Evidence investigation

The Chemical Footprint of the Coal Industry

How substances change form, environmental medium and pathway across the entire coal life cycle

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Natalia Zubkova.

FROM THE AUTHOR

From the moment coal is first extracted from the ground to what remains after it is burned, it leaves a chemical footprint.

The deeper I go into the subject of the coal industry, the more clearly I understand one unpleasant fact: its impact does not begin when coal is burned.

It begins much earlier—from the moment the ground is disturbed to extract coal.

To extract it, they expose coal seams, move enormous masses of rock, reshape the land and disrupt soils and water systems. The coal is then crushed, sorted, stored and transported. It produces dust and comes into contact with water and air. Along with it, substances that were previously held within layers of rock are brought to the surface.

Then the coal is burned. But its story does not end there either.

Ash, slag, waste-rock dumps, contaminated water and disturbed land remain. Some consequences can persist for years and decades. In some cases, the question has to be put more starkly: after several decades of mining, are we leaving behind processes whose consequences will be felt for far longer than our own lifetimes?

That is why, whenever I hear that coal is a cheap source of energy, I find it increasingly difficult to take the phrase seriously.

Cheap—if we count what?

Only the cost of extraction, transport and combustion?

What about the cost of the land that must later be restored? The water that has to be treated? The closure of old mines? Burning waste-rock dumps? The pollution that remains after mining ends? And who pays for the consequences ten, fifty or a hundred years later?

If those costs are simply left out of the price of coal, coal can indeed appear cheap.

But that is no longer the full price.

The more I study this subject, the more it seems to me that the idea of cheap coal rests on precisely this incomplete accounting. A large part of the price lies outside the payment for a tonne of coal or a kilowatt-hour of electricity—it is paid by the land, the state, the people who live nearby and those who will live there after us.

This time, therefore, I decided to look neither at open-pit mines nor at the owners of coal companies.

I decided to look inside coal itself.

But the second research pass made me look around it as well: at the soil that was removed; the rock exposed to oxygen and rain for the first time; the water that passed through a waste-rock dump; the tailings, ash and the mine after closure.

What is all this material made of? What happens to it when it is exposed, crushed, wetted, transported, processed and burned? Where do the substances captured by pollution-control systems go? What remains after coal? And how long does its chemistry continue to operate after the coal itself has ceased to exist as a fuel?

It seems to me that without answering these questions, it is impossible to answer another one honestly:

what does coal really cost?

RESEARCH MAP

Question

What physically and chemically happens to coal, soil, rock, water and waste from the start of mining to decades after the site is closed—and where does the evidence chain actually reach a person or ecosystem?

Short answer

SYNTHESIS. The coal industry moves enormous amounts of geological material. When extracted, processed and burned, the substances they contain are transferred between air, water, soil, sediments, waste and living systems. Documented pathways of exposure have been found for each major stage. Their length varies: some end with a measurement at the source, others extend to tissue, environmental effect or disease.

Finding category	Conclusion
Established	Exposing and crushing material changes the availability of oxygen and water; rain creates runoff and leachate; mining and transport generate dust; open mines emit methane; explosives leave a nitrogen trail; enrichment transfers substances to tailings; combustion distributes the elements between gas, ash, gypsum and water; closure triggers a new hydrochemical regime.

Finding category	Conclusion
Not established uniformly for all sites	Composition and scale are determined by geology, technology, hydrology, temperature, management and time. A neutral pH does not guarantee the absence of an effect, but the presence of a substance in the waste also does not prove its release to the receptor.
Not confirmed as a universal rule	Not every metal near a mine comes from a mine; not every use of ash degrades water; not all reclaimed soil is restored at the same rate; not every detection turns into a dose or disease.
Remains unknown	Complete multi-year balance sheets for many dumps, tailings and residues; a modern water plume from the Centralia fire; the long-term fate of a number of beneficial use scenarios; population effects of many chains.

Check route

Main conclusion	Sections	Basic Source IDs
Soil and rock after opening become a new system	6–7	`CIC2-US-SOIL-001`, `CIC2-CN-SOIL-001`, `CIC2-CN-GW-001`, `CIC2-MN-MAT-001`
Rain turns the dump into a source of runoff and leachate	7, 10	`CIC-CA-N-001`, `CIC2-PL-DUMP-003`, `CIC2-US-REFUSE-001`, `CIC2-PL-RES-001`
Air chains vary in length	8–9, 13	`CIC-US-DUST-001`, `CIC-AU-CH4-001`, `CIC-AU-FIRE-001` – `005`, `CIC-CN-FIRE-HG-003`
Precipitation is part of the path, not the disappearance of the substance	10, 16	`CIC2-US-SED-001`, `CIC-US-ASH-002`
Smoke purification transports elements into residues	15	`CIC2-US-COMB-001`, `CIC2-US-COMB-002`
Centralia - multi-media case	14	`CIC2-US-CEN-001` – `006`, `CIC-US-FIRE-001`, `CIC-US-WAT-003`
Closing does not turn off chemical processes	18	`CIC2-UK-WAT-001` – `003`, `CIC2-PL-WAT-001`, `CIC-RU-WAT-001`

This map does not replace the terms, conditions and restrictions in the relevant sections and appendices.

HOW TO READ THIS PDF

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the article tells the story; the PDF provides the evidence, clarifies it and shows the boundaries of what has been established.

Marker	Meaning
DOCUMENTED (FACT)	The result is directly recorded by a measurement, source or official document.
SYNTHESIS	A conclusion drawn from multiple lines of evidence; not a separate measurement.
HYPOTHESIS	A testable explanation for which there is no direct, complete chain.
MODEL	Calculation, inventory or valuation under given assumptions.
UNKNOWN	The closed corpus does not support a reliable answer.

Chain `C1–C5` reads like this: `C1 source → C2 release → C3 environment/transport → C4 exposure → C5 effect`. Availability `C1–C3` does not by itself justify `C4–C5`.

All 99 claim–context blocks are provided in Appendices A and B. The registry of 127 sources is in Appendix C. The log of 47 search packages is in Appendix D.

1. Introduction: Research Question

The study began with a question about the price of coal. Not about the price per ton or kilowatt-hour, but about the material cost of the entire journey: soil removed, rock moved, water, cleanup, fires, waste and closed mines.

The first pass built chains `source → substance → transport → concentration or exposure → effect`. It produced strong evidence chains for dust, methane, nitrate, mine water, fires, combustion and ash. However, air and individual pollutants have been studied in more detail than the fate of the entire mass of rock, water and waste.

Therefore, a second pass was needed. Its unit was not a pre-selected “alarming” element, but a material flow:

`what was in the ground → what was exposed → what was crushed and moved → what changed through contact with oxygen, water, microorganisms and heat → which stream or residue received the substance → what reached the receptor`.

The second pass does not replace the first. It corrects that imbalance and connects air, soil, water, sediment, tailings, combustion products and post-closure processes in one verifiable map.

2. Brief verdict

SYNTHESIS. Throughout the studied life cycle, substances change their form, environmental medium or pathway. In the studied corpus, no stage was found for which chemical neutrality could be assumed by default.

This does not mean that each site causes the same measurable harm. Results depend on material composition, oxygen and water availability, temperature, technology, treatment, hydrogeology and management. Some flows weaken over time. Some properties of reclaimed soils are closer to reference conditions. Some controlled ash applications did not produce measurable water degradation through the pathways studied.

But a decrease in one flow often means a transition of matter to another. What is captured from the smoke ends up in ash, FGD gypsum or water. What disappears from the water column may be in the sediment. The mineral part removed from saleable coal goes into tailings. A closed mine becomes a flooded hydrochemical system.

3. Search and verification methodology

3.1. Two passes

The first pass included 90 sources, 66 claim–context blocks, and 32 search packages. It covered mining, dust, methane, explosives, water, enrichment, transport, fires, combustion, ash, biota and closure.

The second pass added 37 sources, 33 claim–context blocks and 15 search packages. It examined soil, overburden, waste-rock dumps, rain-driven runoff, burning dumps, Centralia as a system, post-closure mine water, slurry, tailings, power-plant material balances and residue reuse.

No duplicate URLs were found between the two registries. The combined corpus contains 127 records.

3.2. Hierarchy of sources

Priority was given to:

1. primary field research;
2. repeated long-term observations and time series with a clear boundary;
3. full-scale material balances;
4. official technical documents and monitoring;
5. exposure and effect studies;
6. reviews—for navigation, but not instead of the primary support of numbers.

Corporate and operator reports were saved when they provided unique measurements. Their origin remained close to the result.

3.3. Inclusion rules

A source was included if it changed the answer along at least one level: substance origin, release, transport, concentration, exposure, effect, time, distance, negative result, or attribution boundary.

Numbers were stored along with unit, place, term, comparison and conditions. A concentration at a gas vent was not treated as ambient air; a concentration in waste was not called a dose; laboratory leaching was not presented as a field plume.

3.4. Stop rules

The search stopped when a primary support, a significant limit and counter-evidence were found for a given link, or when repeated series reproduced the same established limit. This is a targeted body of evidence rather than a preregistered systematic review of the entire world literature.

3.5. Negative results

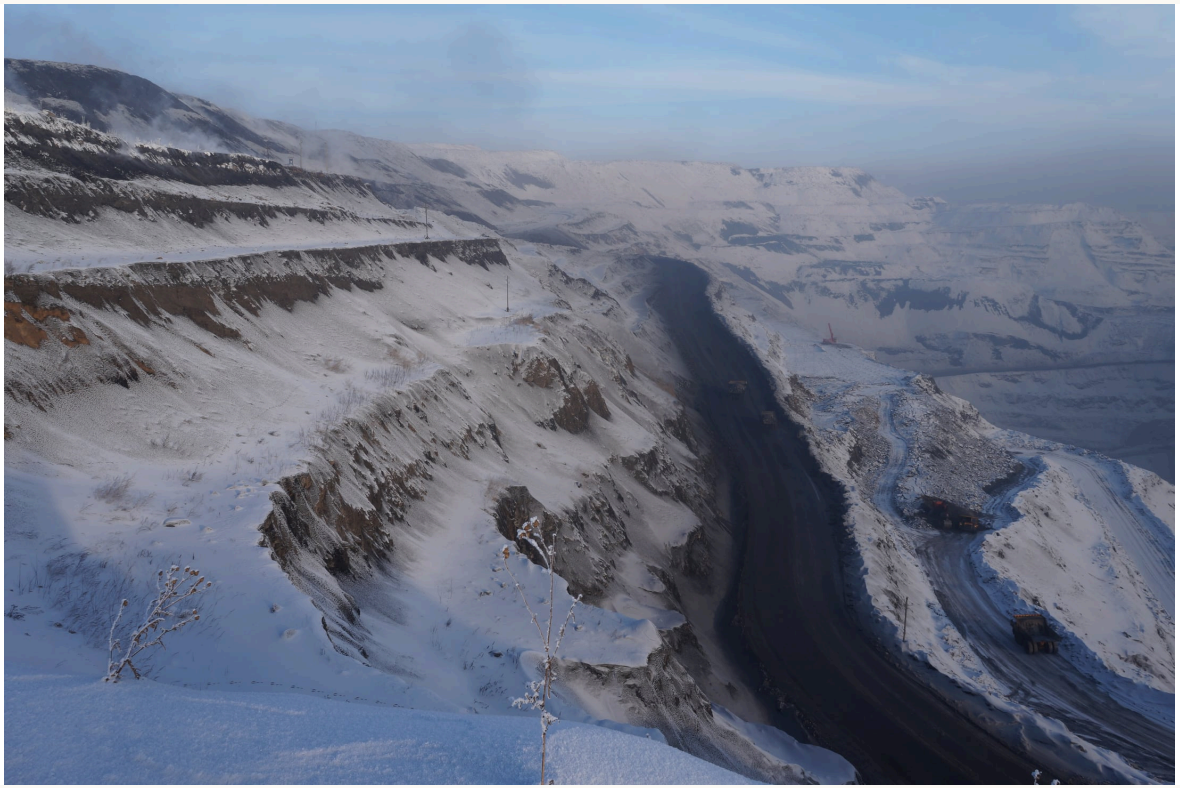
Null or limiting results were not removed. A null or limiting result was included if it changed the permissible strength of the conclusion. The corpus therefore retains low average air concentrations at the three Centralia sites, no growth of Hg in selected post-Dan River biota, weak association of soil metals with the proximity of Mongolian mines, and no water deterioration in several road ash applications.

4. Corpus and geography

The corpus includes the USA, Canada, Australia, China, India, Mongolia, Indonesia, Germany, Great Britain, Poland, Portugal, South Africa, Russia, Turkey, Bulgaria and other territories necessary for individual chains.

The time scale ranges from seconds of explosions and short fire peaks to observations of several decades and more than a century. The spatial scale ranges from gas vents and pore water to catchment and transport hundreds of kilometers down the river network.

The corpus does not provide the same data density for all countries and stages. The best documented are occupational dust, isolated fires, mine waters, elements with well-developed analytics, and major accidents. Weaker are the multi-media datasets for individual dumps, standard tailings ponds and the final fate of some reused residues.



Coal mine in Kuzbass, 2 January 2019. Photograph: Natalia Zubkova. The image shows the apparent scale and geometry of the open-pit mine; it does not establish the chemical composition of the rock, the identity of the site, or the concentration of pollutants.

