-adjustment, biosynthesis of unsaturated fatty acids remained (FDR < 0.05).
Taken together, these findings illustrate that serum concentrations of environmental contaminants may be associated with some metabolic pathways in pregnancy and that mixture modeling identified fatty acid metabolism as a possible pathway of interest for future validation. These findings further demonstrate the potential of robust nontargeted exposome-wide approaches as tools to study and identify the mechanisms of toxicity underlying human disease.
https://doi.org/10.1016/j.envint.2026.110172

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Kuang, H.-X., Liu, Y., Li, M.-Y., Zheng, T., Hu, G.-C., Xiang, M.-D.*, et al.*
Integrated Human Organic Pollutant Exposome and Metabolome Analysis Reveals Biomarkers and Health Risks from Electronic Waste Exposure.
Environmental Science & Technology, Vol. 60 (8), (2026), p. 6033-6047.

Escalating global electronic waste (e-waste) generation contrasts with <20% formal recycling rates. Policy gaps and inadequate enforcement exacerbate pollution transfer to under-regulated regions, causing substantial environmental and health problems. To address this, we investigated chronic exposure hazards and developed rapid pollution identification technologies.
We recruited 2028 participants from e-waste recycling sites and other industrial parks, profiling their urinary organic pollutant exposome (>200 chemicals), oxidative damage, and metabolome by integrating nontargeted and targeted screening methods.
Results showed that exposure to pollutant mixtures was significantly associated with increased oxidative

damage to nucleic acids and cholesterol. Moreover, these pollutant mixtures collectively explained 46.2% of the variance in urinary metabolome alterations among e-waste workers. The affected metabolites were primarily associated with inflammatory diseases, metabolic disorders, neurological conditions, and cancers. By identifying e-waste exposure characteristic pollutants, we further developed accurate e-waste exposure prediction models (AUC > 0.986; ACC > 0.938) and derived simplified prediction functions and diagnostic indexes with comparable efficacy, which performed well across populations and industrial settings.
Overall, this study underscores the significant health risks of e-waste exposure in occupational workers and offers rapid screening tools for e-waste pollution in informal settings, advancing the repurposing of large-scale national exposure monitoring databases for pollution tracking.
https://doi.org/10.1021/acs.est.5c13657

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Yuan, B., Liu, C., Chen, S., Chu, J., Yang, Y., Pan, Y.*, et al.*
Metabolomics-driven, data-augmented machine learning for predicting toxicity of microplastic mixtures.
Ecotoxicology and Environmental Safety, Vol. 312, (2026), p.

Microplastics (MPs) occur as heterogeneous mixtures in real-world environments, making one-by-one toxicity testing impractical. This study aims to use predictive models to quickly and effectively evaluate the toxicity of MPs. We explored three model frameworks : a quantitative structure-activity relationship (QSAR) model based on physicochemical descriptors ; a quantitative bioactivity relationship (QBAR) model with biodescriptors screened by metabolomics data ; and a quantitative structure-bioactivity relationship (QSBAR) model combining both physicochemical and biodescriptors. Under a simplex centroid design, six machine learning algorithms were trained using data augmentation strategies to predict the cytotoxicity of microplastic mixtures.
The results showed that the QBAR-based eXtreme Gradient Boosting (XGB-qbar) model performed best (R2 tra = 0.9322, R2 test = 0.8923), outperforming the QSAR and the QSBAR frameworks. The three descriptor importance methods consistently identified key biological descriptors helpful for toxicity prediction. Moreover, metabolomics analysis indicated that mixed exposure to MPs may mediate toxic responses by reprogramming cellular energy metabolism pathways. The metabolomics-driven and data-augmented machine learning approach proposed in this study can efficiently predict toxicity and provide mechanistic clues in small sample and complex mixture scenarios, providing a feasible path for environmental exposure risk assessment.
https://doi.org/10.1016/j.ecoenv.2026.119944

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Sille, F. C. M., Kopanska, K., Prasse, C., Luechtefeld, T., Hartung, T.
AI redefine untargeted metabolomics : estimating chemical amounts for a Human Exposome Project.
Frontiers in Public Health, Vol. 14, (2026).

The Human Exposome Project aims to map the totality of environmental exposures, but its success relies on transforming qualitative detections into quantitative data. Following our review on AI-driven metabolite identification, this second installment addresses the next critical bottleneck: estimating chemical concentrations in untargeted metabolomics without authentic standards.
Translating LC-HRMS signal intensities into absolute concentrations is hindered by the vast variability in ionization efficiency and matrix effects, particularly for xenobiotics where reference standards are unavailable. We review emerging strategies that leverage artificial intelligence-ranging from descriptor-based regression to deep learning on molecular point clouds-to predict ionization response factors. We further evaluate a "matrix-embedded" calibration approach that utilizes ubiquitous endogenous metabolites (e.g., amino acids, lipids) as internal anchors to normalize response scales across studies. These innovations enable "tiered semi-quantification," allowing the classification of exposures into biologically relevant ranges (e.g., nanomolar vs. micromolar). This stratification facilitates direct integration with toxicological frameworks, such as the Threshold of Toxicological Concern (TTC) and high-throughput bioactivity data (e.g., ToxCast), for rapid risk prioritization. By integrating quantitative AI prediction models

with robust quality assurance, untargeted metabolomics can evolve from a qualitative discovery tool into a quantitative engine for exposure science, providing the necessary evidence to link complex chemical exposures to human health outcomes.
https://doi.org/10.3389/fpubh.2026.1775284

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4. Modèles, Outils méthodologiques

Sarigiannis, D., Anesti, O., Papaioannou, N., Karakoltzidis, A., Karakitsios, S.
Computational standards and tools for exposome-wide association studies linking the human exposome with health outcomes.
Environment international, Vol. 208, (2026), 110117.

The human exposome (the cumulative measure of environmental exposures across the life course) offers a critical complement to genomics in deciphering the multifactorial origins of complex diseases. Exposome-wide association studies (ExWAS) represent an emerging class of high-dimensional epidemiological analyses designed to systematically assess associations between diverse environmental exposures and health outcomes. However, ExWAS requires advanced computational standards and tools capable of handling exposure complexity, temporal variability, co-exposure correlation, and multi-omics data integration.
This review synthesizes current computational methodologies and platforms for ExWAS, highlighting recent advances in statistical modeling, exposure quantification, and bioinformatics tools. We conducted a PRISMA-ScR-guided scoping review across PubMed, Scopus, and Web of Science (2010-2025), with dual-reviewer screening in Rayyan, standardized data charting, and SWiM-aligned narrative synthesis. We explore multivariable and mixture modeling approaches (e.g., weighted quantile sum regression, Bayesian kernel machine regression), integration of external and internal exposome domains, and the application of longitudinal designs and environmental risk scoring. Key platforms such as the rexposome suite, exposomeShiny, and the integrative INTEGRA framework are examined for their role in operationalizing exposomic analyses at population scale. We also discuss the importance of data standardization, including exposure ontologies, harmonization protocols, and federated data infrastructure supporting cross-cohort analyses.
Moreover, we discuss how computational exposomics can elucidate mechanistic pathways linking environmental exposures to disease, particularly when integrated with transcriptomic and metabolomic data. Finally, we outline future directions for the field, including genome-exposome integration, AI-driven causal inference, and translational pipelines for regulatory and clinical implementation. Beyond listing methods, we assess computational maturity and reproducibility (open licensing, containerization, federation readiness) and connect standards+tools to ExWAS workflows and translation. Computationally mature and mechanistically anchored, ExWAS are poised to become central tools in precision environmental health, enhancing the interpretability of genome-environment interactions and the predictive power of integrated omics frameworks.
https://doi.org/10.1016/j.envint.2026.110117

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Fu, H., Qiu, T., Bao, S., Jiang, Y., Lu, Y., Shi, X.
High-throughput analytical method for simultaneously detecting pest control agents and specific metabolites in human urine.
Microchemical Journal, Vol. 224, (2026), p.

Pest control agents are widely utilized for disease prevention and agricultural purposes ; however, their potential health risks necessitate comprehensive evaluation through human biological monitoring. Existing analytical methods exhibit limited coverage of analytes, often overlooking common co-exposure scenarios.

We developed a method that integrates 96-well solid-phase extraction (SPE) with liquid chromatography-triple quadrupole mass spectrometry (LC-MS/MS).
This method enables the simultaneous quantification of 16 pest control agents and specific metabolites in human urine, including diethyltoluamide (DEET) and its three metabolites, ten neonicotinoids and metabolites, and two novel insecticides (sulfoxaflor and flonicamid). Key innovations include mixed-mode SPE with pH-gradient elution (which significantly reduces matrix effects and improves analyte recovery). Additionally, the use of sub-2 mu m UPLC columns allows for the complete elution of all analytes within 11 min. Isotope dilution ensures high accuracy, yielding method detection limits of 0.01-0.21 mu g/L, precision <= 19.0%, and accuracy ranging from 89.5% to 106.6%. When applied to 115 urine samples from a nonoccupationally exposed cohort in the China National Human Biomonitoring Program (CNHBM), this method detected neonicotinoids and metabolites in all samples, DEET and metabolites in 60.9%, and novel insecticides in 9.57%.
This study demonstrates a robust, high-throughput analytical method that is well-suited for large-scale environmental biomonitoring applications. The method addresses a significant gap in environmental exposure assessment through extended analyte coverage, isotope-assisted calibration, and customizable SPE workflows, thus providing a scalable platform for exposomics research.
https://doi.org/10.1016/j.microc.2026.117402

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Dutta, A., Barupal, D.
Predicting toxicity and bioactivity of the chemical exposome : a case study for the blood exposome database.
J Cheminform, (2026)

Humans are exposed to thousands of chemicals throughout their life. Many of these chemicals are detected in blood and have been catalogued in the Blood Exposome Database. Comprehensive hazard assessment of a chemical requires time-consuming and costly lab experiments using animal or cell-lines, which cannot be easily scaled up to the chemical exposome, highlighting the urgent need for computational approaches that can prioritize chemicals based on toxicological information.
In this study, we trained direct message passing neural networks (D-MPNN) models using the Chemprop framework, chemical structure, and bioactivity data from 9,581 compounds profiled in theTox21 program across 148 quantitative high-throughput screening assays corresponding to distinct biological endpoints. Additionally, we trained a complementary model using chemical structures (n = 264,601) labeled with known UN-GHS classifications for acute oral toxicity. The Tox21 bioactivity and UN-GHS models demonstrated strong predictive performances, with the 47 bioactivity models and the GHS classification model each achieving AUCs greater than 0.80. We applied these high accuracy models to 52,055 chemicals from the Blood Exposome Database to predict bioactivity and the GHS hazard classification, enabling scalable in-silico prioritization of understudied chemical exposures for further toxicological investigations. Data and code are available at https://zenodo.org/records/17560382 and https://github.com/idslme/exposome-toxicity-prediction.
Scientific contributions : We have developed an integrated predictive toxicology workflow for exposomics. This unique workflow utilizes Tox21 endpoints, UN-GHS classification and ADME property prediction models, all implemented in the state-of-the-art Chemprop framework, enabling a ranking of exposome compounds for their toxicity potential. By applying it for the Blood Exposome Database, we have prioritized several chemicals that have been detected in blood samples but can be toxic to human health.
https://doi.org/10.1186/s13321-026-01187-5

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Mcgrath, S., Wang, Y., Lin, Y. T., Meeker, J. D., Park, S. K., Warren, J. L.*, et al.*
A comparison and evaluation of statistical methods for mediation analysis with mixtures of environmental exposures.
BMC Med Res Methodol, (2026)

BACKGROUND : Environmental studies often evaluate how exposures influence health outcomes through intermediate biological processes. In practice, researchers are often interested in complex exposure mixtures rather than single agents, creating challenges for mediation analysis due to strong correlations among exposures, sparsity of active exposures, and possible nonlinear and interactive effects. This study compares and evaluates approaches for mediation analysis when exposures involve complex mixtures.
METHODS : We review four strategies: (1) single-exposure mediation analysis that analyzes each exposure separately; (2) principal component-based mediation analysis that summarizes correlated exposures into orthogonal components; (3) environmental risk score-based mediation analysis that constructs a supervised prediction score for the exposure set and treats the score as the exposure; and (4) Bayesian kernel machine regression causal mediation analysis that flexibly models nonlinear and interactive mixture effects. For each approach, we clarify the target estimand and the assumptions required for causal interpretation. We conduct a simulation study to systematically evaluate the operating characteristics of these four methods to estimate global indirect effects and to identify individual exposures contributing to the global mediation under varying sample sizes and effect sizes. We then illustrate an application of these approaches in an observational birth cohort.
RESULTS : In the simulation study, the single-exposure mediation analysis approach often produced highly biased estimates when not adjusting for co-exposures, and this bias was substantially reduced after co-exposure adjustment. For the mediation analysis methods designed to address the correlation and complexity in exposure mixtures, the performance often depended on a number of method-specific analytic choices, such as the number of principal components retained or the variable selection approach used in the Bayesian kernel machine regression method. In the data application, all methods found limited evidence of non-null global indirect effects and had broad agreement in which individual exposures were identified as potentially active, despite differences in their assumptions and causal estimands.
CONCLUSION : Multiple strategies are available for mediation analysis with exposure mixtures, each with distinct strengths. The study provides guidance on selecting and applying methods according to study aims and data features.
https://doi.org/10.1186/s12874-026-02809-0

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El Balkhi, S., Machon, C.
Toxicology of Heavy Metals in Biological Matrices : A Paradigm Shift From Single-Analyte Measurement to Comprehensive Screening.
Therapeutic Drug Monitoring, 2026, Vol. 48 (2) p.196-209.

Background : The clinical diagnosis of heavy metal toxicity presents a formidable challenge, largely because of symptomatology, which is notoriously nonspecific and capable of mimicking a wide array of common medical conditions. The current diagnostic paradigm, which relies on measuring a single metal in response to specific clinical suspicion, is often inadequate. This approach fails to account for the complex, interconnected nature of the human metallome, in which the toxicity of 1 element is profoundly influenced by the status of others. Antagonistic and synergistic interactions between toxic and essential metals are fundamental to the pathophysiology of toxicity and are largely ignored in single-analyte testing.
Methods:This narrative review argues for a paradigm shift from targeted measurements to comprehensive quantitative screening.
Results: We delineated the diagnostic difficulties due to nonspecific symptoms and how existing clinical guidelines focus on single-element action levels. We then present an intricate web of metal-metal interactions that render the current approach insufficient. The cornerstone of this argument is the maturation of analytical technology. Inductively coupled plasma tandem mass spectrometry (ICP-MS/MS)

has overcome the longstanding challenge of atomic and polyatomic interference in complex biological matrices owing to its high selectivity, enabling the development of robust, validated, and high-throughput multielement panels.
Conclusions :By providing a holistic view of an individual's elemental profile, the metallomic footprint of their exposome, this approach offers a more complete and clinically relevant picture, capturing not only the toxicant but also the biological context in which it acts.
We conclude that quantitative multielement screening is no longer a theoretical possibility but a practical necessity for clinical toxicology to enhance diagnostic accuracy and improve patient outcomes.
https://doi.org/10.1097/ftd.0000000000001416

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Varner, P. M., Brinkley, G. T., Weisner, M. L.
Identification of Potential Cumulative Chemical Exposures in Overburdened Communities for Chemical Policy Applications.
Environmental Justice, Vol. **0** (0), (2026), 19394071261430108 p.