5. Full life cycle map

Stage	What physically moves	Major transformation	Air	Soil/rock	Water/sediment	Residual stream	Typical limit of proof
Extraction	Soil, overburden, coal	Crushing, drying, oxidation	Dust, CH_4	Lost profile, new geochemistry	Drainage, suspension, ions	Overburden	Resident exposure is measured less frequently than the source

Stage	What physically moves	Major transformation	Air	Soil/rock	Water/sediment	Residual stream	Typical limit of proof
Explosion	Explosive charge and rock	Incomplete reaction of nitrogen compounds	Brief release	Residues in blasted rock	Long-term NO_3 leaching	Blasted rock	Source and transport are stronger evidence than a separate field effect of NO_3
Waste-rock dump	Rock, residual coal	Oxidation, infiltration, sometimes heating	Dust, gases	New minerals and mobile fractions	Runoff, leachate, groundwater discharge	Burnt/unburnt material	It is rare to have complete rows across all environments at once.
Enrichment	Coal, water, reagents	Separation of mineral and organic parts	Dust	—	Process water	Sludge and tailings	The composition of the waste is better known than the plume to the receptor
Transport and storage	Coal fines and stockpiles	Dust, runoff, spillage	Settled and resuspended dust	Precipitation	Acid drainage, coal in sediment	Spilled coal	Source attribution is often confounded by roads and urban sources
Uncontrolled burning	Coal and rock	Pyrolysis, oxidation, melting, condensation	PM, CO, VOC, Hg and other measured substances	Heating, dips, new phases	Infiltration through a hot system	Burnt rock	High concentration at the gas outlet is not equal to the population dose
Combustion	Coal and air	Evaporation, condensation, trapping	Gas and particles	Deposition	Wastewater	Fly ash, bottom ash, slag, FGD	"Removed from gas" does not mean destroyed
Placement/Use	Ash, slag, gypsum	Leaching, aging, carbonation	Dust	Ground contact	Leachate, plume or no measured output	Storage/structure	We need a scenario-based, not a universal assessment
Closure	Water, residual rock and gases	Flooding, buffering, recovery processes	CH_4, CO_2, H_2S locally	Subsidence, new water paths	First flush and long-term discharge	Sediment cleaning	Declining over time is not the same as disappearing

Benches of a coal mine in Kuzbass, 22 January 2019. Photograph: Natalia Zubkova. The photograph shows the extent of the physical movement of rock; it is not a measurement of dust, water, overburden composition or environmental effect.

6. Soil and overburden

What is established

Open-pit mining removes or destroys the original profile. The replaced topsoil lies on a different landform, often compacted, mixed and hydrologically altered. Individual functions may move closer to the reference, but not at the same pace.

Soil after mining

What is confirmed

- Mining destroys or removes the original profile, and reclamation creates a new substrate with a different sequence of horizons, density, structure, water regime and biota.
- Some indicators are indeed capable of recovery. In Wyoming, many microbial markers approached undisturbed soils after 5–14 years, but the trajectory depended on vegetation (`CIC2-US-SOIL-001`).
- In the Spanish chronosequence, after 20 years, microbial abundance and enzyme activity approached the control, but the structure of the microbial community remained different (`CIC2-ES-SOIL-001`).
- At Pingshuo, individual organic carbon and nitrogen trajectories took about 20 years to become comparable to undisturbed land; other properties and different types of land use developed differently (`CIC2-CN-SOIL-001`).
- In Australia, a survey of 90 sites measured not only vegetation, but 57 structural and functional indicators. Sites aged 3–12 years did not follow a single recovery trajectory, and older sites were partially confounded with the effect of a specific mine (`CIC2-AU-SOIL-001`).
- On former coal-mine spoil in the Bowen Basin, even the addition of 10 or 20 cm of stockpiled topsoil did not eliminate all the limitations in a short time: salinity, sodicity, dispersion and erosion and functional discontinuities in microbial carbon metabolism remained (`CIC2-AU-SOIL-002`).

What these data do not allow us to say

- Returning one indicator to the reference range does not mean restoring the original soil.
- A chronosequence is not repeated observation of the same site through time.
- Vegetation cover is not sufficient evidence of restoration of structure, hydrology, microbiome and local community.
- There is no single time frame for “the soil has recovered”: carbon, nitrogen, structure, fungi, bacteria, infiltration and native vegetation all have different trajectories.

Overburden and underground material at surface

A field comparison of Yimin showed precisely a change in the geochemical regime: opening and drainage increased the access of oxygen, supported the oxidation of pyrite and was accompanied by a decrease in pH, an increase in sulfate, iron, calcium, magnesium and hardness. At the same time, TDS, COD and the sum of Na + K decreased (`CIC2-CN-GW-001`).

This is an important counterexample to the too simple formula “all indicators are getting worse.” The material system is rearranged, and different parameters can move in opposite directions.

Baganuur provides an even clearer material-specific result. Most of the waters studied met the suitability criteria used by the authors. But one interstratal rock had a pH of 3,29–4,26 and released in a sequential leaching test 4019,07 mg/kg sulfate and 803,12 mg/kg cobalt. 5,57–14,17 mg/kg arsenic was measured in dust (`CIC2-MN-MAT-001`). This is the laboratory potential of a particular material rather than a proven regional exposure, but it shows why the overburden cannot be considered chemically homogeneous.

What cannot be stated

The return of one indicator does not establish restoration of the historical soil. It is impossible to transfer the period of one chronosequence to another climate, substrate and method of reclamation. Every metal in an urban soil cannot be attributed to a nearby mine without spatial or geochemical attribution.

7. Waste-rock and burning dumps

What is established

A waste-rock dump is an artificial geochemical system. Crushing increases the contact area. Oxygen supports oxidation. Rain produces surface runoff and infiltration. Combustion changes the mineral phases and sometimes the proportion of matter available for subsequent transfer.

Landscape disturbed by mining operations in Kuzbass, 20 January 2019. Photograph: Natalia Zubkova. The image captures the shape of the relief and the state of the surface under the snow; it does not specify material composition, stability, reactivity or degree of recovery.

Waste-rock dump as a new geochemical system

Solid phase

Starzykowiec has existed since the early twentieth century and again showed thermal activity in 2006. Uneven degrees of heating and combustion were found within one dump. Oxidation of organics, degassing, coking, oxidation of pyrite and marcasite, dehydration of clays, recrystallization, melting and formation of high-temperature phases occurred (`CIC2-PL-DUMP-001`).

A critical finding is that a major restructuring of mineralogy is not necessarily accompanied by an equally obvious change in the bulk abundances of most major and trace elements. The element may remain in the material, but move to another mineral phase and acquire a different subsequent mobility.

Transfer to soil and plant surfaces

In the self-heating dumps of Silesia, in the soils and on the surface of plants there were characteristic signatures of coal-waste-derived compounds: biomarkers, alkyl aromatic compounds, PAHs and phenols (`CIC2-PL-DUMP-002`). This is evidence of local migration. It is not a measurement of dose absorbed by the plant, toxic effect or risk to the public.

Water

Biogenic compounds, geochemical markers, dissolved self-heating products and external anthropogenic compounds were found in reservoirs on the dumps and near them (`CIC2-PL-DUMP-003`). The sources are mixed, so each class cannot be automatically assigned to a coal waste.

In 16 reservoirs near the waste of Upper Silesia, electrical conductivity reached 21,5 mS/cm, chloride - 9279 mg/l, sulfate - 5277 mg/l, sodium - 4783 mg/l (`CIC2-PL-RES-001`). The study confirms a strong change in surface water. The risk to the shallow aquifer remains potential until a separate hydraulic and tracer chain is constructed.

Mercury and the effects of combustion on mobility

At abandoned Fojo, both burned and unburned material had mean pseudo-total Hg of 1,2 mg/kg versus 0,6 mg/kg in the local high background. The main difference was not in the total concentration: the mobile fraction was 16% in burned waste and 8% in unburned waste (`CIC2-PT-DUMP-001`).

This is a useful clarification: combustion does not necessarily increase the gross content of the element, but can change the form of its occurrence. At the same time, the region is naturally enriched in Hg, and downslope transport in the study is described as possible rather than definitively traced.

Decades after closure

Green Valley contains approximately 2,7 million cubic yards of coarse coal waste and fine tailings. The mine was operating in 1948–1963 and the site was reclaimed, but a study begun in 2008 still documented acidic drainage from groundwater discharge to nearby watercourses (`CIC2-US-REFUSE-001`).

Consequently, surface reclamation can change the flow and reduce part of the load, but does not necessarily stop reactions immediately within the old dump.

Material path of rain

`precipitation → dump surface or fractures → dissolution and particle entrainment → runoff / leachate / groundwater discharge → stream, water body, groundwater or sediment`.

In a burning dump, water comes into contact not only with the original rock, but also with the material after degassing, oxidation, melting and recrystallization. Therefore, the gas and water phases of the fire should be tested together, but not mixed into one universal composition.

What cannot be stated

It is impossible to describe all dumps by one concentration or period of activity. The possibility of leaching cannot be considered a proven plume. It is impossible to determine its mobility or bioavailability by the gross content of an element.

Industrial landscape in Kuzbass, 2 January 2019. Photograph: Natalia Zubkova. The frame shows emissions and winter haze; photography does not identify the sources of each plume, air chemistry, concentration, or human exposure.

8. Air, dust and occupational exposure

DOCUMENTED (FACT). For miners, accumulated exposure to respirable coal and mineral dust is associated with pneumoconiosis, chronic obstructive pulmonary disease, and decreased lung function (`CIC-US-DUST-001`, `CIC-CN-OCC-001`).

Near an open pit in Kuzbass, settled fractions PM0.1 and PM10, quartz, talc, clays and a spatial trace of PAHs were measured in the snow (`CIC-RU-DUST-002`). Snow load indicates transport and accumulation, but is not air concentration or resident dose.

In Jhariya, high PM2.5 and related elements existed in a mixture of mining, roads, resuspended dust, fires and meteorology (`CIC-IN-AIR-001`, `CIC-IN-AIR-002`). Modelled risk is not an observed disease.

What cannot be stated

The occupational dose cannot be transferred to the general public. Deposition cannot be equated with inhalation without exposure measurements or modelling. A low concentration at a distant station does not prove the absence of a high local concentration at the source.

9. Methane and nitrogen from explosives

Open-cut mine methane

At Hail Creek, two independent airborne measurement techniques produced estimates of `14,0 ± 3,3 t/h` in 2022 and `9,6 ± 1,9` or `11,3 ± 5,3 t/h` in 2023 (`CIC-AU-CH4-001`). Satellite analysis of six Australian mines showed a disproportionate contribution from a small group of sites (`CIC-AU-CH4-002`).

This is evidence of a mine-specific methane emission flux on sampled days. It is not a toxic dose, and it cannot be converted into a continuous annual release without temporal extrapolation.

Nitrate after explosion

Elk Valley, Canada: strong source and transport chain

Mahmood et al. examined waste-rock dumps constructed in 1982–2012: rock before and after blasting, dump profiles up to 180 m thick, waste dump drainage water and laboratory leaching tests. Concentrations and stable isotopes of nitrate confirmed the origin of nitrate from explosives. Within the studied dump, denitrification was limited or undetectable. The estimated field leaching efficiency was 80–90%; for most of the cases examined, leaching could continue for decades.

This closes the chain:

`explosive → nitrate residue in blasted rock → infiltration through a coal waste-rock dump → drainage water`.

But the study does not close:

`drainage water → individual dose to a person or organism → established effect`.

Therefore, the source and long-term transport have been proven, and harm to a specific receptor has not been established by this study.

Source: CIC-CA-N-001 — https://doi.org/10.1016/j.scitotenv.2017.05.253

Central Appalachia, USA: strong load chain but mixed origin

Brooks et al. compared data from six large catchments and repeated measurements from four small catchments affected by mountaintop removal mining. The annual nitrate flux in mining-affected catchments was `3.68–26.4 kg N ha−1 yr−1` — one to two orders of magnitude higher than the neighboring forest control catchment. In the 2016 water year, nitrate exports were 7–50

times higher than the control level. Concentrations decreased after mining ceased, but did not return to control levels in any of the affected catchments studied; elevated exports persisted for decades.

However, the isotopic signature of nitrate in the streams did not clearly match the proposed characteristics of the suspected sources—explosives and fertilisers. The authors consider explosive residues a plausible major source during the active phase, but fertilizers, nitrogen from rock, valley fills, and altered hydrology and nitrogen cycling are also considered for the long-term export.

Correct formula:

> Active and completed mountaintop-removal mining is associated with large and long-term export of nitrate; explosives are likely important during mining, but available data do not allow the entire decades-long flow to be attributed to them.

Incorrect formula:

> Explosives have been poisoning all waters with nitrate for decades.

Source: CIC-US-N-001 — https://doi.org/10.1029/2019JG005174

What cannot be stated

You cannot assign all the nitrate to one source without isotopic and technological support. The laboratory measure of effect is not an established population effect of the river. The percentage increase in concentration is not the percentage increase in disease.

10. Surface water, groundwater and sediment

Water carries a mixture rather than one convenient ion. pH, sulfate, salinity, Fe, Al, Mn, suspended matter and altered flow can change together. Neutral water can also damage habitats through iron deposition.

Water after mine closure

Closure stops production, but changes the hydrogeological regime: the pumps are turned off, the water level rises, oxidized surfaces and weathering products are flooded, then water can escape through old workings, cracks or springs.

Temporal pattern of the process

Across 32 old discharges in Scotland, including six systems with particularly long time series, the worst pollution was often in the first decades after water began to be released. Iron generally declined to a lower asymptotic level over approximately 40 years, but did not disappear. Very low pH was often not maintained due to carbonate buffering (`CIC2-UK-WAT-001`).

This is both confirmatory and limiting evidence:

- the consequences can last for decades or more than a century;
- the maximum concentration does not necessarily remain constant;
- neutral pH does not mean the absence of Fe, sulfate or sediment;
- behavior depends on fluctuations in water level, geology and mine design.

Catchment scale

At Almond River, the 15-year series spanning 1994–2008 and a map of more than 300 abandoned mine and waste sites showed a long-term supply of Fe and sulfate. The sum of numerous small point and diffuse sources turned out to be significant (`CIC2-UK-WAT-002`).

In the Przemsza basin, the volume of mine water in 2023 was approximately 42% lower than in 1991. The daily load of chloride and sulfate decreased from 534,8 to 480,1 Mg, but during low flows the river conductivity increased from approximately 2000 to 6700 µS/cm (`CIC2-PL-WAT-001`). A decline in load and an increase in concentration can coexist when dilution decreases.

New discharge pathways: dissolved gases

The 16 Scottish discharges measured not only metals, but CO2 and methane. Isotope data pointed to modern biogenic, thermogenic, and coal-associated hydrogenotrophic sources of methane. Treatment removed Fe and As effectively, but only partially removed Ni, Co and Mn (`CIC2-UK-WAT-003`).

This adds another post-closure flow: a flooded mine can be not only a source of dissolved substances, but also a carrier of dissolved gases. The measured concentration in water is not yet equal to the regional atmospheric flux.

Sediments are not the end of the pathway

At Huff Run, iron, aluminum, manganese, and copper released by mine drainage were heterogeneously distributed in the channel sediment. Above and below the dam and stepped reaches, Fe mineral phases, extractable elements and pore-water chemistry differed; below some structures, the pore water contained more Fe and Mn (`CIC2-US-SED-001`).