Many individuals are exposed to multiple toxic chemicals that contribute to the same adverse health impacts. However, these co-exposures and community vulnerability to exposures are not often considered in chemical assessments and regulations.
In this study, we develop an approach to identify the potential co-exposures of chemicals causing similar adverse health effects and community vulnerability where these exposures occur. Co-releases of toxic chemical pairs in the same health endpoint groups were assessed from the U.S. Environmental Protection Agency's Toxics Release Inventory (TRI). Comparative impacts from toxic chemical releases that occur in overburdened communities were conducted using the Climate Vulnerability Index (CVI). Analysis of variance (ANOVA) was used to determine if the magnitude of releases was significantly different between facilities releasing one or multiple chemicals, and ANOVAs with post hoc Tukey's Honestly Significant Difference were performed to determine if CVI scores were significantly different depending on endpoint group or chemicals.
This study found the occurrence of TRI co-releases of chemical pairs causing similar health effects ranges from 0% to 72%, with high co-releases in similar volatile organic compounds and metals. Facilities releasing multiple chemicals released statistically significantly higher amounts of these chemicals from 2017 to 2022 than facilities that release only one chemical—over 285,000 lbs. more on average ($p < 0.0001$). Additionally, chemicals such as vinyl chloride and hexachlorobutadiene are released frequently in more vulnerable communities, with the CVI of communities near these chemical-releasing facilities being 8%–16% greater on average. This study provides an approach for identifying toxic chemical co-releases and community vulnerability where chemicals are released, which can aid state and federal agencies in prioritizing chemicals for assessment and regulation based on their potential for cumulative risks in overburdened communities, scoping for cumulative risk assessments, and identifying opportunities for co-benefits to at-risk communities.
https://doi.org/10.1177/19394071261430108

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5. Co-expositions aux métaux lourds

Narayanan, M.
Heavy metal exposure among industrial workers mechanisms of toxicity biomonitoring strategies and public health risk assessment.
Discover Public Health, 2026, Vol. 23 (146).

Exposure to heavy metals is still a significant occupational health issue in the manufacturing industry and

millions of workers globally are exposed to heavy metal substances. Many industrial processes, such as mining, smelting, welding, electroplating, battery manufacturing, and electronic waste recycling, result in exposure to airborne fumes, dust, and contaminated surfaces, leading to inhalation, ingestion, and dermal absorption of metals such as lead, cadmium, mercury, arsenic, chromium, nickel, and manganese.
Chronic exposure results in oxidative stress, inhibition of enzymes, DNA damage, mitochondrial dysfunction, and epigenetic alterations, culminating in detrimental health effects on the nervous system, kidneys, liver, and cardiovascular system. A biomonitoring assay that tests blood, urine, hair, and nails can fully check for internal exposure in addition to environmental monitoring and provides the opportunity to detect subclinical toxicity early. Guidance is given by established reference values and occupational exposure limits, while biomarkers of effect, either renal or neurobehavioral indicators, serve as the basis for risk assessment on the basis of exposure.
This review highlights current research on sources and pathways of occupational heavy metal exposure, elucidates the molecular and systemic mechanisms of toxicity, and identifies biomonitoring strategies for risk assessment. Focus is on co-exposure scenarios, vulnerable worker populations, and the application of biomarker-based surveillance in prevention with occupational health in the workplace as part of occupational health prevention programs. In conclusion, combining ecological surveillance with biomarker-based biomonitoring is a strong way to find and stop heavy metal–related occupational diseases promptly, especially when people are exposed to more than one substance at a time. To safeguard vulnerable workers and lower long-term health risks, it is important to strengthen this kind of monitoring in occupational health initiatives.
https://doi.org/10.1186/s12982-026-01431-1

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Métaux lourds et grossesse

Tang, F., Guo, J., Wu, L.-a.-S., Fan, X.-Y., Zhang, H.-W., Kartiosuo, N.*, et al.*
A study on the association between early-pregnancy hair metal levels and gestational diabetes mellitus.
Environmental pollution (Barking, Essex : 1987), Vol. 395, 15 April 2026, 127765.

Gestational diabetes mellitus (GDM) is a common complication of pregnancy with a complex etiology, and environmental exposure to metals is considered a potential and important risk factor. However, there is still insufficient research on the comprehensive effects of long-term mixed exposure to multiple metals during early pregnancy on GDM and the potential mediating factors.
This study aimed to systematically explore the independent and combined effects of exposure to 15 metals during early pregnancy on GDM risk and to clarify the potential mediating role of saturated fatty acids (SFAs) through a prospective cohort of 665 pregnant women recruited between September 2015 and June 2017. Hair samples were collected during early pregnancy, and metal concentrations were measured using inductively coupled plasma mass spectrometry (ICP-MS). SFAs levels in mid-pregnancy were measured by gas chromatography-mass spectrometry (GC-MS). Statistically, logistic regression and restricted cubic splines (RCS) were used to assess the effects of individual metals, and Weighted Quantile Sum (WQS) and Bayesian kernel machine regression (BKMR) model were applied to analyze the combined effects of metal mixtures. Additionally, mediation analysis was conducted to investigate the mediating roles of three SFAs.
The results showed that potassium (K), rubidium (Rb), niobium (Nb), silver (Ag), and thallium (Tl) were positively associated with GDM risk, while Nb, Ag, and mercury (Hg) exhibited non-linear exposure-response relationships. Metals mixture had an overall possitive effect on GDM risk. Mediation analysis revealed that myristic acid (C14:0) mediated the associations of K, Rb, Nb, and Ag with GDM risk; pentadecanoic acid (C15:0) mediated the associations of K, Rb, and Nb with GDM risk; and heptadecanoic acid (C17:0) mediated the associations of Rb and Ag with GDM risk.
https://doi.org/10.1016/j.envpol.2026.127765

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Zheng, P., Yin, B., Lei, M., Hu, W., He, L., Tang, F.*, et al.*
Association between multiple metals and gestational diabetes mellitus : a cohort study from Eastern China.
Environmental Sciences Europe, 2026, Vol. 38, article number 26.

Metal exposure is an emerging factor affecting the risk of gestational diabetes mellitus (GDM). This study aimed to explore the association between multiple metals (calcium [Ca], copper [Cu], iron [Fe], zinc [Zn], magnesium [Mg], and lead [Pb]) during early pregnancy and the risk of GDM using four statistical methods and further identify the critical metals within the mixture associated with GDM.
A total of 763 pregnant women were included in this prospective cohort study. Blood samples were collected before 14 gestational weeks, and metal concentrations were measured by atomic absorption spectrometry. An oral glucose tolerance test was conducted at 24-28 gestational weeks to diagnose GDM. Binary logistic regression analysis and restricted cubic spline (RCS) models were applied to assess the association between individual metal concentration and GDM. Quantile g-computation (QGC) analysis and Bayesian kernel machine regression (BKMR) were used to evaluate the associations between metal mixture exposure and GDM. The mean concentrations of Zn and Pb were significantly higher in the GDM group than in the non-GDM group.
In the logistic regression analyses, maternal blood Zn, Fe, and Pb were associated with an increased risk of GDM. RCS analysis showed that Zn and Pb were linearly and positively associated with the risk of GDM. According to QGC analysis and the BKMR models, the mixture of six metals was significantly and positively associated with the risk of GDM. Pb, Fe, and Zn made the major contributions. These findings underscore the importance of considering multiple metal exposures in understanding the risk factors for GDM.
https://doi.org/10.1186/s12302-025-01310-7

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Yao, W., Zhang, L., Wang, Z., Yao, W., Wu, W., Zeng, F.*, et al.*
Association between serum metal exposure in early pregnancy and preterm birth: Mediation by inflammatory blood cell parameters.
Journal of Hazardous Materials, March 2026, 141560, Vol. 505.

Several studies have linked metal exposure to preterm birth (PTB), but the underlying mechanisms remain poorly understood. This study investigated the mediating role of inflammatory blood cell counts in the relationship between metal exposure at 10-12 weeks of gestation and PTB.
The combined effects of metals were assessed using quantile g-computation (Q-gcomp) and Bayesian kernel machine regression (BKMR) models. Linear and logistic regression models evaluated the associations between individual metal levels and blood cell counts, as well as their impact on PTB risk. Mediation analysis was conducted to explore the potential role of blood cell counts in mediating the metal exposure-PTB relationship. Metal exposure was significantly associated with PTB, with serum levels of barium (Ba), lead (Pb), and cadmium (Cd) showing positive correlations with PTB risk. Mediation analysis revealed that white blood cell (WBC) and neutrophilic granulocyte (NE) counts mediated the association between serum Ba exposure and PTB. Additionally, mixed-exposure analysis demonstrated that higher overall metal exposure was linked to an increased risk of PTB.
This study highlights the association between early pregnancy serum Ba exposure and PTB, with WBC and NE counts mediating this relationship. These findings offer valuable insights into the mechanisms underlying PTB.
https://doi.org/10.1016/j.jhazmat.2026.141560

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Ding, X., Liu, L., Liu, Z., Zuo, S., Huang, Y., Yan, Y.*, et al.*
Metal mixture exposure and elevated risk of hypertensive disorders in pregnancy: Insights from a case-control study in northwestern China.

Journal of Environmental Sciences, (2026) Vol. 162, 486-494.

Exposure to metal mixtures has been associated with increased hypertensive disorders of pregnancy (HDP) risk, but evidence in northwestern China concerning the impact of environmental metals exposure on HDP risk remains limited. Thus, this study aims to investigate the association between multi-metal exposure and HDP among pregnant women in northwestern China.
We conducted a case-control study from January 2023 to May 2024 involving 94 pregnant women with newly diagnosed HDP and 188 controls. Plasma concentrations of 23 metals were measured. Single-metal models and multiple metal mixture models, including logistics regression, variable selection, weighted quantile sum (WQS), quantile g-computation (Q-gcomp), and bayesian kernel machine regression (BKMR) models, were fitted to evaluate the individual and joint effects of metal concentrations on HDP. After adjusted for potential confounders, single-metal models revealed significant associations with HDP risk: positive associations for rubidium (Rb) (odds ratio (OR) = 2.34, 95 % confidence interval (CI): 1.50, 3.67), thallium (Tl) (OR = 1.95, 95 % CI: 1.21, 3.14), cesium (Cs) (OR = 1.87, 95 % CI: 1.19, 2.94), and manganese (Mn) (OR = 2.25, 95 % CI: 1.30, 3.87), and a negative association for cobalt (Co) (OR = 0.64, 95 % CI: 0.43, 0.95). In multiple-metal models, WQS, Q-gcomp, and BKMR analyses indicated a positive joint effect of the five-metal mixture on HDP, with Rb as the strongest contributor. Interaction analysis showed that high Tl with low Co significantly increased HDP risk.
Our findings indicate that both individual and combined exposure to metals during pregnancy was associated with an increased risk of HDP. Potential interaction effects between Tl and Co on HDP risk were also observed.
https://doi.org/10.1016/j.jes.2025.07.040

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Shim, S. R., Moon, N., Kim, J. H.
Joint effects of prenatal endocrine disrupting chemicals and heavy metal mixture on birth size and maternal complication in the Korea children's environmental health cohort study.
Environmental research, 2026, Vol. 299, 124368.

BACKGROUND: Prenatal exposure to mixtures of heavy metals and endocrine-disrupting chemicals (EDCs) may adversely affect birth outcomes, but their joint effects remain understudied.
METHODS: This study analyzed 4715 Korean mother-infant pairs from the Ko-CHENS cohort. Maternal whole blood was used to measure three heavy metals (lead, cadmium, mercury), while urine samples were collected to quantify 15 non-persistent EDCs, including phthalate metabolites, bisphenols, and parabens. Birth size was assessed using INTERGROWTH-21st z-scores. Weighted Quantile Sum (WQS) regression and Bayesian Kernel Machine Regression (BKMR) were applied to evaluate mixture effects. RESULTS: Individual chemical analyses revealed significant negative associations between birth weight and MEOHP (beta=-0.146, p=0.034), MCOP (beta=-0.057, p=0.023), MtP (beta=-0.032, p=0.021), and Cd (beta=-0.141, p=0.023). Birth length showed similar patterns with MEOHP and MCOP. Weight-for-length was negatively associated with BPS (beta=-0.100, p=0.008) and Pb (beta=-0.253, p=0.048). WQS analysis demonstrated significant negative mixture effects on birth length (beta=-0.052, p=0.040) and weight-for-length (beta=-0.108, p=0.017). BKMR revealed threshold-dependent relationships, with adverse effects becoming significant when exposure levels exceeded the 50th percentile. Heavy metals emerged as primary drivers of mixture effects, while subgroup analyses showed no significant effects from phthalate or phenol mixtures alone.
CONCLUSIONS: Prenatal exposure to environmental chemical mixtures significantly reduces birth size through threshold-dependent mechanisms. Heavy metals are key contributors to adverse mixture effects, highlighting the need for cumulative risk assessment approaches in environmental health policy.
https://doi.org/10.1016/j.envres.2026.124368

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Risque de cancers

Xie, Y. F., Ding, Y. Z., Gao, Y. L., Yang, K., Zhang, Y. B., Li, L.*, et al.*
Association between multi-metal co-exposure and thyroid cancer risk in Shanxi, China: A case-control study.
Plos One, 2026, Vol. 21 (1) : e0334872.

Environmental metals are established thyroid carcinogens, yet how their co-exposure collectively reshapes carcinogenic mechanisms remains elusive. This study used ICP-MS to quantify plasma concentrations of 18 metals in 368 thyroid cancer patients and matched controls, with free thyroxine (FT4) levels abstracted from medical records. Subsequently, we applied integrative statistical modeling comprising WQS regression, BKMR modeling, interaction analysis, and causal mediation analysis to elucidate exposure-response relationships and mediating pathways.
Cases exhibited elevated plasma levels of Cr, Co, Mn, Ni, Cu, As, Cd, and Sn. WQS regression prioritized Sn, Cd, Ni, and As as risk-contributing metals demonstrating positive weight values, while Sb, Pb, and Zn showed inverse associations. BKMR modeling visualized exposure-response relationships, indicating elevated thyroid cancer risks at higher quantiles of co-exposure. A critical synergistic interaction was identified between the Cd-Sn pair. Causal mediation analysis confirmed FT4 mediates 46-69.3% of thyroid cancer risk for Sn, Cd, Ni, and As. Collectively, these findings highlight the need to incorporate metal mixture surveillance and FT4-based endocrine pathway screening into precision prevention frameworks.
https://doi.org/10.1371/journal.pone.0334872

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Boffetta, P. a. C.
Combined occupational exposure to carcinogenic metals/metalloids and risk of lung cancer.
Front. Oncol., Vol., (2026), Volume 16.