This is direct field confirmation of three points:

1. the disappearance of dissolved metal from the water column may indicate its precipitation;
2. the sediment remains chemically active and associated with pore water;

3. its behavior depends on the hydraulic gradient and channel shape.

The work did not measure the full secondary load during extreme flood events. The findings therefore support a conclusion about the local dynamic storage role of sediment, but not a numerical assessment of the repeated release of all accumulated metal.

The environmental effect is not limited to acidity

In the old Pennsylvania stream study, the pH downstream of the discharge remained 6,5–8. However, iron hydroxide precipitation reached 3 g/m² per day near the outlet; invertebrate biomass decreased from approximately 14 to 0,1–1,5 g wet weight/m², and fish standing stock decreased from approximately 228 to 11 kg/ha (`CIC2-US-ECO-002`).

Therefore, the formula “water is not acidic means it is safe” is incorrect. Sediment has the ability to physically change the habitat and food supply.

Comparisons of polluted, treated, and reference streams in the anthracite and bituminous regions revealed changes in production, respiration, nitrogen and phosphorus uptake, leaf decomposition, and invertebrate communities (`CIC2-US-ECO-001`). The two regions' reactions varied. Even the category “mine drainage” does not have one environmental profile.

What cannot be stated

pH cannot be considered the only indicator. Mineral precipitation cannot be treated as removal of a substance from the system. Contamination cannot be attributed to a nearby site without background locations, flow direction and, where possible, tracers.

11. Beneficiation and tailings

Beneficiation and tailings: where did the mineral part go?

At Kailuan, during washing, 15 elements studied were redistributed among the cleaned coal, middlings, slurry and tailings. All of them could enter the slurry; most were enriched in the tailings, and for As the maximum tailing enrichment factor reported was 34,4% (`CIC2-CN-BEN-001`).

177 components were analyzed in sludge from six West Virginia sites. At one or more sites, Al, Sb, As, Fe, Pb, Mn, and several inorganic ions exceeded selected benchmarks; detected volatile and semi-volatile organic compounds were below the corresponding benchmarks (`CIC2-US-BEN-001`).

These data close the link:

`raw coal → beneficiation → concentrate + tailings/slurry`.

They do not establish the following link:

`slurry → confirmed groundwater plume → receptor exposure`.

This is where a significant gap remains. The hazardous composition of the stored material cannot be automatically converted into evidence that contaminants have crossed the facility boundary. But the reduction of impurities in saleable coal cannot be called their destruction: they were transferred to another stream.

Routine operation, chronic release and accident

For the water section, three different evidentiary regimes must be maintained:

- **routine material transfer:** redistribution of elements into tailings and water;
- **chronic release:** infiltration, leachate, mine-water discharge and slow diffuse flows;
- **accident:** dam break, reagent spill, sudden release of accumulated material.

One regime does not prove the other. The composition of the sludge does not prove a leak. The MCHM accident does not prove a constant routine release from every plant. A closed water cycle, in turn, does not prove the absence of seepage, overflow and post-closure flow.

MCHM as the boundary between routine operation and an accident

Laboratory experiments showed strong sorption of MCHM on coal and tailings and low desorption; release beyond the facility boundary during routine operation was considered unlikely (`CIC-US-BEN-003`). The 2014 Elk River accident demonstrated another pathway: a tank leak and the mixture entering the municipal water supply (`CIC-US-BEN-001`, `CIC-US-BEN-002`).

The composition of the reagent, the process loop and the emergency tank are different evidentiary situations.

12. Storage, transport and handling

At the Georges Creek coal yards, the effluent had a pH `1,4–3,1` and high Mn, Al, Zn, Fe and sulfate (`CIC-US-STOR-001`). In the Queensland rail corridor, coal particles were present in settled dust but did not dominate all measured particulate matter (`CIC-AU-TRAN-001`).

In the South Gobi, herders reported dust on pastures and animals, but the chemical composition and mass of particles were not measured (`CIC-MN-ROAD-001`). In children from three soums, the highest Pb in the blood was not found in the coal-mining soum; without paired environmental samples, the result cannot be attributed to Tavan Tolgoi (`CIC-MN-BIO-001`).

In the Muara Berau transfer area, coal material was found at all ten sediment stations to a depth of 25 cm; metals accumulated in plankton and fish, but adverse effects and human consumption were not established (`CIC-ID-TRN-001`).

13. Uncontrolled fires: four different chains

Case	Strongest link	Key Dimension	Effect	What cannot be stated
Hazelwood, Australia	Source → model personal exposure → multiple outcomes	PM2.5 to `731 µg/m³`; CO up to `33 ppm` at the nearest point	Associations with respiratory hospitalizations and selected outcomes; series of zero results	The maximum point is not the dose of each resident; observational design
Jharia, India	Mixed regional load	PM2.5 about `170 ± 45 µg/m³` in an annual study	Model risk; non-personal causal chain	It is impossible to completely separate the fire from mining, roads and resuspended dust
Wuda, China	Source and area near it	Hg at 46 gas vents: average `5908`, range `1022–31 750 ng/m³`	Not measured in the population	The concentration at the gas outlet is not equal to the residential air concentration or dose
Centralia, USA	Heat, ground, soil, microbiome, surface hazard	See section 14	Soil modification; failures; official danger	Late low average air does not describe the entire system; the water plume from the fire has not been established

Fires cannot be combined into one universal composition. Even a single element such as Hg does not describe the entire mixture and does not determine exposure without distance, wind and time.

14. Centralia: a multi-media case

Centralia as a system, not just air

Confirmed links

1. **Combustion and heat.** The official Pennsylvania DEP as of 2026 continues to consider the fire active since May 1962 (`CIC2-US-CEN-006`).
2. **Soil chemistry.** Temperature correlated with ammonium and nitrate; Areas recovering after cooling had a mean pH of 4,4 versus 5,9 at reference sites (`CIC2-US-CEN-001`, `CIC2-US-CEN-004`). Great heterogeneity makes it impossible to describe all of Centralia with a single concentration.

3. **Microbiome.** The hottest soils had lower diversity and the most divergent communities. After cooling, a convergence with reference communities was observed. Seven-year follow-up confirmed signs of persistence and return, but also revealed the role of inactive taxa in the apparent recovery (`CIC2-US-CEN-001` — `003`).
4. **Water–heat–soil.** In 2011, about 185 cm of precipitation was accompanied by the formation of nine new sinkholes. Water penetrated the hot rock, increased steam release, weakened the regolith and rock; the sinkholes coincided with thermal anomalies and the position of coal seams (`CIC2-US-CEN-005`).
5. **Surface and safety.** Dangerous gases and risk of sudden collapse have been officially confirmed (`CIC2-US-CEN-006`).
6. **Air.** The result of monitoring 2006–2007 from the first pass is retained: an Hg signal was detected when winds came from the combustion zone, but the average concentrations at the selected sites were relatively low (`CIC-US-FIRE-001`).

What was not found

- No strong work has been found that separates the modern groundwater chemistry specifically caused by the Centralia Fire from the mining legacy, regional geology, and normal mine drainage.
- No reliable primary basis has been found for the popular precise statement “the fire will burn for another 200 years.”
- No evidence was found to characterise the entire city as a zone of constantly the same high toxic exposure.

Revised interpretation of Centralia

Centralia is not a case of “the air turned out to be almost clean.” This is a multi-environment system in which simultaneously there are:

`underground combustion → rock heating → changes in soil and microbiome → fractures/subsidence → gas and steam release → vegetation change → danger to people`.

But a separate link `fire → groundwater contamination` remains insufficiently established.

Case summary

Centralia cannot be reduced to either the phrase “the city is constantly breathing a high toxic dose” or the phrase “late air monitoring was low, which means the fire is harmless.” What is established is ongoing combustion, heat, changes in soil and microbiome, a connection between heavy rainfall, steam and sinkholes, gas releases, and the officially recognised danger at the surface. Separate modern chain `fire → groundwater → receptor` remains unclosed.

15. Combustion and material balance

The furnace does not destroy elements

At a full-scale 795 MW unit, coal, gas at different stages, bottom and economizer ash, fly ash, wet desulfurization products and waste water were simultaneously sampled (`CIC2-US-COMB-001`). The results differed fundamentally by element:

- the reported element-specific removal efficiencies across the electrostatic precipitator were about 88% for As, 56% for Se, 17% for Hg and 8% for B;
- wet flue-gas desulfurization then removed more than 90% of the chloride, 77% of the B, 76% of the Hg, 30% of the Se and 5% of the As from the gas stream entering it;
- about 90% Hg and 99% Se removed by desulfurization were associated with gypsum;
- more than 99% of the B and chloride leaving the coal-combustion process through this loop were in the wastewater.

These are not universal industry ratios. This is one unit, one coal, one configuration and one sampling campaign. But the logic of material balance is strong: lower concentrations in the stack can mean that the material has been transferred to a solid or liquid residue.

In two other US installations, the balance without FGD estimated the fraction captured by fly ash as 48% As, 58% Cr, 54% Pb, 20% Se and 2% Hg (`CIC2-US-COMB-002`). You cannot assign Hg, As and Se to the same fate.

Terms that should not be mixed

- **fly ash** — fine fraction carried away by gas and captured;
- **bottom ash** - larger residue at the bottom of the boiler;
- **boiler slag** — molten or vitrified bottom material of certain fireboxes;
- **FGD residues / gypsum** — products of sulfur dioxide removal;
- **wastewater** — separate liquid path for soluble components;
- **coal combustion residuals (CCR)** - an umbrella category, not just one material.

Conflating these terms breaks the chain of evidence because particle size, glass phase, carbon, pH, mineral form and leachability are different.

What cannot be stated

The percentage of removal from the gas cannot be called destruction. The Hg allocation cannot be transferred to As or Se. The concentration in the stack before dispersion is not the population dose. One generating unit does not establish coefficients for the entire industry.

16. Ash, slag, FGD and reuse

Ash in storage and ash in the river

The first pass already contains a strong evidence set:

- isotopically and hydrochemically confirmed leaks of part of ash dumps into ground and surface water (`CIC-US-ASH-003`);
- alternative attribution at two Indian sites, where well mineralization was attributed primarily to domestic wastewater and brick-kiln effluent, and the direct impact of the ash dump was low (`CIC-IN-ASH-002`);
- residual ash and As/Se in river sediment eight years after Kingston with limited immediate release of metals into water (`CIC-US-ASH-002`);
- increase in Se in fish relative to the reference after Kingston without increasing over time and without reaching the risk thresholds used (`CIC-US-ASH-004`);
- no increase in Hg was found in aquatic invertebrates and fish in the first three years after the Dan River (`CIC-US-ASH-005`).

These results do not contradict each other. They share different stages:

`element in ash → mobile form → water/sediment → organism → effect`.

River sediment after the accident

After Kingston, some of the residual ash was retained in the channel sediment and was buried further downstream by approximately 13 cm of new natural sediment. Increased As persisted in shallow horizons closer to the center of the spill. A significant portion of the metals was adsorbed or associated with the acid-soluble fraction (`CIC-US-ASH-002`).

Correct interpretation:

- the material has not disappeared;
- presence in sediment does not equal a constant high concentration in water;
- changes in pH, Eh, erosion or mechanical disturbance can change fate, but specific remobilisation rates require separate measurements.

Reuse instead of landfill

Ten-year road foundation inspection

In the Netherlands, laboratory predictions were compared with material, percolation water and soil profile after approximately ten years on four road structures (`CIC2-NL-USE-001`). This is more important than one short lab test because it shows actual design and timing.

Negative field result

In the United States, data from seven road sites, 18 points, and several years of observations—in some places over a decade—revealed no deterioration of ground or surface water for the trace elements tested for specific stabilization, foundation, and fill methods (`CIC2-US-USE-001`).

This result must be retained. It does not prove the safety of any ash or any use, but it refutes the automatic formula "ash use always means measurable water pollution."

What remains unresolved

- Long-term behavior of ash in concrete after structural failure.
- Long-term behaviour of undiluted or loosely bound ash used in large structural fills.
- Mine backfilling and contact with rising mine water.
- Application as a soil additive and transfer to biota.
- Comparable field material balance for Hg, As, Se, B, Mo and Sb from coal to final storage.
- The role of aging, carbonation and alternating redox conditions in specific storage facilities.

Terms

Term	Material	Why the distinction is important
Fly ash	Fine fly ash recovered from gas	Large surface, enrichment of some elements
Bottom ash	Large bottom residue	Other mineralogy and leaching
Boiler slag	Melted/vitrified bottom material	The glassy matrix changes mobility
FGD residues / gypsum	Desulfurization products	Can concentrate Hg and Se; soluble substances go into water
CCR	Umbrella category of combustion residues	Should not replace a specific material

17. Ecosystem and food webs

The presence of a substance, bioaccumulation, biomarker, individual effect and population change are different steps.

In the Elk Valley, selenium was traced more than 575 km down the river network (`CIC-CA-SE-001`). In trout eggs, high concentrations were accompanied by the absence of viable offspring (`CIC-CA-SE-003`). In the American dipper, selenium was elevated in water, food, blood, eggs, and

feathers, but no significant reduction in clutch size or hatching success was found (`CIC-CA-SE-004`).

After Kingston, Se in fish was higher than the reference, but did not grow for five years and did not exceed the applied thresholds (`CIC-US-ASH-004`). After the Dan River, the growth of Hg was not found in the studied biota (`CIC-US-ASH-005`). These results do not negate the presence of ash; they limit the statement to a specific element and effect.

18. After closure

Closure stops production but changes the hydrogeology. Stopping pumping raises water levels, floods oxidised surfaces, changes Eh and creates new discharge pathways.

Long time series from Scotland and the Almond River and Przemsza catchments, as well as dissolved gases in mine waters, are given in section 10. Additional post-closure chains are retained here that do not duplicate that review.

Coupled soil–water–surface–vegetation pathway

Middelburg Colliery in South Africa provides an almost complete material chain. After the closure in 1947, the fire weakened the pillars, subsidence and cracks appeared, through which more than 50% of precipitation across much of the site infiltrated into the workings. Highly mineralised acidic water emerged in springs, entered the stream and caused vegetation loss across approximately 3 hectares (`CIC2-ZA-WAT-001`).

This is a strong impact case, but not a universal model for all mines. Fire, subsidence, a new infiltration path and acid drainage act together in it.