Exposure to arsenic, cadmium, chromium (VI) and nickel increases the risk of lung cancer; whereas humans are exposed to mixtures, epidemiology studies refer to individual metals/metalloids.
We analyzed the data of a case-control study of lung cancer conducted in seven European countries and comprising 2861 cases and 2936 controls, with detailed assessment of occupational exposure to arsenic, cadmium, chromium (VI) and nickel, to estimate the odds ratio (OR) of lung cancer for combined exposure to these metals/metalloids, after adjustment for potential confounders. Odds ratios for combined exposure to arsenic and cadmium and to arsenic and chromium (VI) were higher than those for individual metals (in order of 1.2–1.4 for single metals and above 2.0 for combined exposure), although formal tests of interaction on additive and multiplicative scales were imprecise and compatible with no interaction. Estimates for combined exposure to chromium (VI) and nickel were lower than expected under additive or multiplicative models, but confidence intervals for the interaction metrics included the null.
Results for co-exposure to three or four metals/metalloids were based on small numbers of exposed subjects. Findings provide limited evidence of statistical interactions between occupational exposure to these metals in relation to lung cancer risk.
https://doi.org/10.3389/fonc.2026.1772676

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Dépression, cognition

Guo, Y. X., Chen, Y. X., Zhou, H. F., Fan, Y. T., Feng, T., Ma, Z. R.
Association between heavy metals exposure and depression: findings of the NHANES from 2003 to 2020.
European Journal of Medical Research, 2026 Vol. 31, article number 266.

Background : Heavy metals are recognized neurotoxicants implicated in depression, yet limited research examines combined metal impacts. This study aimed to investigate the joint effect of heavy metals on depression and identify key contributors within the mixture.
Methods : Analyzing National Health and Nutrition Examination Survey data, adults with complete data on nine urinary metals (antimony, barium, cadmium, cobalt, cesium, molybdenum, lead, thallium, and tungsten), three blood metals (cadmium, mercury, and lead), depression status, and key covariates were assessed via four methods (multivariate logistic regression, restricted cubic spline (RCS) regression, weighted quantile sum (WQS) regression, and Bayesian kernel machine regression (BKMR)) to evaluate metal-depression associations.
Results : Among 8814 participants (731 with depression), those with depression showed higher urine and blood cadmium levels, but lower blood mercury and urine thallium levels compared to controls. Adjusted analyses linked elevated urine antimony (OR = 1.34, p = 0.029) and tungsten (OR = 1.42, p = 0.008) to increased depression risk, while higher urine thallium (OR = 0.52, p < 0.001) and blood mercury (OR = 0.7, p = 0.005) reduced risk. RCS analysis revealed nonlinear relationships between depression and urine cadmium (p = 0.004), cobalt (p = 0.005), lead (p = 0.024), antimony (p < 0.001), tungsten (p < 0.001), as well as blood cadmium (p < 0.001) and mercury (p < 0.001). The mixture analysis revealed both positive and negative exposure-response relationships, which were, respectively, dominated by urinary tungsten (29.3% weight in the WQS index) and blood mercury (44% weight). BKMR analysis confirmed multi-metal co-exposure elevates depression risk, and urinary barium showed the highest BKMR-derived posterior inclusion probability (PIP = 0.448).
Conclusion : Our findings link heavy metal mixtures to depression, identifying tungsten and antimony as risk contributors, versus inverse associations for mercury and thallium, with barium as a key interactive factor. Further studies are needed to validate these metal-specific impacts and uncover additional depression-linked metals.
https://doi.org/10.1186/s40001-026-03850-x

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Li, P. X., Chang, S. D., Tan, S. P., Xing, Y. Q., Wang, Z. Y., Zhou, T., *et al.*
Joint effects of exposure to polybrominated diphenyl ethers (PBDEs) and multiple metals on the risk of depression in adults.
Journal of Affective Disorders, 15 June 2026, Vol. 403, 121450.

Background: Synergistic health risks may arise from co-exposure to polybrominated diphenyl ethers (PBDEs) and metals, yet evidence on their joint associations with depression in adults is limited. Objectives: We examined individual and joint effects of PBDEs and metals on depression risk in adults. Methods: Data were drawn from the National Health and Nutrition Examination Survey (NHANES, 2005-2016), and 5872 adults were included in the analysis. Associations between individual PBDEs, five metals (cadmium, lead, mercury, calcium, and iron), and depression were assessed using multivariable logistic regression and Restricted Cubic Splines (RCS). Mixture effects were assessed using Weighted Quantile Sum (WQS) regression and Bayesian Kernel Machine Regression (BKMR).
Results: Higher cadmium exposure was linked to increased depression risk (adjusted odds ratio [adj. OR] = 2.55, 95% confidence interval [CI]: 1.84-3.54), whereas mercury was inversely associated (adj. OR = 0.60, 95% CI: 0.45-0.79). Most PBDE congeners showed no linear associations, though BDE28 exhibited an inverted U-shaped dose-response. The PBDE mixture alone was not associated with depression risk. In contrast, the joint PBDEmetal mixture was linked to significantly increased depression risk in both WQS and BKMR models, with BDE209, cadmium, and calcium as predominant contributors. In addition, stronger associations were observed among women, non-Hispanic Whites, and individuals with lower body mass index (BMI).
Conclusions: Co-exposure to PBDEs and metals was correlated with higher depression risk in U.S. adults, with susceptible subgroups identified by gender, race, and BMI. These findings underscore the importance of considering joint pollutant effects on mental health and prevention strategies.
https://doi.org/10.1016/j.jad.2026.121450

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Du, G., Ouyang, L., Yang, S., Li, Q., Li, J., Zhuang, X.*, et al.*
Cognitive behavioral dysregulation induced by low-level lead, cadmium, and mercury co-exposure is linked to AMPA receptor-associated with E/I imbalance.
Ecotoxicol Environ Saf, 2026, Vol. 313, 119988.

We previously found low-level heavy metals lead (Pb), cadmium (Cd), and mercury (Hg) co-exposure impairs cognition even at their respective no observed adverse effect levels. However, the underlying mechanisms and complex interactions within mixture remain poorly understood from neurobiological basis perspective. Therefore, following low-level Pb, Cd, and Hg co-exposure, we systematically investigated the effects of that on synaptic efficiency, excitation/inhibition (E/I) balance, active neurons, and cognitive behavior impairment using electrophysiology, c-Fos active neuron labeling, and cognitive behavioral tests. In vitro factorial design experiments indicated that very low-level Pb, Cd, and Hg co-exposure specifically disrupted hippocampal synaptic transmission mediated by alpha-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid (AMPA) receptors, potentially serving as a neurobiological basis for cognitive impairment following that exposure. This synaptic dysfunction may further shift E/I balance toward hyperexcitability, with increasing baseline hippocampal neuronal activity and inducing mice risk-taking behavior in resting state. Paradoxically, with mild stimulation by foot-shock, co-exposure attenuated both neuronal and behavioral responsiveness.
Further analysis showed that while baseline active excitatory neurons and vGluT1 expression (particularly in dentate gyrus) were elevated, their stimulus-evoked plasticity was impaired, following low-level Pb, Cd, and Hg co-exposure. Overall, our findings suggest that AMPA receptor-associated E/I imbalance from low-level Pb, Cd, and Hg co-exposure was linked to altered neuronal activity patterns and impaired cognitive behavioral regulation.
This study provides valuable insights for researchers and managers in revising safety thresholds, exploring mechanisms, and searching interventions for low-level heavy metal exposure.
https://doi.org/10.1016/j.ecoenv.2026.119988

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Wei, X. X., Zhao, H., Zhang, J., Sun, C.
The combined effect of cadmium and 50 Hz magnetic fields exposure at occupational levels on DNA damage in human fetal lung fibroblasts.
Ecotoxicology and Environmental Safety, February 2026, Vol. 311, 119861.