In Kuzbass, the water of the flooded horizons of the Severnaya mine maintained reducing conditions, temperature `10–13 °C`, Eh from `–112` to `–174 mV` and H_2S up to `6 mg/L` (`CIC-RU-WAT-001`). At other sites, the background upstream was already contaminated, so the downstream excess cannot be automatically attributed to a closed mine (`CIC-RU-WAT-002`).

SYNTHESIS. The formula “harm lasts forever” has not been established. The evidence shows that some processes weaken, some change form, and some loads continue for decades or longer.

19. Time and space

Process	Documented timescale	Spatial boundary
Explosion	Seconds; leaching of residual N - years/decades	From the blasted mass to the catchment
Methane plume	Campaign hours; an annual estimate requires extrapolation	Mine site and downwind plume
Dump fire	Decades at individual sites	Gas vent, dump, adjacent soil and water
Mine drainage	Decades and, in some time series, more than a century	outlet, stream, catchment
Selenium	Long-term trends	More than 575 km down the network in one basin
Ash dump	Years/decades, depends on hydrogeology	From the facility to a confirmed plume

A high concentration at the gas outlet, in leachate or a stack is not equal to the concentration in the city. But a low concentration at a distant station does not prove the absence of local impact at the source.

20. Where the evidence reaches an effect

Chain	Stage reached	Strength	Evidence gap
Occupational dust	C5: lung disease and function	Strong accumulated literature	Does not automatically transfer to residents
Hazelwood	C4–C5: model exposure and multiple outcomes	Longitudinal and cohort analyses	Residual mixing; unequal outcomes
Wuda Hg	C2–C3: source and area near it	Many direct measurements	No population dose and effect
Nitrate in Elk Valley	C1–C3 and laboratory effect indicator	Strong source/transfer	The contribution of nitrate alone to the field effect
Selenium in Elk Valley	C3–C5	Transfer, tissue, part of reproductive effects	Variation among species, responses and effect measures
Beneficiation tailings	C1–C2	Distribution within a process	No routine long-term chain to a receptor
Ash dumps	C3, sometimes C4 or an ecological effect	Some sites have source tracers	Human consumption and internal dose are rare
Reclaimed soil	Features and communities	Lots of comparisons and timelines	There is no one time limit or indicator for full recovery

21. Negative and limiting evidence

Result	What does it change?	What it does not prove
In Centralia, the average concentrations of a number of airborne substances at the three monitored sites in 2006–2007 were relatively low	Prevents describing the entire city as a constant, uniform high airborne exposure	Does not describe gas vents, soil, early years, sinkholes and the entire fire
In Mongolian coal towns, Cd, Cu, Pb, and Zn were little dependent on mine proximity	Prevents attribution of each metal to a mine	Does not exclude other substances, water, dust and local points
At seven road sites with ash, no measurable water degradation was found along the pathways studied.	Refutes the universal formula “any use of ash pollutes water”	Does not guarantee the safety of every ash and application
After the Dan River spill, no increase in Hg was found in the selected biota	Limits the statement about Hg and the food web	Does not exclude ash, other substances or other effects
Most of the waters studied at Baganuur met the applied criteria	Shows the heterogeneity of the site	Does not exclude acid-forming interburden
Some soil properties were close to the reference	Confirms the actual restoration of individual functions	Does not prove the identity of the profile and ecosystem
Treatment removed large proportions of elements from the gas	Confirms the effectiveness of air control	Does not mean the element disappears from the system

22. Boundaries of the study

The study does not prove that every tonne of coal or every site causes the same harm. It does not calculate a universal monetary estimate of coal’s full cost.

This is not a meta-analysis and it does not provide a single effect size. The geography of the corpus is uneven. Some long trajectories are chronosequences rather than repeated observations of a single site. For a number of sources, access is limited to an abstract or official report. Operator data are retained with their origin stated.

Not established:

- uniform long-term chemistry of all rock dumps;
- a modern contaminating groundwater plume caused specifically by the Centralia fire;
- complete multi-media datasets for a single dump simultaneously for gas, solid phase, soil, water and biota;
- a sufficient number of causally traced routine-operation tailings impoundments;
- the ultimate fate of all CCRs in concrete, embankments and mine fill;

- population effects for many pathways currently established only as far as water, sediment or tissue.

The formula “not found within the closed corpus” does not mean “does not exist.”

23. ElepiCup: Elephant in a Cup Method

ElepiCup—the Elephant in a Cup Method is an experimental method for structuring large evidentiary texts, developed by independent journalist Natalia Zubkova.

A large document is an elephant. The fragment that the AI receives when searching, shortening or translating is a cup. The whole elephant does not fit in the cup. But a piece of an elephant should not pretend to be the whole elephant; from that piece, a person and an AI should still understand that in front of them is an elephant, and not a crocodile.

Example 1. Big number at the source

Answer	Context that must remain nearby
`5908 ng/m³ Hg`	Average of 2,760 measurements at 46 gas vents of the burning Wuda dump; range `1022–31 750 ng/m³`; it is a gas vent, not ambient air, not a dose, and not a disease; `CIC-CN-FIRE-HG-003`.

Example 2. Large percentage increase

Answer	Context that must remain nearby
`+784% nitrate`	Flow-normalised concentration in the Elk River over 1979–2022; load `+697%`; in Kootenay `–8,5%`; other substances changed together; this is not a percentage increase in disease; `CIC-CA-N-003`.

Example 3. High removal efficiency

Answer	Context that must remain nearby
`88% As`	The share captured by the electrostatic precipitator at one 795 MW generating unit; the element entered a residual stream rather than disappearing; other elements were distributed differently; `CIC2-US-COMB-001`.

Example 4. Rain over the dump

Answer	Context that must remain nearby
"Rain carries substances away from the dump"	Attributing contamination in a specific well requires material composition, infiltration, flow direction, background and tracing. On a burning dump, heat can change the mineral form and mobile fraction; `CIC2-PL-DUMP-003`, `CIC2-PT-DUMP-001`.

Author of the method: Natalia Zubkova. Sergey Nikolaevich Severin and Viktor Andreevich Svetlov participated in developing and applying the evidence architecture of this investigation, but are not authors of the Elephant in a Cup Method.

The effectiveness of the method has not yet been demonstrated. No claim is made to absolute novelty, worldwide priority or the status of an established discipline.

Final formula

AI must find not only the answer, but also the boundaries of that answer.

Appendix A. Claim-context ledger of the first pass

All 66 independent evidentiary blocks of the first pass are stored below. Each row is not a summary of the entire source: it associates a specific statement with conditions, units, a boundary, and a negative result.

Claim ID	Source ID	Claim	Status / chain	Source and path	Conditions / units / term	Critical limitation	Negative or limiting result
CLM-001	CIC-IN-WAT-001	In 92 mine water samples from Jharia, neutral or slightly alkaline pH coexisted with elevated TDS, sulfate, hardness and concentrations of individual metals.	FACT; C1-C3	mine water and pyrite oxidation → mine water → water quality; suitability for use	drinking water standards and differences between sites; pH 6.2–8.6; TDS 437–1593 mg/L; single spatial dataset of 92 samples	no measurement of actual water consumption or disease	most samples are assessed as suitable or acceptable for irrigation; the pattern differs among sites
CLM-002	CIC-US-WAT-002	In 37 West Virginia streams, macroinvertebrate community condition declined along ionic strength gradients at mining sites and valley fills.	FACT; C3-C5	mountaintop mining and valley fills → surface waters → benthic macroinvertebrate communities	10 non-mining and 27 mining streams; conductivity categories; sampling March–May; conductivity categories <500 500–1000 >1000 µS/cm	observational design does not isolate the causal fraction of each ion	results were consistent at the family and genus levels; environment and precipitation were also taken into account
CLM-003	CIC-AU-CH4-001	Airborne measurements detected a persistent methane plume from the Hail Creek open-cut mine during separate campaigns and yielded consistent estimates by two independent techniques.	FACT; C2-C3	Hail Creek open-cut mine → atmospheric plume downwind → methane release from the site	operator reporting and two airborne measurement systems; 14.0 ± 3.3 t/h in May–June 2022; 9.6 ± 1.9 and 11.3 ± 5.3 t/h in September 2023	campaigns do not produce a continuous annual flux without temporal extrapolation	the annual equivalent in the article is clearly conditional: if sustained
CLM-004	CIC-AU-FIRE-004	After the six-week Hazelwood fire, individual exposure to PM2.5 was associated with subsequent respiratory hospitalizations.	FACT; C3-C5	open-cut coal mine fire → modelled individual PM2.5 exposure plus residential history → hospitalization of residents	exposed and comparison towns; intragroup dose gradient; for every 10 µg/m3: HR 1.09 for respiratory hospitalization over 5 years	an emergency fire does not represent normal mine operation; exposure was simulated	no associations were found for hospitalizations in a number of other categories including cardiovascular diseases over the full five-year period
CLM-005	CIC-US-ASH-003	At selected ash dumps in the southeastern United States, the combination of B and Sr with isotopic signatures provided strong evidence of leakage to surface and groundwater.	FACT; C1-C3	unlined coal ash dumps → seepage into shallow groundwater and adjacent surface waters → water quality	background values and ash isotopic profile; 7 surface-water sites; 15 shallow-groundwater sites in five states; 165 monitoring wells	the sampled sites are not representative of all ash dumps in the United States; environmental contamination does not establish human exposure or ingestion	exceedances of drinking-water or ecological standards was found only in the affected surface-water samples

Claim ID	Source ID	Claim	Status / chain	Source and path	Conditions / units / term	Critical limitation	Negative or limiting result
CLM-006	CIC-US-ASH-004	After the Kingston accident, selenium in fish at affected sites was above reference values, but did not exceed the risk thresholds considered and did not increase over five years.	FACT; C2-C5	accidental release of coal ash → water sediment food chain → selenium in whole-body fish and fillets	affected and reference sites; tissue thresholds; five-year post-spill series; thresholds considered 4–9 µg/g whole body and 11.8 µg/g fillet dry weight	thresholds have been debated and are not a universal clinical limit for humans	the increase relative to the background was not accompanied by an increase over time or exceeding the considered thresholds
CLM-007	CIC-US-ASH-005	After the Dan River accident, a study found no increase in mercury in aquatic invertebrates and fish downstream or over time in the first three years.	NEGATIVE EVIDENCE ; C2-C5	emergency release of coal ash → river sediments and aquatic food web → Hg in sediment invertebrates fish	spatial and temporal comparisons; sampling approximately 17 and 29 months after February 2014 spill	the absence of detected growth in biota does not prove the absence of buried ash or other contaminants	spilled ash itself had Hg above river sediments; the ash could have been buried deeper
CLM-008	CIC-IN-WASH-001	In two coal preparation plants, suspended solids and Mn were released into the process water, while As Se Hg and Cd from coal were not detected in it.	FACT; C1-C2	Kedla and Rajrappa coal beneficiation → process water and slurry pond water → chemical composition of discharge	raw water process streams and effluent standard; six-month sampling	two plants do not represent all technologies and types of coal; reported detection limits require verification against the full text	the presence of As Se Hg Cd in coal did not mean their release into water under these conditions
CLM-009	CIC-MN-COMB-001	Controlled combustion of three Mongolian coals produced a significant PM10 VOC and submicron particle fraction.	FACT; C1-C2	coal combustion Alag Tolgoi Baganuur Nalaikh → smoke and particles → source emissions	three coals with the same heat flux; PM10 factors 1122.9 ± 526.2; 958.1 ± 584.0; 472.0 ± 57.1 mg/kg; dominant 0.35–0.45 µm fraction	The calorimetric experiment does not reproduce the ventilation of the furnace combustion mode or the personal dose in the house	the differences between the three coals show the impossibility of one universal coefficient
CLM-010	CIC-MN-SOILWAT-001	Near the mining enterprises of the South Gobi, pockets of elevated salts and metals were found in the water and soil of local farms.	FACT; C1-C3	Tavan Tolgoi and Oyu Tolgoi districts → soil wells and boreholes → local farm environment	sanitary and hygienic standards and comparison areas; fieldwork 2024; publication 2026	A joint study of the coal and copper regions does not automatically attribute every excess to coal	the geogenic conditions of the arid, saline region require separate background controls
CLM-011	CIC-RU-WAT-001	For many years, the well of the flooded Severnaya mine discharged reduced water with H2S and active microbial sulfur cycling.	FACT; C1-C3	flooded Severnaya mine → flowing borehole and stream discharging to the Tom River → water chemistry and microbial community	long-term measurements of one well; temperature 9.8–13.8°C; redox −112 to −174 mV; H2S 5.4 mg/L in July 2017; discharge 166–170 m3/h	one mine and one discharge point; no measured population dose or downstream effect	neutral pH and low sulfate at one sampling time reflected active sulfur cycling rather than absence of reduced sulfur

Claim ID	Source ID	Claim	Status / chain	Source and path	Conditions / units / term	Critical limitation	Negative or limiting result
CLM-012	CIC-CA-SE-001	Selenium from the Elk Valley mines was traced in concentration, loads and trends more than 575 kilometers downstream.	FACT; C2-C3	surface coal mines and dumps → Elk–Koocanusa–Columbia river network → Se concentration and load	five downstream sites and an unaffected site; flow-normalized trends 2005–2021; annual loads 2013–2017	The transport study indicates aquatic life risk but does not measure biological effect	concentration and trend decreased with distance while loads increased consistent with downstream transport
CLM-013	CIC-ZA-WAT-001	During heavy rainfall, pollution from a coal mine catchment and coal-handling runoff was washed into the Boesmanspruit Dam, which supplied Carolina with drinking water.	FACT; C1-C4	mine seepage wetland and coal-handling ponds → storm flushing into drinking-water reservoir → quality of drinking water source	pre-event and sub-basin chemical tracing; January 2012; pH 3.7; elevated Fe Al Mn sulfate; disruption lasted about seven months	individual dose and clinical effects were not measured; mechanism of rapid pollution reconstructed for a specific event	the authors considered a similar rapid episode less likely for large upper Vaal reservoirs although gradual pollution remained plausible
CLM-014	CIC-CA-SE-003	In trout eggs from an active coal mining site, selenium concentration was associated with alevine mortality; at the highest concentrations, the eggs were not fertilized or were not viable.	FACT; C2-C5	selenium-containing runoff from surface coal mining → aquatic food web and accumulation in eggs → fertilization, fry viability and alevine mortality	12 females from the Clode Pond exposure site and 16 from the O'Rourke Lake reference site; egg Se 11.8–140.0 µg/g dry weight at exposed site; >86.3 µg/g nonviable or unfertilized; 46.8–75.4 µg/g fertilized but no viable fry	field fish eggs were grown in the laboratory; small samples and concentration thresholds cannot be automatically transferred to other species or populations	an earlier study of the same general system found no toxic response; at 11.8–20.6 µg/g no connection with deformations was found
CLM-015	CIC-CA-SE-004	Below the Elk Valley mines, selenium was elevated in water at the base of the invertebrate food web and American dipper tissue, but no significant reduction in clutch size or hatching success was observed.	**NEGATIVE EVIDENCE**; C2-C5	Elk Valley surface coal mines → water–periphyton–invertebrates–aquatic birds → selenium in blood eggs and feathers; clutch size; hatching success	exposed and reference areas within and outside the catchment; water Se up to 20 times wildlife regulatory level; mean egg Se 0.9 times regulatory threshold	the null result applies to the selected nests, study period and two reproductive endpoints and does not prove the absence of any ecological effect	multi-media accumulation was confirmed despite the absence of an identified effect on hatching

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CLM-016	CIC-CN-BIO-001	In the coal-mining city of Yulin, potentially toxic metals in soil and street dust, their in vitro bioaccessibility and lead in the blood of 229 children were simultaneously measured.	FACT; C3-C4	urban mixture of mining, coal combustion, transport and other sources → soil and street dust; lung and gastrointestinal bioaccessibility; blood → lead in the blood of children 0–6 years old	age groups and proportion of values above 50 µg/L; age-group medians 27.12–37.83 µg/L; 1.31–4.80% above 50 µg/L depending on age group	the presence of a biomarker does not determine the share of coal mining and is not a measured clinical effect; cross-sectional design	for most metals, the calculated risks were below accepted levels; the authors isolated Pb and Ni for further control
CLM-017	CIC-CN-OCC-001	In a three-year prospective cohort of new underground miners, FEV1 declined nonlinearly: faster in the first year, barely changed in the second, and partially recovered in the third.	FACT; C4-C5	professional work in an underground coal mine → inhalation of total and respirable dust → longitudinal spirometry FEV1	317 new miners and 132 reference participants; smokers and non-smokers; pre-employment plus 15 follow-ups over three years; area dust sampling twice monthly	area sampling does not provide a personal chemical dose; smoking increased the decline; early dynamics does not equal a diagnosis of pneumoconiosis	the partial recovery by the third year shows that the short-term early decline cannot be described as a monotonous irreversible deterioration
CLM-018	CIC-MN-EPID-001	In Ulaanbaatar schoolchildren, outdoor concentrations of SO2 were associated with persistent cough, and NO2 with current wheezing.	FACT; C3-C5	urban coal combustion and road transport → outdoor air of residential areas → questionnaire respiratory symptoms of children 6–12 years old	four districts; distance to the road; household smoking and other covariates; 1109 valid questionnaires; persistent cough 28.5%; SO2 OR 1.12 (95% CI 1.04–1.22); NO2 OR 1.33 (1.01–1.75) for wheeze	cross-sectional design and area measurements do not provide individual dose; SO2 and NO2 are markers of a complex urban mixture	the association with NO2 indicates that the entire effect cannot be attributed to coal alone; household coal use and road impacts varied between areas
CLM-019	CIC-US-FIRE-001	Year-long air monitoring of Centralia in 2006–2007 did not detect overall high chronic concentrations of Hg CO SO2 H2S TSP As Cd or Pb at the three sites.	**NEGATIVE EVIDENCE**; C2-C3	Centralia anthracite mine underground fire → outdoor air at Main Town and Background sites → air pollutant concentrations	background and regional values; ambient standards and health reference levels in force at that time; Hg0 average 1.6 ng/m³; CO 8-hour 0.3/0.5/0.3 ppm; SO2 annual 0.004 ppm; H2S 24-hour 0.003 ppm; TSP annual 21/24 µg/m³	three sites and one period do not exclude short-term peaks at individual vents or historical exposure before monitoring; individual dose not measured	when winds came from the fire zone, Main-minus-Background Hg0 was slightly higher than in other winds 0.21 versus 0.07 ng/m³, but the average values remained near the regional background

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CLM-020	CIC-US-WAT-003	The Centralia Mine Tunnel discharged acidic water containing sulfate and dissolved Fe Al Mn into the Big Mine Run in March and August 2001; this tributary had the most severely compromised water quality among the basin's streamwater sites in terms of acidity and dissolved metals.	FACT; C1-C3	dewatering of abandoned anthracite mine system → mine-tunnel discharge → Big Mine Run → Mahanoy Creek → water quality and chemical loading	two seasons of base-flow; other AMD sources in the catchment; M19 flow 6560/4130 L/min; pH 3.9/3.6; Fe 7.6/4.6 mg/L; Al 5.5/8.7 mg/L; Mn 4.9/5.9 mg/L; combined dissolved-metal load 62.1/41.7 Mg/year	this is evidence of the consequences of abandoned coal mining, but not evidence that it was the ongoing fire that created the measured AMD; human consumption and clinical effect not measured	there were other large AMD discharges in the catchment; less than 10% metal load attenuated before Big Mine Run entered Mahanoy Creek
CLM-021	CIC-DE-WAT-001	A geochemical trace of lignite mining products in the Spree sediments was detected at least approximately 90 km below the mine area, while elevated sulfate in the water persisted further along the 190 km profile to Berlin.	FACT; C2-C3	open pit mining of lignite and pyrite oxidation after drainage → groundwater and tributaries → River Spree sediments and water → longitudinal gradient Fe S Ni Co Al and sulfate	190 km profile from the mining region to Berlin; source-near and urban signatures; sediment mining signature at least ~90 km; high river-water sulfate persisted along the flow path	sediments and sulfate do not provide an individual drinking dose; in Berlin the chemical signature is mixed and then overprinted by urban sources	in Berlin urban Zn Cr Pb Cu signature became dominant while mining Fe and S sediment signal was strongly diminished
CLM-022	CIC-DE-ECO-001	At Spree sites with high iron loads, the abundance of benthic invertebrates and fish CPUE was lower, and fish were more dependent on terrestrial insects; community composition and fish biomass did not differ significantly.	FACT; C3-C5	iron-rich drainage and iron flocculation from Lusatian lignite landscape → river water sediment benthic food web → benthic abundance fish abundance biomass and diet	three high-iron upstream and three low-iron downstream reservoir sites; benthos 982 ± 1100 versus 5945 ± 2106 individuals/m²; fish CPUE 60 ± 35 versus 158 ± 49 individuals/1000 m; single field season	the dam and temperature differences coincide with the iron gradient; the design does not isolate the causal effect of Fe and covers one point in time	fish community composition and BPUE were not significantly different; result supports food-web alteration rather than disappearance of fish community
CLM-023	CIC-AU-BLAST-001	Long-term fence-line monitoring of a large open cut showed that NO2 near the border cannot be reliably attributed to explosions alone: diesel power plant equipment, road and rail transport were operating simultaneously.	FACT; C2-C3	blasting operations with ANFO and other equipment in an open pit → blast plume and regional ambient air → NO2 at the site boundary	two leeward fence-line sites and an additional site near the administrative zone; DOAS monitoring April 2011–October 2012; third-site NOx analyzer November 2010–April 2011	a verified project abstract is available but not a full numerical report; no personal exposure or health endpoint; coal industry financing	the project explicitly recommended regional source modeling because blast emission factors and the actual contribution remained uncertain

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CLM-024	CIC-AU-TRAN-001	In monitoring of the southern Queensland rail corridor, coal particles were detected in settled dust, but ambient particle concentrations met target values, and the bulk came from other urban and resuspended sources.	**NEGATIVE EVIDENCE**; C2-C3	transportation of coal in open wagons and resuspension of corridor dust → air and settled dust at the rail corridor → share of coal particles and total PM concentration	pre/post wagon veneering; multiple monitoring sites; coal about 10% of deposited-dust surface coverage with individual samples trace–20%; ambient objectives met during monitored periods	one transport corridor and the selected averaging periods do not exclude short peaks or other exposure on other routes; clinical effect not measured	dust changes tracked all passing trains and urban sources; most rail-related dust was resuspension rather than direct wagon loss
CLM-025	CIC-US-STOR-001	Runoff from two Georges Creek coal yards had a pH of 1.4–3.1 and high Mn Al Zn Fe and sulfate; downstream of the entry points, the runoff added stress to the macroinvertebrate community	FACT; C1-C5	open coal yards → rainfall runoff → Georges Creek → water chemistry and macrobenthos	runoff high/low flow; creek sites above and below two storage areas; sampling July August September 1982 and February July 1983; creek outside runoff near pH 7	periodic drought and upstream organic inputs also strongly influenced abundance and diversity; old two-site study does not represent all types of coal and storage	even in perennial reaches, diversity was low; therefore the environmental endpoint cannot be reduced to runoff alone
CLM-026	CIC-US-BEN-001	After approximately 10 000 gallons of the MCHM/PPH mixture entered the Elk River, contamination entered the municipal system; presentations with predominantly mild cutaneous respiratory and gastrointestinal symptoms have been reported.	FACT; C2-C5	emergency leak of beneficiation chemicals from an above-ground storage tank → Elk River → water intake → treated public water → reported exposure → poison-center calls emergency-department visits and household reports	three independent descriptive data sources; review exclusions; 44 treated-water samples in the first two days 0.18–3.12 ppm MCHM mean 0.88 median 0.76; 2000 poison-center records; 369 ED records retained	individual concentration and dose were not measured so the cause of symptoms has not been established; the odor could cause physiological and psychological reactions independent of toxicity	symptoms usually resolved without or with minimal treatment; 215 of 584 candidate ED records were excluded after review
CLM-027	CIC-US-BEN-002	The body of subsequent NTP studies found no effects attributable to MCHM at or below the drinking-water screening level used; birthweight analysis found no meaningful differences associated with time of accident.	**NEGATIVE EVIDENCE**; C0-C5	experimental testing of the mixture after an accident → rodent cell fish worm and computational models plus human birth records → multiple toxicology endpoints and birthweight	screening level used in emergency response; multiple experimental systems; NTP final collective interpretation; human birthweight analysis by spill timing	experimental systems and birthweights do not cover all possible acute symptoms or long-term outcomes; actual individual dose of residents is unknown	effects in some models occurred at much higher doses; this does not prove that all residents' reports were wrong

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CLM-028	CIC-CA-N-001	In the Elk Valley coal dumps, chemical and isotope analysis linked nitrate in blasted rock and drainage water to explosive residues; For the dump studied, the estimated field leaching efficiency was 80–90%, and leaching could continue for decades.	FACT; C1-C3	ammonium nitrate explosives in open-pit coal mining → residues in blasted waste rock → infiltration through dumps up to 180 m → rock-drain water → concentration and isotopic signature of nitrate in rock and water	pre-blast versus post-blast rock; dumps constructed 1982–2012; field versus laboratory leaching; field-scale leaching efficiency 80–90%; flushing time in most cases several decades	the study traces source and transport but does not measure human dose or downstream environmental effects; the rate of leaching depends on the dump design and hydrology	limited to no denitrification was detected within the studied dump; this strengthens the transport chain but does not turn it into a chain of established harm
CLM-029	CIC-US-N-001	In mountaintop-removal mining watersheds, annual nitrate export was 3.68–26.4 kg N/ha/year and was one to two orders of magnitude higher than the neighboring forest reference; after the cessation of production, it decreased, but remained above the reference decades later.	FACT; C2-C3	open-pit coal mining with valley fills explosions and reclamation → subsurface flow pathways through valley fills → baseflow → headwater streams → concentration and annual nitrate export	six large watersheds; four repeatedly sampled small mined watersheds; nearby forest reference; 3.68–26.4 kg N ha−1 yr−1; WY2016 flux 7–50 times reference; repeat records 2000 2010 2015 2016	the isotopic ratios did not match unambiguously with the proposed endmembers of explosives or fertilizers; the work does not establish an individual drinking dose or clinical effect	explosive residue plausibly explains much active-mining export but fertilizer rock-derived N valley-fill hydrology and altered cycling may explain persistence; none of the mined sites studied returned to reference
CLM-030	CIC-US-BEN-003	In laboratory batch and column experiments, MCHM was quickly removed from water mainly due to sorption on coal and tailings and was poorly desorbed; the authors considered it unlikely to leave the coal preparation plant during normal operation.	**NEGATIVE EVIDENCE**; C1-C2	MCHM as a reagent for flotation enrichment of fine coal → process water ↔ coal and tailings; volatilization sorption leaching desorption → retention and potential mobility of MCHM	coal and tailings; batch and column systems; short-time sorption versus leaching; sorption was most significant at <1 h; qualitative conclusion of low transport under normal operation	this is a laboratory model and not field discharge monitoring; it does not cover emergency storage failures, leaks and bypass flows and all types of tailings storage facilities	the result contradicts the generalization that the use of MCHM in itself means its routine release to surface water or groundwater; The Elk River accident was a separate storage failure