In occupational environments with a high risk of cadmium (Cd) exposure, such as electroplating plants, workers are concurrently exposed to power frequency magnetic fields (MFs). However, health implications of combined exposure to these agents remain poorly understood.
In this study, we examined both short-term (24 h) and longterm (4 weeks) exposure to Cd at an occupational exposure relative concentration (100 nM) and 0.4 mT, 50 Hz MFs on DNA damage, apoptosis, and cell viability in human fetal lung fibroblasts (WI-38).
We found that coexposure to Cd and 50 Hz MFs have no significant impact on these endpoints. Additionally, we evaluated short-term exposure to high-dose Cd (10 mu M) combined with 50 Hz MFs, as well as long-term exposure to 50 Hz MFs in cells pre-treated with 10 mu M Cd for 24 h. Consistently, no significant effects of combined exposure were observed. In conclusion, at occupational relevant exposure levels, co-exposure to Cd and 50 Hz MFs does not appear to induce synergistic adverse effect on DNA integrity, apoptotic activity, or cell viability in WI-38 cells.
https://doi.org/10.1016/j.ecoenv.2026.119861

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Qiu, T., Liu, Q. M., Guan, Q. Y., Mo, X. T., Li, X. L., Zhong, L. Y.*, et al.*
Plasma Multi-Metal Exposure, Renal Function, and Anemia Risk in Rural China: The Mediating Role of Serum Creatinine.
Biological Trace Element Research, 12 Mars 2026.

This study aims to analyze the association between plasma multi-metal exposure and anemia, as well as to investigate whether serum creatinine levels mediate this relationship. This study based on data from the Guangxi Eco-Environment Health and Aging Survey (GEHAS) in China, plasma metal concentrations were measured using ICP-MS, and hemoglobin and creatinine levels were assessed. Initially, LASSO regression was employed to identify metals with a high correlation to anemia for subsequent analysis. Subsequently, logistic regression was used to analyze the associations between metal and creatinine levels and anemia, while linear regression examined the relationship between metals and creatinine. Restricted cubic spline regression was used to assess potential non-linear associations.
The effects of multi-metal exposure were evaluated using QG-Comp, WQS, and BKMR models. Additionally, mediation analysis was conducted to explore the potential mediating role of creatinine in the relationship between metal exposure and anemia. We observed significant positive correlations between plasma levels of metals Mo, Co, and Sr and anemia, while levels of Fe, Rb, Cu, Ti, Se, Zn, Ba, and Mg exhibited negative correlations.
Multi-metals analysis indicated that combined exposure to these metals generally exerts a protective effect against anemia, with Fe contributing most significantly, followed by Rb. Specifically, serum creatinine mediated 11.5%, 10.53%, and 3.86% of the Mg-anemia, Mo-anemia, and Se-anemia relationships, respectively.
However, due to the cross-sectional nature of the study design, longitudinal cohort studies or experimental designs are further required to elucidate their causal relationships. Environmental metal exposure influences anemia risk, with combined exposure showing overall protective effects, while specific metals (Mo, Co, and Sr) increase risk. Renal function may partially mediate these associations, highlighting the need for targeted prevention and control strategies, especially in populations with impaired kidney function.
https://doi.org/10.1007/s12011-026-05022-8

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Zhong, Z. J., Chen, K., Qiu, B., Chen, P., Lian, C. Y., Wang, L.
Chronic Co-exposure to Environmentally Relevant Concentrations of Cadmium and Glyphosate Exerts Aggravating Nephrotoxicity in Mice.
Biological Trace Element Research, 21 mars 2026.

Cadmium (Cd) and glyphosate (GLY) are two prevalent environmental contaminants. Their widespread use in agricultural activities has caused frequent co-contamination incidents within ecosystems. The kidney is a primary target organ and the major excretory organ for these pollutants. However, the nephrotoxic effects of their co-exposure on mammals remain unclear.
Sixty healthy mice housed in a specific pathogen-free facility were randomly divided into 4 groups (n = 15) and exposed to GLY (8.75 mg GLY/kg feed) and/or Cd (1.45 mg Cd/kg feed) via diet for 24 weeks; subsequently, the urine, serum, and kidney samples were collected for respective analyses. Data showed that serum levels of renal injury biomarkers in the combined group were significantly higher than those in the alone group, consistent with the renal pathological findings. Urinary levels of proteins and enzymes in the combined group were also markedly higher than those in the alone group, respectively, consistent with the ultrastructural changes of proximal tubular microvilli. Moreover, mitochondria and nuclei in the renal cortex of combined group exhibited more severe ultrastructural damage than those in the alone group, indicating the characteristic of apoptosis.
Data from apoptotic assays further suggested that the combined group exhibited more obvious apoptotic

damage than those in the alone group. Collectively, these findings demonstrated that GLY itself exhibits low nephrotoxicity, but combined exposure to GLY and Cd significantly enhances Cd's nephrotoxic effects, characterized by exacerbated apoptotic damage to proximal tubule cells.
https://doi.org/10.1007/s12011-026-05074-w

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6. Expositions multiples aux polluants organiques, pesticides, BTEX

Ogundare, O., Obeng-Gyasi, E.
Association of PFAS, Metals, Phthalate and Organophosphate Metabolites with Depression Among U.S. Adults.
International Journal of Environmental Research and Public Health, 2026, Vol. 23 (2), 205.

Depression is a major public health concern, and evidence continues to show that environmental toxicants may contribute to its development. This study evaluated the association between depressive symptoms and per- and polyfluoroalkyl substances (PFAS), heavy metals, phthalates, and organophosphate metabolites using data from NHANES 2017–2018.
Depressive symptoms were measured with the Patient Health Questionnaire-9 (PHQ-9). Environmental exposure variables were analyzed using multivariable linear regression and Bayesian Kernel Machine Regression (BKMR). All models adjusted for demographic, socioeconomic, behavioral, and clinical covariates. In multivariable linear regression models adjusted for demographic, socioeconomic, behavioral, and clinical covariates, higher urinary dimethylphosphate concentrations were significantly associated with increased depressive symptom scores (β = 0.15; 95% CI: 0.04, 0.27; p = 0.0098). Mono-(2-ethylhexyl) phthalate (MEHP) was also positively associated with PHQ-9 scores (β = 0.001; 95% CI: 0.0003, 0.0019; p = 0.0043).
Because environmental mixtures tend to follow non-linear patterns, BKMR analysis was run. BKMR analyses indicated that organophosphate metabolites exhibited the greatest overall contribution to depressive symptoms (group posterior inclusion probability = 0.7875), with diethylphosphate emerging as the most influential individual exposure within the group (conditional PIP = 0.7211). Exposure–response functions suggested non-linear and threshold relationships for several metabolites. These findings identify specific organophosphate and phthalate metabolites as potential contributors to depressive symptoms and support the importance of evaluating chemical mixtures rather than single exposures. Additional longitudinal studies are needed to clarify temporal relationships and to inform public health efforts aimed at reducing exposure to organophosphate pesticides and endocrine-disrupting chemicals.
https://doi.org/10.3390/ijerph23020205

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Tang, Y. J., He, L. X., Ding, S. Y., Li, S. R., Zhang, T. T., Zhang, Z., *et al.*
Combined effects of persistent organic pollutants and endocrine-disrupting chemicals on thyroid disease risk: A WQS-XGBoost analysis of US population data.
Ecotoxicology and Environmental Safety, 2026, Vol. 310, 119681.