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CLM-031	CIC-CN-BEN-001	In laboratory flotation tests on Wulantuga coal, some minerals and elements entered the process water; for individual elements, the calculated release rates were high, but the experiment did not track the release of this water outside the factory.	FACT; C1-C2	flotation of mine-specific Ge-rich low-rank coal → grinding and argillation → coal-preparation process water → distribution of trace elements between cleaned coal tailings and water	feed coal versus cleaned coal, tailings and release-experiment water; examples: Mn 85.68%; Ni 67.54%; Co 61.20%; Zn 59.98%; values are release-test percentages not environmental concentrations	bench-scale release percentage is not equal to the real effluent concentration and does not account for recycling, treatment, settling, dilution or discharge; receptor and effect not measured	F, As and Hg were difficult to remove from coal while other elements partitioned differently; therefore, it is impossible to describe all potentially toxic elements with one coefficient
CLM-032	CIC-IN-ASH-001	Seasonal groundwater samples from six villages around the unlined ash pond Parichha measured Pb 0.170–0.581 ppm Ni 0.024–0.087 ppm Fe 0.186–11.98 ppm Cr 0.036–0.061 ppm and Mn 0.013–0.178 ppm; the authors reported exceedances of the WHO guideline values.	FACT; C1-C3	wet disposal of coal fly ash at the Parichha thermal power plant → unlined ash pond → suspected leaching → nearby village groundwater → groundwater chemistry and drinking-water guideline comparison	six villages; winter pre-monsoon and monsoon 2015; coal and fly-ash samples; Pb 0.170–0.581 ppm; Ni 0.024–0.087; Fe 0.186–11.98; Cr 0.036–0.061; Mn 0.013–0.178	without a hydrologic or isotopic tracer, every exceedance cannot be attributed solely to ash; actual water consumption and internal dose of residents were not measured	the very proximity to ash pond is a spatial basis and not a complete source attribution; need upstream/background wells and tracers
CLM-033	CIC-IN-ASH-002	An isotope study at Koradi and Khaperkheda showed that the high salinity of the contaminated wells came mainly from untreated domestic and brick-kiln wastewater; The direct impact of ash ponds on groundwater turned out to be low.	NEGATIVE EVIDENCE ; C2-C3	ash ponds next to mixed land use → pond drainage streams brick-kiln wastewater domestic wastewater and aquifer recharge → source attribution of groundwater salinity and sulfate	oxygen hydrogen strontium uranium and radium isotopes plus Sr/Ca ratios; three ash ponds; six groundwater sites; three surface-water sites in the Kanhan–Kolar area	the result relates to two specific power plants and a specific hydrogeology; it does not exclude other ash-derived contaminants or leakage at other sites	87Sr/86Sr with Sr/Ca identified brick-kiln wastewater as dominant sulfate source; uranium isotopes confirmed low ash-pond influence
CLM-034	CIC-ZA-ASH-001	Around the Matimba ash dump, MSc field work revealed a saline groundwater plume with NaCl/CaCl2 facies and exceedances of guideline values for TDS EC sulfate chloride sodium magnesium manganese and iron; only 12.5% of sampled boreholes received an excellent domestic-water rating.	FACT; C1-C3	dry disposal of coal fly ash at Matimba power station → ash and seepage → groundwater plume near disposal facility → groundwater chemistry and suitability indices	spatial sampling of CFA seepage and boreholes; SANS WHO and South African guidelines; about two-thirds Na-K-Cl-SO4 facies; one-third Ca-Mg-Cl-SO4; 12.5% excellent boreholes; about 50% require pretreatment	source: MSc thesis and the current entry is based on the repository abstract; individual ingestion, an ecological endpoint and health effect not measured; full numerical tables need independent audit	majority of boreholes were nevertheless classified suitable for irrigation by several indices; domestic and agricultural suitability are not interchangeable

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CLM-035	CIC-CN-COMB-001	In two pulverised-coal power plants in Huainan simultaneously sampled feed coal bottom ash fly ash and FGD products showed different volatility of As Hg Sb and Se: Hg was the most volatile and Sb the least volatile.	FACT; C1-C2	combustion of bituminous coal and operation of pollution-control systems → feed coal → combustion → bottom ash fly ash FGD products and residual flue-gas pathway → material partitioning of As Hg Sb and Se	two Huainan power plants with simultaneous input and output sampling; plant-specific material balances; relative volatility rather than receptor concentration	partitioning does not equal release outside the station; abstract-level data does not provide individual stack fractions for each element and does not measure external exposure	different elements cannot be combined into one formula: volatility and capture pathways differ for Hg As Se and Sb
CLM-036	CIC-CN-COMB-002	At the 320 MW generating unit studied, 72.3–98.0% of twelve trace elements were in fly ash and 1.90–27.6% in bottom ash; SCR+ESP+WFGD removed 99.79–99.99% of elements from the flue-gas pathway, and stack concentrations were 0.01–12.88 μg/m³.	FACT; C1-C3	coal combustion with SCR ESP and WFGD → coal → boiler partitioning → bottom ash and ESP fly ash → WFGD → stack → mass fractions removal efficiency and stack concentration	simultaneous EPA Method 29 sampling across one 320 MW unit; fly ash 72.3–98.0%; bottom ash 1.90–27.6%; combined stack plus WFGD 0.11–0.66%; stack 0.01–12.88 μg/m³	one generating unit does not establish universal emission factors; stack to concentration atmospheric dispersion is not a population dose; captured material remains in ash and FGD waste streams	high air-pollution-control efficiency means bulk transfer from gas to solid and liquid residues and not the disappearance of elements
CLM-037	CIC-CN-ASH-001	In 34 fly-ash samples out of 15 Guizhou power plants, total Hg was 30–870 ng/g but in tested leaching conditions 0.000–0.110% was released; measured leachate Hg remained below 6.5 ng/L.	**NEGATIVE EVIDENCE**; C1-C2	Hg captured in coal fly ash → precipitation or water contact → potential aqueous leaching → Hg binding forms release fraction and extract concentration	15 plants; sequential extraction and USEPA Method 1316 across pH and solid-liquid ratios; strong-complexed fraction 64–91%; release fraction 0.000–0.110%; extract <6.5 ng/L	laboratory leaching of Hg does not describe other elements field hydrology erosion particulate transport or unusual geochemistry; comparison of an extract with drinking-water standards is not a drinking-water exposure assessment	with tested natural-condition scenarios Hg leaching was negligible even though total Hg in ash varied nearly twenty-fold; content in ash is not equal to mobile fraction
CLM-038	CIC-IN-COMB-001	In samples of feed coal, fly ash and bottom ash from five Indian power plants, all 13 elements studied were more enriched in fly ash than in bottom ash; As Hg Pb and Cd in fly ash were 0.19–0.35 0.51–2.13 7.6–35.3 and 0.6–0.93 μg/g, respectively.	FACT; C1-C2	coal combustion at five thermal power plants → feed coal → volatility and condensation → fly ash versus bottom ash → trace-element concentration and enrichment in combustion residues	five plants; parallel coal fly-ash and bottom-ash sampling; fly ash: As 0.19–0.35 μg/g; Hg 0.51–2.13; Pb 7.6–35.3; Cd 0.6–0.93	concentration in collected ash does not show stack release leaching resuspension intake or biological effect; plant practices and coal geology varied	the maximum enrichment was for Mn; element behaviour differed with volatility, so fly ash cannot be described by one universal toxic profile

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CLM-039	CIC-MN-ROAD-001	Focus groups interviews and participant observation in the South Gobi documented consistent reports by herders of dust from unpaved mining and coal-haul roads on grasslands and animals, but the study did not measure the concentration or chemical composition of this dust.	FACT; C0	truck traffic on unpaved roads serving Oyu Tolgoi and the Tavan Tolgoi coal corridor → road disturbance → visible and deposited dust reported on pasture and livestock → reported livelihood animal-health and place impacts	84 semi-structured interviews in 2011–2013; 30 follow-up interviews in 2015; multiple soums and Ulaanbaatar stakeholders; qualitative fieldwork over 2010–2012 plus one month in 2015	the reported experience is real as social evidence but does not establish PM mass silica metal content inhaled dose or clinical causation; copper and coal traffic partly coexist	official and company actors disputed responsibility and infrastructure obligations; perception data cannot allocate dust among coal haulage other mining natural dust storms and local roads
CLM-040	CIC-MN-DUST-002	InSAR time-series analysis identified areas of aeolian erosion and a potential dust-transport footprint near the surface coal mines of the Mongolian Gobi, but did not measure airborne PM concentration or particle composition in humans and livestock.	FACT; C2-C3	disturbed surfaces and stockpiles at surface coal mines → wind erosion → modeled or inferred downwind transport footprint → surface change and potential dust-source footprint	mine surfaces and surrounding Gobi landscape across satellite time series; remote-sensing temporal series; no gravimetric or filter-chemistry exposure sampling	InSAR detects changing surface properties not chemical identity; transport modelling does not prove that a receptor inhaled coal-derived particles	natural desert dust road traffic and other disturbed surfaces remain alternative contributors until chemical tracers and near-road monitors are added
CLM-041	CIC-RU-WAT-001	Water from a well intersecting the flooded workings of the closed Severnaya mine maintained reducing conditions for more than ten years, contained up to 6 mg/L H2S and, at discharge, showed a measured sulfate reduction of up to 178 g reduced sulfur/year.	FACT; C1-C3	wet closure and flooding of Severnaya coal mine in Kemerovo → flooded mine aquifer → monitoring borehole discharge → stream discharging to the Tom River → mine-water redox sulfur chemistry and microbial process rate	more than ten years of observations; in-situ radiotracer sulfate-reduction measurement; temperature 10–13°C; Eh −112 to −174 mV; H2S up to 6 mg/L; up to 178 g reduced S/year at borehole discharge	one borehole at one flooded mine; downstream concentration, dilution, ecological receptors and human exposure were not measured; a separate 2017 sample downstream was mixed with residential drainage	known sulfate-reducer phylotypes did not dominate despite measured sulfate reduction; microbial community and chemical flux cannot be inferred from taxonomy alone

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CLM-042	CIC-RU-WAT-002	On a number of named receiving rivers in Kuzbass, water upstream of the mine-water discharge did not meet the standards: for example, Mn reached 21 MPC in Mishikha near Sudzhenskaya and 56 MPC in Bolshaya Kamyshnaya near Yagunovskaya, and Aba was heavily polluted regardless of the quality of the discharged water.	NEGATIVE EVIDENCE; C2-C3	closed-mine water discharge into already impacted rivers → mine pumping or outflow → receiving river with contaminated upstream baseline → hydrochemical monitoring above and around discharge points	upstream/background sections and named mines/rivers; examples upstream: Mishikha Fe to 5.8 and Mn to 21 MPC; Bolshaya Kamyshnaya Fe to 2.9 and Mn to 56 MPC; Aba suspended solids to 32.3 and Mn to 15 MPC	MAC multipliers do not replace raw concentrations flow and load; the source of upstream contamination is not separated; the article does not provide an individual dose or ecological endpoint	a heavily polluted upstream baseline means that the downstream exceedance cannot be automatically attributed to the closed mine without paired loads and flow correction
CLM-043	CIC-ID-WAT-001	In July 2016, the water of the four pit lakes at Tanjung Enim had a pH of 2.6–5.9 and sulfate of 868–2010 mg/L; the authors also found elevated Fe and Mn, in some places above the Indonesian discharge limits.	FACT; C1-C2	oxidation of potential-acid-forming interburden in named open pits → pit walls and waste rock → pit-lake mine water → mine-water acidity major ions and dissolved metals	Air Laya MTBU Banko Barat pit 1 and Banko Barat pit 3; dry-season comparison with wet-season follow-up; pH 2.6–5.9; sulfate 868–2010 mg/L in July 2016	this is the chemistry inside the mine-water system, not the concentration after dilution in the receiving river; different pits were different and the difference cannot be attributed solely to the coal seam	wet-season dilution was limited and spatial variation was linked by authors to heterogeneous acid-forming interburden rather than a single uniform coal property
CLM-044	CIC-ID-WAT-001	Mine water treatment in Tanjung Enim worked differently: in Air Laya the treatment system reduced Mn in 2015 from 24.5 to 0.1 mg/L and Al and Fe below the detection limit, while in MTBU in the dry season Fe decreased from 2.5 to 0.2 mg/L, but Mn only from 6.6 to 5.8 mg/L and the output did not meet the standard.	FACT; C2-C3	passive treatment of pit and stockpile drainage → mine water → sequential ponds wetlands and liming → treatment outlet → element-specific treatment performance	paired inlet and outlet measurements at Air Laya and MTBU systems; Air Laya Mn 24.5→0.1 mg/L in 2015; MTBU Fe 2.5→0.2 and Mn 6.6→5.8 mg/L in dry season	different years water sources and treatment trains cannot be compared as a controlled trial; no downstream receptor measurement	Fe removal did not mean Mn removal; in 2016 Air Laya feed was less contaminated because it came only from coal-stockpile drainage

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CLM-045	CIC-ID-WAT-002	Along a 15.4-km section of the Lati River, the highest sediment concentrations of Mn, Cr and Ni were found at SPL 10, a stream receiving the discharge of the active mine-water treatment system; the average values for 15 stations were Fe 33,856, Mn 1,615, Cr 162.8, Ni 56.6 and Pb 17.11 mg/kg.	FACT; C1-C3	treated drainage from multiple open-pit coal-mine catchments → mine and treatment outlet → river flow → sediment deposition → metal concentration and spatial accumulation in river sediment	15 composite sediment stations aligned with 10 mine-water treatment outlets; means mg/kg: Fe 33,856; Mn 1,615; Cr 162.8; Ni 56.6; Pb 17.11	one spatial survey does not measure temporal flux bioavailability or biological effect; several outlets, inactive areas and geological background contribute; association at the highest-concentration station is not a complete causal apportionment	authors found no progressive decline in overall sediment quality despite moderate Fe/Ni and high Mn/Cr contamination-factor classifications
CLM-046	CIC-ID-TRN-001	Within approximately 4 km around the ship-to-ship coal-transfer area Muara Berau, coal debris was found at all 10 sampling stations up to 25 cm in sediment; the volume of spill material significantly correlated with some metal concentrations in sediment, and the BAF of the studied metals was 11.54–426.20.	FACT; C1-C4	coal loss during barge-to-mother-vessel transfer → coal spill → marine sediment and water → fish and plankton → coal-debris distribution and metal bioaccumulation	10 marine sampling stations around one transfer area; fish caught by mini trawl; coal debris to 25 cm; BAF 11.54–426.20; BSAF 0.02–5.04	no proven adverse-effect endpoint or human intake; without the complete table, each species- and metal-specific threshold cannot be checked; correlation with spill volume does not exclude other regional metal sources	fish-muscle metals followed Fe>Mn>Zn>Cu>Pb>Cd>As>Hg while plankton ordering differed; organism compartment and element cannot be generalized as one exposure
CLM-047	CIC-US-FIRE-002	In 1980, a federal study examined Centralia as an underground fire directly beneath the populated borough: the Bureau of Mines installed CO detectors in 10 homes closest to the fire zone, and Pennsylvania inspectors conducted weekly gas seepage checks.	FACT; C0-C2	anthracite fire propagating through abandoned workings beneath Centralia → subsurface fire → fractures workings and possible building pathways → residential surveillance → recognized CO intrusion and subsidence hazard to occupied properties	ten homes with detectors plus weekly inspections; engineering study of fire-control options; status documented in the August 1980 case study published as RI 8799 in 1983	installation of detectors shows a reasonable need for monitoring but does not prove excess or poisoning in every home; accessible bibliographic and excerpt layer does not provide a population dose distribution	the proposed cutoff trench was abandoned, among other things, because it required the destruction of private houses; technically preferred control options were expensive and highly disruptive

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CLM-048	CIC-CA-N-003	In Elk River, flow-normalized concentration nitrate increased by 784% and load by 697% from 1979–2022; in the paired Kootenay watershed without coal mining, nitrate fell 8.5%, which attributes the strong long-term increase in river transport to the expansion of coal operations.	FACT; C2-C3	explosive residues and mine-waste drainage from expanding open-pit coal operations → Elk River → transboundary Koocanusa Reservoir → flow-normalized nitrate-plus-nitrite concentration and load	paired Elk and Kootenay watersheds; multi-decade trend models; NO3 concentration +784% and load +697% in Elk River 1979–2022; Kootenay concentration −8.5%	study reports nitrate with selenium and sulfate and does not allocate nitrate among individual mines or prove a nitrate-specific receptor effect; trend percentage is not an individual exposure	sulfate and selenium also rose strongly in Elk River while reference-watershed patterns differed; co-occurrence prevents assigning any field biological change to nitrate alone
CLM-049	CIC-CA-N-004	In site-water toxicity tests for Fording River, approximately 10% effect levels were 16 mg/L NO3-N for 39-day rainbow-trout development, 11 mg/L for 8-day Ceriodaphnia reproduction, and 19 mg/L for 14-day Hyalella biomass; The severity-dependent Level 1 benchmark across the most sensitive receptors ranged from approximately 8 to 16 mg/L.	FACT; C3-C5	mine-related nitrate in hard Fording River water → aqueous exposure in controlled tests using augmented site water → development reproduction and biomass endpoints	species-specific controlled tests with hardness adjustment; Level 1: trout 16; Ceriodaphnia 11; Hyalella 19 mg/L NO3-N at representative hardness; seasonal benchmark about 8–16 mg/L	controlled-test effect concentrations are comparators, not observations of field injury; plan and tests were produced within a mine-management process and need independent field confirmation	hardness reduced nitrate toxicity and newer site testing reportedly changed some predicted-effect relationships; a single universal nitrate threshold would be misleading
CLM-050	CIC-AU-FIRE-001	During a 45-day fire at the Hazelwood open-pit lignite mine in Morwell South, approximately 500 m from the mine, the maximum daily PM2.5 concentration reached 731 µg/m3 and the maximum eight-hour CO concentration was 33 ppm; PM2.5, CO, benzene and benzo[a]pyrene exceeded applicable standards or guidelines.	FACT; C1-C3	open-cut brown-coal mine fire → fire plume → community ambient air → ambient concentration near the mine	air-quality standards and guidelines; monitoring sites at different distances; 45 days; PM2.5 max daily 731 µg/m3; CO max 8-hour 33 ppm; Morwell South about 500 m	PM2.5 and CO monitoring began approximately four days after the fire, and the targeted sampling of air toxics began only on the 17th day, after the most intense period; a monitoring-site concentration is not an individual dose	The temporal and spatial heterogeneity of plume means that these maxima cannot be transferred to each resident or to the entire 45-day period

Claim ID	Source ID	Claim	Status / chain	Source and path	Conditions / units / term	Critical limitation	Negative or limiting result
CLM-051	CIC-AU-FIRE-002	In the Hazelwood Fire Pregnancy Study, an interquartile range increase in modeled individual PM2.5 exposure was associated with an increase in the risk of gestational diabetes to approximately RR 1.06–1.07 for mean and RR 1.15–1.16 for peak exposure; the strongest association was observed in the second trimester.	FACT; C3-C5	Hazelwood mine-fire smoke → modelled time-location PM2.5 exposure during pregnancy → gestational diabetes; hypertensive disorders; abnormal placentation	exposed and comparison communities with adjustment for measured covariates; RR per IQR of average or peak pregnancy PM2.5; trimester-specific analysis	exposure was simulated and not measured with a personal device; observational design does not rule out residual confounding and does not prove the mechanism	for hypertensive disorders of pregnancy and abnormal placentation, no association was identified; a positive result does not automatically transfer to all complications of pregnancy
CLM-052	CIC-AU-FIRE-003	In the same Hazelwood pregnancy cohort, no relationship was found between modeled fire PM2.5 exposure and preterm birth, term low birth weight, small-for-gestational-age, or large-for-gestational-age.	FACT; C3-C5	Hazelwood mine-fire smoke → modelled maternal PM2.5 exposure → birth outcomes	exposed and comparison communities; multiple birth outcomes; adjusted RR: preterm average exposure 1.00 (0.97–1.04) and peak exposure per 10 µg/m3 0.99 (0.97–1.02); term low birth weight about 0.99 for both metrics	a null result for the selected outcomes and a given exposure model does not prove the absence of any prenatal effect; confidence intervals and possible exposure misclassification are preserved	the result limits the generalization of the positive GDM signal: different pregnancy outcomes produced different results
CLM-053	CIC-AU-FIRE-005	Nine years after the Hazelwood fire, in the adult subsample studied, PM2.5 exposure was not associated with chest tightness, dyspnea, or chronic cough; The association with wheeze persisted, especially in people with asthma before the fire.	FACT; C3-C5	Hazelwood mine-fire smoke → modelled individual PM2.5 exposure from time-location histories → long-term self-reported respiratory symptoms	exposed and comparison participants; stratification by pre-fire asthma; baseline 4056 adults; weighted nine-year follow-up sample 519, including 346 exposed	the nine-year subsample was significantly smaller than the original one and was enriched with participants with asthma; symptoms self-reported, exposure simulated; lack of association with measured symptoms does not describe unmeasured diseases	No persistent association was identified for chronic phlegm or nasal symptoms either; most of the early symptomatic connections weakened, but wheeze did not disappear as a signal

Claim ID	Source ID	Claim	Status / chain	Source and path	Conditions / units / term	Critical limitation	Negative or limiting result
CLM-054	CIC-IN-AIR-001	In a comparison of Jharia sites, air quality indicators in areas affected by coal fires were approximately 1.5 times worse than in mining areas without fire; multivariate analysis identified fire as a major contributor to pollution.	FACT; C1-C3	coal-seam fires within an active mining region → fire emissions plus mining and traffic sources → community ambient air → ambient air-quality index and measured pollutants	fire-affected versus non-fire mining areas; study-period site comparison; AQI ratio approximately 1.5	the comparison does not isolate the fire from active mining, vehicles, resuspended road dust and meteorology; ambient index is not equal to the individual dose and does not establish the disease	even non-fire mining sites were contaminated; the result shows a gradient within a mixed industrial environment rather than a pure fire-only experiment
CLM-055	CIC-IN-AIR-002	During May 2018–April 2019, the average PM2.5 concentration in the Jharia industrial coal belt was 170 ± 45 µg/m3; in the PM2.5-related fraction, the elements were located Fe > Mn > Cu > Zn > Cr > Pb > Co > Ni > Cd > As, and the highest levels were observed at fire-affected sites.	FACT; C2-C4	coalfield fires mining transport and resuspended road dust → mixed-source PM2.5 → ambient inhalation pathway → ambient fine-particle concentration and trace-element composition; modelled health risk	seasonal and spatial sites including fire-affected locations; mean PM2.5 170 ± 45 µg/m3 over one year	PCA and correlations indicate a mixture of fire, active mining, vehicles and road dust, rather than a quantifiable fire-only contribution; HQ, HI and excess cancer risk are calculated models, not measured internal dose or observed disease	spatial connection with fire-affected sites strengthens the source hypothesis, but does not close the individual exposure-response chain
CLM-056	CIC-CN-FIRE-HG-002	In the underground fire zone, Wuda gaseous mercury in boreholes was 6.42 ± 0.73–123.53 ± 34.66 ng/m3 (average about 49 ± 44), and in near-surface air around boreholes it was 2.38 ± 0.28–13.10 ± 0.97 ng/m3 (average 6.68 ± 3.09) with background below 2 ng/m3; concentrations were positively correlated with temperature and CO.	FACT; C1-C3	underground coal fire and borehole gas release → subsurface combustion → boreholes → near-surface air → source and near-source gaseous mercury concentration	borehole gas near-surface air and background; ng/m3; repeated field measurements at Wuda fire zone	near-surface measurements around boreholes are not population exposure distribution; the study did not measure absorbed dose or health endpoint; correlation does not prove that mercury reflects the entire composition of emissions	background below 2 ng/m3 provides a local comparator, but does not translate the near-source difference into proven clinical harm
CLM-057	CIC-CN-FIRE-HG-003	On a coal-gangue hill burning for more than 50 years in Wuda, with 2,760 measurements at 46 vents, the mean gaseous-mercury concentration in vent gases was 5908 ng/m3 with a range of 1022–31,750 ng/m3.	FACT; C1-C2	spontaneously burning coal-gangue waste pile → combustion vents → direct source exhaust → gaseous mercury at vents	46 vents across a 100-m-high hill with roughly 2000-m foot perimeter; 2760 readings; mean 5908 ng/m3; range 1022–31,750 ng/m3	these are concentrations measured directly in vent exhaust, not in residential ambient air, not an inhaled dose and not health effect; mercury does not describe the full chemical composition of gases	very high source concentration does not determine the concentration in the population or the magnitude of the risk without dispersion and exposure data

Claim ID	Source ID	Claim	Status / chain	Source and path	Conditions / units / term	Critical limitation	Negative or limiting result
CLM-058	CIC-CA-N-005	In Fording River Operations LAEMP 2023, observed deviations in benthic-invertebrate community structure were not interpreted as primarily caused by nitrate; the authors considered the potential risk of adverse nitrate effect to be low with continued reductions in concentrations due to treatment.	**NEGATIVE EVIDENCE**; C3-C5	mine-related nitrate and co-occurring constituents → mine drainage and treated effluent → upper Fording River → benthic-invertebrate community structure and chronic-toxicity context	reference/exposed expectations; upstream-downstream and pre/post-treatment comparisons; 2023 field program with historical comparison	this is an operator monitoring report; nitrate changes simultaneously with selenium nickel cadmium sulphate flow habitat and treatment; the phrase “not likely the primary cause” does not prove the absence of nitrate effect and is not a nitrate-only experiment	the field result limits the transfer of controlled-toxicity benchmarks to a statement about the observed population effect in the river
CLM-059	CIC-GLOBAL-BEN-001	In a survey of more than 180 US coal-preparation facilities using wet cleaning, more than 60% of facilities under various conditions reported closed water circuits; the characteristics of raw process water depended significantly on the specific enrichment technology.	FACT; C1-C2	routine wet coal preparation → process water circulation treatment and potential discharge → facility process-water architecture rather than environmental receptor	more than 180 facilities; varied terrain and processes; 1976 US technical survey	the historical survey does not describe the current frequency of leaks and does not measure reagent-specific environmental concentration; closed circuit does not mean zero release during overflow failure maintenance or waste handling	the absence of an open discharge pathway in a closed-circuit design is limiting evidence against the assumption of a constant direct effluent pathway, but not evidence of absence of impact
CLM-060	CIC-MN-BIO-001	In 118 children 9–12 years old from three South Gobi soums, blood Cd, Pb and Hg, hair Hg, and total urinary As were measured; at Tsogttsetsii, where the Tavan Tolgoi coal mines operate, the geometric mean blood Pb was 4.78 µg/dL, while a higher value of 7.42 µg/dL was at Bayandalai, away from large coal mines.	**NEGATIVE EVIDENCE**; C3-C4	mixed mining household fuel containers paint and small-scale sources → multiple environmental and domestic pathways → child internal dose → blood hair and urine metal biomarkers	Tsogttsetsii coal-mining area versus Khanbogd copper-gold area and Bayandalai small-scale-mining area; n=118; July 2017 cross-sectional survey	there were no paired samples of air, soil, water or coal-road dust; cross-sectional groups differed in housing fuel water containers paint and mine type; biomarker pattern cannot be assigned to Tavan Tolgoi	the highest blood Pb was not in the coal-mining soum; authors discuss batteries reused containers paint coal/biomass and other mines as alternative sources
CLM-061	CIC-RU-DUST-002	In the snow cover near the Kuzbass open pit at the stage of stripping and preparatory work, the mass of fractions was 204 ± 18 µg/cm2 for PM0.1 and 401 ± 14 µg/cm2 for PM10; In PM10, quartz talc and clay minerals were detected, and higher PAH levels coincided with the prevailing easterly wind direction.	FACT; C2-C3	open-pit overburden and pre-mining activities → airborne particles → winter snow deposition → deposited particle mass mineralogy and PAHs	three directions and near-to-far sampling positions; snow-accumulation season; mean particle size within PM10 about 1 µm	snow loading µg/cm2 is not ambient µg/m3 or personal inhaled dose; there was no monotonic decrease in mass with distance; nearby transport and support activity cannot be fully separated	the study covers the composition and spatial transfer of deposited dust, but not the health endpoint and not individual exposure

Claim ID	Source ID	Claim	Status / chain	Source and path	Conditions / units / term	Critical limitation	Negative or limiting result
CLM-062	CIC-ID-WAT-003	A field study of the Lati River receiving coal-mining waste from Berau Coal reported pH up to 3.23, TDS 2555.2 mg/L, TSS 280.3 mg/L, Mn 4.64 mg/L and Fe 10.88 mg/L along with a decrease in plankton diversity index to 0.965 in the most polluted category and 1.745 in the moderate category.	FACT; C2-C5	coal-mine waste discharge to Lati River → mine wastewater → river chemistry → plankton community → water chemistry and plankton diversity	purposively selected river locations and dilution by tributaries; 2004 field survey; values reported in the abstract	only repository abstract is available without station table temporal replication taxonomy and uncertainty; pH, solids, Fe, Mn and other stressors covary, so the effect cannot be attributed to one substance	tributaries diluted pollutants and supported partial self-recovery; this spatial recovery is relevant counter-evidence against treating all downstream reaches as equally exposed
CLM-063	CIC-TR-AIR-001	In 2004–2006, 44 stations in a 30-km zone around the Soma coal-fired power plant showed a spatial pattern of metals in Xanthoria parietina: the most polluted areas were closer to the station and along the prevailing west-to-southeast wind corridor.	FACT; C2-C4	atmospheric emissions from a coal-fired power plant → atmospheric transport and deposition → epiphytic lichen tissue → As Cd Co Cr Cu Fe Hg Ni Pb Se Th U V and Zn in lichen	3×3-km grid; distance topography and prevailing wind; 44 stations; samples collected 2004–2006	lichen is an integrative biomonitor and not a human dose or direct adverse effect; without source-isotope or stack-to-receptor mass balance other industry traffic and soil dust remain possible contributors	some Cd Co Hg Ni and Pb values were lower than literature comparators; element-specific patterns should not be collapsed into one generic metal effect
CLM-064	CIC-BG-WAT-001	In the Sokolitsa River, most measured physicochemical variables, including temperature conductivity hardness calcium sulphate and nitrogen nutrients, increased downstream of the coal-fired power-plant discharge compared to the upstream site; At the same time, the habitat condition, taxonomic richness and abundance of phytobenthos and macrozoobenthos deteriorated.	FACT; C2-C5	coal-fired power plant wastewater in a lignite energy complex → wastewater discharge → downstream river → river chemistry phytobenthos and macrozoobenthos community	upstream versus downstream; historical monitoring 2013–2022 plus sampling 2023–2024; multi-year monitoring and two recent field seasons	many chemical and physical factors changed together, including temperature nutrients salts hardness hydromorphology and other pollutants; lignite mines and power infrastructure coexist, so one cannot assign one contaminant sole cause	this is a field ecological association with a strong spatial comparator, but not an individual human exposure or single-chemical toxicity experiment