To assess the combined effects of mixed persistent organic pollutants and endocrine-disrupting chemicals on thyroid disease risk, we analyzed data from 1847 participants in the National Health and Nutrition Examination Survey 2011-2014. Environmental exposures included per- and polyfluoroalkyl substances, heavy metals, and phthalate metabolites. Thyroid disease was defined by self-reported physician diagnosis or laboratory criteria.
We applied weighted quantile sum regression to assess mixture effects and identify individual chemical contributions. Machine learning analysis used extreme gradient boosting (XGBoost) with Bayesian optimization for prediction, with model interpretability assessed through Shapley additive explanations

(SHAP) framework. The environmental chemical mixture shows a positive association with increased thyroid disease risk in the crude model (OR = 2.74, 95 % CI: 1.16-6.46, p < 0.05), which became marginally significant after covariate adjustment (adjusted OR = 2.30, 95 % CI: 0.97-5.47, p = 0.059). Five chemicals account for 68 % of the mixture effect: 2-(N-methyl-PFOSA) acetate (weight = 0.28), perfluorohexanesulfonic acid (0.14), blood cadmium (0.10), blood lead (0.08), and mono(2-ethyl-5-oxo) phthalate (0.08). The XGBoost model achieves excellent predictive performance (AUC = 0.978, precision = 0.986, recall = 0.900, and F1-score = 0.940). SHAP analysis reveals significant age-chemical mixture interactions, with individuals over 63 years showing dramatically increased susceptibility to environmental exposures (80 % higher predicted risk at high exposure levels).
These results suggest that combined exposure to environmental chemical mixtures marginally increases thyroid disease risk in US adults, with older populations representing a particularly vulnerable subgroup. The cumulative effects of mixed exposures highlight the importance of mixture-based risk assessment approaches.
https://doi.org/10.1016/j.ecoenv.2026.119681

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White, A. R.
The impact of military occupational combustion smoke inhalation on neuroinflammation and brain health.
Neurotoxicology 2026, Vol. 113, 103394.

Airborne combustion emissions from military burn pits, wildfires, and urban/industrial sources are increasingly recognized as a component of the neurotoxic exposome, with potential consequences extending beyond cardiopulmonary disease to brain health. These aerosols comprise heterogeneous mixtures of fine and ultrafine particulate matter (PM2.5/PM0.1), polycyclic aromatic hydrocarbons, volatile organic compounds, metals, and reactive gases whose composition varies with fuel type, combustion efficiency, and atmospheric aging.
Evidence from experimental models, epidemiology, and exposed human cohorts supports two principal routes by which inhaled pollutants may influence the central nervous system: (i) the lung-brain axis, where pulmonary oxidative injury and systemic immune activation promote endothelial dysfunction and compromise blood-brain barrier integrity; and (ii) the olfactory (nose-to-brain) pathway, in which ultrafine and lipophilic constituents interact with the olfactory neuroepithelium and are associated with early neuroimmune changes in olfactory-connected brain regions. At the cellular level, these exposures converge on microglial and astrocytic activation, TLR-NF-kappa B and inflammasome signaling, mitochondrial dysfunction, and lipid peroxidation, processes that can sustain chronic neuroinflammation and plausibly interact with 'second hits' such as traumatic brain injury, psychological stress, heat stress, sleep disruption, and cardiometabolic comorbidity. Veterans and wildland firefighters represent sentinel occupational groups for defining exposure-biomarker-outcome relationships.
This review brings together current evidence linking combustion-derived aerosols to neuroinflammatory and neurodegeneration-relevant mechanisms, highlighting source-specific considerations for military operational exposure, and outlines translational strategies for exposure monitoring, multi-omic biomarker discovery (blood and nasal/olfactory sampling), and early risk stratification to enable targeted prevention in vulnerable populations.
https://doi.org/10.1016/j.neuro.2026.103394

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Sang, Y., Huang, D., Chen, X., Lin, X., Li, M., Xie, C.*, et al.*
Association between pesticide exposure and breast cancer risk : a two-sample Mendelian randomization study.
Int Arch Occup Environ Health 2026, Vol. 99 (2).

BACKGROUND: Several observational studies have suggested a link between pesticide exposure and breast cancer, but the causal relationship remains debated.

METHODS: This study employed a two-sample Mendelian randomization (MR) approach to explore the potential causal link between pesticide exposure and breast cancer risk. Genetic instruments for pesticide exposure were identified from a genome-wide association study (GWAS) of 88,141 participants. Breast cancer data was sourced from the Breast Cancer Association Consortium. The primary MR analysis was conducted using the Inverse Variance Weighted (IVW) method, supplemented with additional sensitivity analyses to ensure result validity.
RESULTS: The IVW analysis demonstrated strong statistical evidence supporting a causal relationship between pesticide exposure and breast cancer risk (Overall breast cancer: OR = 3.213, 95% CI = 1.326-7.785, p = 0.010; ER + breast cancer: OR = 3.963, 95% CI = 1.258-12.480, p = 0.019; ER - breast cancer: OR = 6.886, 95% CI = 1.490-31.825, p = 0.013). These findings were reinforced by two additional MR analysis methods and further sensitivity testing.
CONCLUSION: The findings from this MR study suggest that pesticide exposure may contribute to an increased risk of breast cancer.
https://doi.org/10.1007/s00420-025-02192-1

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Kuang, H.-X., Liu, Y., Li, M.-Y., Zheng, T., Hu, G.-C., Xiang, M.-D.*, et al.*
Integrated Human Organic Pollutant Exposome and Metabolome Analysis Reveals Biomarkers and Health Risks from Electronic Waste Exposure.
Environmental science & technology, 2026, Vol. 60 (8), 6033-6047.

Escalating global electronic waste (e-waste) generation contrasts with <20% formal recycling rates. Policy gaps and inadequate enforcement exacerbate pollution transfer to under-regulated regions, causing substantial environmental and health problems. To address this, we investigated chronic exposure hazards and developed rapid pollution identification technologies.
We recruited 2028 participants from e-waste recycling sites and other industrial parks, profiling their urinary organic pollutant exposome (>200 chemicals), oxidative damage, and metabolome by integrating nontargeted and targeted screening methods. Results showed that exposure to pollutant mixtures was significantly associated with increased oxidative damage to nucleic acids and cholesterol. Moreover, these pollutant mixtures collectively explained 46.2% of the variance in urinary metabolome alterations among e-waste workers.
The affected metabolites were primarily associated with inflammatory diseases, metabolic disorders, neurological conditions, and cancers. By identifying e-waste exposure characteristic pollutants, we further developed accurate e-waste exposure prediction models (AUC > 0.986; ACC > 0.938) and derived simplified prediction functions and diagnostic indexes with comparable efficacy, which performed well across populations and industrial settings.
Overall, this study underscores the significant health risks of e-waste exposure in occupational workers and offers rapid screening tools for e-waste pollution in informal settings, advancing the repurposing of large-scale national exposure monitoring databases for pollution tracking.
https://doi.org/10.1021/acs.est.5c13657

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Okeke, C. O., Okoye, F. C., Okeke, C. M., Obi, E., Mazi, F. I.
Changes In the Levels of Serum Iron, Total Iron-Binding Capacity and Erythrocyte Sedimentation Rate and Association with Work-Related Exposure to Petrochemical Products in Petrol Station Attendants.
Australian Journal of Biomedical Research 2026, Vol. 2 (1) aubm016.

Background: Acute and chronic exposure to petrochemical products through inhalation or ingestion affects the health of individuals, with prolonged exposure likely to cause more adverse effects. Attendants at petrol stations in developing countries rarely use protective wear and are usually occupationally exposed to petrochemical gases. It is hypothesized that exposure to petrochemical gases may interfere with iron homeostasis.
Objective: This study examined the changes in the levels of serum iron, total iron binding capacity (TIBC)

and erythrocyte sedimentation rate (ESR) in relation to work-related exposure to petrochemical products in petrol station attendants.
Method: This cross-sectional study included 100 age and sex matched participants comprising 50 petrol station attendants and 50 control subjects. Venous blood samples were collected from the subjects and analyzed for serum iron, TIBC and ESR. The Statistical Package for Social Sciences version 25 was used for statistical analysis.
Results: The mean levels of serum iron and TIBC were significantly lower in petrol station attendants than in control participants. However, the ESR did not differ significantly between the two groups. The levels of serum iron and TIBC was decreased with longer work duration (> 12 months) than with 1- 6 months duration, whereas the ESR increased with longer duration of work-related exposure (>12 months) than with shorter durations of work-related exposure (7-12 months and 1-6 months respectively) ($p<0.05$). There was also a significant positive correlation, between work-related duration of exposure to petrochemical gas and ESR and a significant negative correlation between the work-related duration of exposure and TIBC ($P< 0.05$). Additionally, male petrol station attendants had significantly higher levels of serum iron than females, whereas the ESR was greater in females than in males. Additionally, male control participants had higher levels of serum iron and TIBC than females, while the ESR was greater in females than the in males ($P<0.05$).
Conclusion: Petrol station attendants had significantly lower levels of serum iron and TIBC than unexposed control. This may imply that occupational exposure to petrochemical products may affect iron homeostasis.
https://doi.org/10.63946/aubiomed/18030

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Friesen, M. C., Xie, S., Locke, S. J., Baris, D., Schwenn, M., Rothman, N.*, et al.*
Enhancing a job exposure matrix with subject-specific information to assess combined exposure to benzene, toluene, and xylene in a case-control study.
Ann Work Expo Health, Vol. 70 (3) April 2026, wxag014.

OBJECTIVES: We modified an existing job-exposure matrix (CANJEM) to estimate the combined exposure to benzene, toluene, and xylene, which are highly correlated (hereafter, BTX), and integrated subject-specific occupational information to assess BTX exposure for participants in a bladder cancer case-control study.
METHODS: We linked CANJEM to the lifetime occupational histories of subjects in a population-based case-control study of bladder cancer. We derived CANJEM-based estimates of the probability, intensity, and frequency of BTX exposure by assigning the highest rating observed among the benzene, toluene, and xylene CANJEM metrics. We used subject-specific exposure information in the occupational histories and exposure-oriented modules to refine the CANJEM-based BTX metrics when confirmatory exposure information was identified (hereafter, hybrid BTX metrics). We compared agreement between the CANJEM-based and hybrid BTX metrics at the job- and subject-level using kappa for the ordinal probability metrics and Spearman correlation for the continuous intensity and cumulative exposure metrics.
RESULTS: The hybrid BTX approach increased 7% and decreased 5% of the CANJEM-based BTX probability ratings at the job-level and 16% and 7% at the subject-level, respectively. The CANJEM-based and hybrid BTX metrics identified 3.2% and 6.8% of the job records and 13% and 24% of the subjects as having a high probability of BTX exposure, respectively. The BTX-exposed subjects identified through the hybrid approach generally had lower cumulative exposures than those identified solely using CANJEM. CANJEM-based and hybrid BTX metrics had moderate agreement at the subject-level (probability: kappa = 0.62; cumulative metrics, Spearman correlation = 0.61).
CONCLUSIONS: Supplementing a JEM with subject-specific exposure information identified within-job exposure heterogeneity that was not captured by using only a JEM.
https://doi.org/10.1093/annweh/wxag014

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D'Errico, A., Moirano, G., Pizzi, C., Popovic, M., Chatzi, L., Andrusaityte, S.*, et al.*
Chemical exposome patterns in mothers and children across urbanisation levels in five European birth cohorts.
J Expo Sci Environ Epidemiol, 2 April 2026).

BACKGROUND: Urbanisation can be an important determinant of human exposure to synthetic chemical pollutants. The impact of contaminant exposures on health is of particular concern during susceptible periods of life, such as in utero and during childhood, when exposure may lead to adverse health effects in childhood and later adulthood.
OBJECTIVE: We aimed to examine how contaminant exposures vary between urban and non-urban areas across five different European birth cohorts in Spain, France, Greece, the UK, and Lithuania.
METHODS: Urine and blood samples were collected from a total of 1021 mother-child pairs during both pregnancy and childhood (6-11 years old). Concentration levels of forty metabolites-including PFASs, phenols, phthalates, metals, and organophosphate and persistent pesticide metabolites-were measured. We used a spatial indicator to define the participants' degree of urbanisation. Linear Mixed-Effect Models were used to compare the distribution of exposures between urban and non-urban areas for the two life stages separately.
RESULTS: The concentrations of contaminants varied by degree of urbanisation and life stage. Overall, concentrations of phenols (GMRs; Geometric Mean Ratios, ranging from 1.06 to 1.56) and PCBs (GMRs ranging from 1.07 to 1.15) were higher among pregnant mothers living in urban areas compared to those in non-urban areas. Children showed more heterogeneous patterns of exposure across contaminant families. Children in urban areas had lower concentration levels of PFASs (GMRs ranging from 0.84 to 0.97) but higher concentration levels of phenols (GMRs ranging from 1.05 to 1.15) and phthalates (GMRs ranging from 1.05 to 1.17) compared to those in non-urban areas.
SIGNIFICANCE: Our study contributes to the understanding of how the degree of urbanisation characterises children's exposure to hazardous substances. Our findings align with the existing literature, which shows varying profiles of environmental exposures based on different degrees of urbanisation.
IMPACT: Our study provides important insights into how the degree of urbanisation can influence children's exposure to hazardous substances during critical developmental windows, with potential implications for both immediate and long-term health outcomes. Specifically, phenols, phthalates, and PCBs were found to be more prevalent in individuals living in urban areas, with notable heterogeneity of PCB concentrations across European cohorts. In contrast, PFAS concentrations were higher in children residing in non-urban areas. Understanding the geographic variations in exposure to hazardous contaminants is useful for identifying areas with higher contaminant levels, which may have important implications for vulnerable populations.
https://doi.org/10.1038/s41370-026-00859-6

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Honles, J., Cerapio, J. P., Monge, C., Marchio, A., Ruiz, E., Fernández, R.*, et al.*
Mapping pesticide mixtures to cancer risk at the country scale with spatial exposomics.
Nature Health, published 01 April 2026.

Despite decades of concern over the carcinogenic potential of agricultural pesticides, toxicological studies relying on single endpoints have yet to establish a definitive link between environmental pesticide exposure and cancer in real-world contexts. Here we use an integrative spatial Bayesian framework that merges high-resolution environmental pesticide risk modelling with comprehensive cancer registry data to map pesticide-linked cancer clusters in Peru with unprecedented precision.
Our process-based model, encompassing 31 key pesticide active ingredients, together with an innovative stratification of cancer cases by developmental lineage, reveals a robust spatial association between environmental pesticide exposure risk and cancer incidence. In pesticide-associated cancer hotspots, exposomic profiling of liver tissue—a primary target of chemical carcinogens—uncovers a distinct transcriptomic signature of pesticide exposure, implicating a non-genotoxic mode of action that disrupts core regulatory circuitries sustaining cell identity.

Collectively, these findings strongly support a mechanistic link between pesticide exposure and cancer, challenging assumptions of human non-carcinogenicity derived from reductionist experimental models. This study redefines the exposome as a lineage-conditioned, mechanistically tractable framework and shows how complex pesticide mixtures can contribute to carcinogenic trajectories, with profound and far-reaching implications for global health policy and socio-ecological equity.
https://doi.org/10.1038/s44360-026-00087-0

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