Claim ID	Source ID	Claim	Status / chain	Source and path	Conditions / units / term	Critical limitation	Negative or limiting result
CLM-065	CIC-GLOBAL-CH4-001	For surface coal mines, IPCC lower-tier inventories calculate methane as production × emission factor, while Tier 3 uses mine-specific measurements; Therefore, production tonnage by itself does not measure the actual plume and does not capture site and time variability.	FACT; C0-C2	surface coal mining → coal and surrounding strata disturbance → diffuse atmospheric methane → inventory estimate versus measured mine-scale flux	Tier 1 Tier 2 and Tier 3 hierarchy; annual activity data and method-specific emission factors or direct measurements	even Tier 3 requires representativeness in time and space; inventory guidance is not independent plume observation; production and gas-content uncertainty propagate into results	the difference in methods means that the discrepancy between satellite or aircraft estimates and an inventory should be analyzed using temporal coverage attribution wind and activity data, and not automatically declared an error on one side
CLM-066	CIC-AU-CH4-002	TROPOMI observations for 2018–2019 estimated the total methane flux of six Australian surface and underground coal mines at 570 ± 98 Gg/year; these mines provided about 7% of the national coal production, but about 55 ± 10% of the reported national coal-mining methane, with approximately 40% of the satellite-quantified total coming from the Hail Creek surface mine.	FACT; C2-C3	six Australian coal mines including Hail Creek → regional methane plumes observed from space → inverse mass-balance estimates → mine-cluster methane emission rate	national reported inventory and mine locations; two years of satellite observations; 570 ± 98 Gg/year	TROPOMI spatial resolution and cloud/aerosol filtering limit mine attribution and temporal sampling; six selected super-emitting sites are not representative of all mines; annualization depends on observed-day representativeness	independent later aircraft work at Hail Creek supports a large plume but episodic aircraft rates still do not by themselves validate every day of the satellite annual estimate

Appendix B. Claim-context ledger of the second pass

All 33 claim-context blocks from the second pass are provided below. They complement, rather than replace, the first-pass ledger.

Claim ID	Source ID	Site / case	Material path	Measured result	Comparison / time / scale	Critical limitation	Negative or limiting result
CIC2-CLM-001	CIC2-US-CEN-001	Centralia	Soil heating and deposition of combustion products → soil chemistry and microbiome	The hottest soils had lower diversity and were more distinct; the cooled areas moved closer to reference conditions.	18 sites along two fronts; recovery classes spanning approximately 10–20 years.	The time series is not a repeated observation of one soil and does not prove the restoration of all functions.	Stability was observed, but the average pH of the cooled sections remained 4,4 versus 5,9 for the reference.
CIC2-CLM-002	CIC2-US-CEN-001	Centralia	Heating and influence of gases/condensates → variable NH_4, NO_3, sulfur and pH	Ammonium and nitrate correlated with temperature: R=0,50 and 0,54; The pH of the cooled areas is 4,4 versus 5,9.	2014 Campaign; top 20 cm; temperature gradient and reference.	Most other indicators were not strongly correlated with temperature; hot areas were sometimes similar to unheated ones.	Heterogeneity prohibits all Centralia soil from being described as equally contaminated.
CIC2-CLM-003	CIC2-US-CEN-002	Centralia	Seven years of general cooling → change in active and total bacterial fraction	Both the active and total fractions showed signs of stability; cooled and reference communities were more stable.	Repeat plots; 7 years.	Microbiome resilience does not prove geotechnical safety, revegetation, or contaminant removal.	Inactive taxa enhanced the appearance of recovery; The active and complete fractions must not be mixed.
CIC2-CLM-004	CIC2-US-SOIL-001	Surface coal mine, Wyoming	Reconstructed soil under grasses or wormwood → microbial community development	Mining initially reduced biomass and diversity; many markers returned to baseline levels within 5–14 years.	Time series less than 1–26 years; comparison with undisturbed soil.	Space-for-time and individual markers do not prove recovery of an entire profile or ecosystem.	The trajectory depended on the vegetation; recovery of individual markers does not imply recovery of community identity.
CIC2-CLM-005	CIC2-ES-SOIL-001	Lignite-mine reclamation chronosequence, Spain	Soil under wheat → 0–20 years of development	The number of microorganisms and enzymatic activity approached the control, but the structure of the community remained different after 20 years.	0, 5, 10, 15 and 20 years; control soil.	The chronosequence and monoculture limit the transfer of results.	Functional convergence and structural difference refute green cover or a single indicator as evidence of restoration.
CIC2-CLM-006	CIC2-DE-SOIL-001	Open-pit mine reclamation chronosequence, Germany	Agricultural and forestry reclamation → carbon accumulation and microbial development	After 30 years, carbon reached 0,8% in agricultural and 1,7% in forested areas; microbial C varied.	30 years; two types of land use.	Historical work; carbon alone does not prove a return to the original profile.	Forestry and agricultural trajectories show that age does not determine one end state.
CIC2-CLM-007	CIC2-CN-SOIL-001	Pingshuo mine, China	Reconstructed topsoil under different land use types → soil properties	OC and N under forest and grass followed a U-shaped path and became comparable to undisturbed soil in about 20 years; other properties varied.	More than 200 samples; 0–30 cm; about 20 years.	Comparable OC and N do not demonstrate restoration of the profile, biota, hydrology and all nutrients.	Arable land, forest, grass and bare earth did not form a single age trajectory.

Claim ID	Source ID	Site / case	Material path	Measured result	Comparison / time / scale	Critical limitation	Negative or limiting result
CIC2-CLM-008	CIC2-CN-GW-001	Yimin section, China	Dewatering and oxygen ingress → oxidation and change in hydrochemistry	The environment shifted towards oxidising, bicarbonate–sulfate conditions; pH decreased, sulfate, Fe, hardness, Ca and Mg increased.	Long-term development of the mine; regional aquifer.	Drying, mixing, and water–rock reactions are combined; one source is not isolated.	TDS, COD and Na+K decreased simultaneously: not every indicator moved in the same direction.
CIC2-CLM-009	CIC2-PL-DUMP-001	Starzykowiec dump, Poland	Oxidation, degassing, coking, melting and weathering → new mineral phases	The long fire greatly altered the organic and mineral phases, although bulk concentrations of many elements remained similar.	History from the beginning of the twentieth century; new activity in 2006; heterogeneous dump.	The source material is poorly documented, and heating intensities varied; The universal composition of fire cannot be derived.	Most gross trace concentrations have changed little despite major phase changes.
CIC2-CLM-010	CIC2-PL-DUMP-002	Self-heating dumps of Silesia	Vapor, condensation and sedimentation → waste markers on soil and plants	Biomarkers, alkyl aromatics, PAHs and phenols from waste were preserved on plant surfaces and in soil.	Local surfaces and hot spots; field campaign.	Surface presence does not measure uptake, toxicity or population effect.	The signatures remained basin-specific and do not describe all dumps.
CIC2-CLM-011	CIC2-PT-DUMP-001	Fojo dump, Portugal	Combustion and possible runoff/erosion → Hg redistribution	Burned and unburned waste had mean pseudo-total Hg of 1,2 mg/kg versus 0,6 mg/kg background; mobile share 16% versus 8%.	One-time campaign; dump and adjacent slopes.	There is a natural enrichment of Hg; downslope transport has not been traced; extraction does not equal bioavailability.	Combustion did not increase gross Hg relative to unburned waste; changed the mobile fraction more clearly.
CIC2-CLM-012	CIC2-US-REFUSE-001	Green Valley, USA	approximately 2.7 million cubic yards of waste → infiltration, sulfide weathering and groundwater discharge	Acid drainage continued to flow for decades after mining and after reclamation.	Mine operated 1948–1963; studied since 2008; site 159 acres.	Stability depends on the geology, waste volume, cover and drainage of the particular site.	The cover, vegetation and dolomite channels changed the flow and neutralization, but did not remove the underground source.
CIC2-CLM-013	CIC2-UK-WAT-001	Abandoned mines of Scotland	Flooding and flushing of oxidation products → evolution of mine outlets	The heaviest pollution usually occurred in the first decades; Fe often declined to lower levels over about 40 years, but persisted.	32 discharges; six long time series; decades and more than a century.	Fluctuating water levels, geology and the design of the mine change the trajectory.	Consistently very low pH was not typical due to carbonate buffering; decline is not the same as extinction.
CIC2-CLM-014	CIC2-UK-WAT-002	Almond River catchment, Scotland	Numerous mines and dumps → point and diffuse drainage	Historical mining continued to change Fe, sulfate and major ions; the sum of small sources was significant at the catchment level.	1994–2008; more than 300 abandoned mine and waste sites.	Coal-mining, oil-shale and urban sources overlap; it is an aggregate attribution, not an object attribution.	The effect varied with runoff and buffering rather than maintaining one concentration.

Claim ID	Source ID	Site / case	Material path	Measured result	Comparison / time / scale	Critical limitation	Negative or limiting result
CIC2-CLM-015	CIC2-US-SED-001	Huff Run, USA	Fe, Al, Mn and Cu from drainage → precipitation, storage and exchange with pore water	Mineral forms and pore water varied along the channel; the sediment was an active and heterogeneous compartment.	July–November 2014; scale from meters to a river section.	The secondary load of the entire catchment area during a flood has not been calculated.	The pH of the surface water was around 6 due to limestone buffering.
CIC2-CLM-016	CIC2-US-ECO-002	Pennsylvania mountain stream	Alkaline mine outlet with Fe → iron hydroxide at the bottom	At pH 6,5–8, sedimentation reached 3 g/m²/day and fish standing stock decreased from approximately 228 to 11 kg/ha.	Gradient downstream of the discharge; field campaign.	A historical study of one stream does not establish every mechanism.	A strong biological effect occurred without low pH.
CIC2-CLM-017	CIC2-US-ECO-001	Anthracite and bituminous regions of Pennsylvania	Mine drainage → water chemistry, sediment and stream functions	Polluted, treated, and reference streams differed in production, respiration, nutrient flows, decomposition, and communities.	A comparative field study of two regional triplets.	Few streams; regional chemistry rules out one universal effect size.	Treatment improved some conditions, but the communities did not become identical to the reference ones.
CIC2-CLM-018	CIC2-US-COMB-001	795 MW coal-fired generating unit	Coal → SCR, electrostatic precipitator, wet desulfurization → gas, ash, gypsum, water	The electrostatic precipitator retained 88% As, 56% Se, 17% Hg and 8% B; FGD - >90% Cl, 77% B, 76% Hg, 30% Se, 5% As; most of the removed Hg and Se went into gypsum, B/Cl into water.	Simultaneous full-scale stream-sampling campaign.	Percentages refer to one generating unit and are not air concentrations or doses.	High gas removal meant transfer to ash, gypsum or wastewater rather than destruction.
CIC2-CLM-019	CIC2-US-COMB-002	Two US power plants	Combustion and particle collection → bottom, economizer and fly ash	At plants without FGD, the estimated fractions in fly ash were 48% As, 58% Cr, 54% Pb, 20% Se and 2% Hg.	Two campaigns at stations.	FGD and final placement were out of balance; two stations do not define a universal distribution.	The low uptake of Hg and Se relative to Cr/Pb/As shows different fates of the elements.
CIC2-CLM-020	CIC2-NL-USE-001	Road structures, Netherlands	Ash in the base → weathering and percolation → soil and water	Field measurements after approximately 10 years were used to test laboratory leaching predictions.	Four applications on two sites; about 10 years.	Mixing recycled materials and designs does not provide a one-size-fits-all result for fly ash.	Reuse should be assessed by scenario and field behavior rather than by gross content.
CIC2-CLM-021	CIC2-US-USE-001	Road-base applications in four US states	Fly ash in stabilization and embankments → possible leaching → water monitoring	Applications studied showed no measurable trace-element deterioration of ground or surface water.	Seven sites, 18 monitoring points; several years, in some places more than a decade.	The null result is limited to the materials, designs and pathways tested.	The carbon residue in some controlled applications remained below applicable water thresholds.

Claim ID	Source ID	Site / case	Material path	Measured result	Comparison / time / scale	Critical limitation	Negative or limiting result
CIC2-CLM-022	CIC2-CN-BEN-001	Coal beneficiation at Kailuan, China	Raw coal → washing and separation → concentrate, middlings, sludge and tailings	All 15 elements could enter the slurry; most became enriched in the tailings; for As the maximum enrichment factor was 34,4%.	Study of process streams.	Distribution within a process does not prove release from storage or exposure.	The reduction of impurities in the product was achieved by concentrating them in another material flow.
CIC2-CLM-023	CIC2-US-BEN-001	Coal slurry in West Virginia	Mineral fines, water and reagents → coal slurry	Al, Sb, As, Fe, Pb, Mn and several ions exceeded the selected benchmarks at one or more sites; the organic matter found was below the guidelines.	177 analytes across six sites.	The hazardous composition is not a proven groundwater plume or human exposure.	Not all organic compounds detected were at concentrations of concern.
CIC2-CLM-024	CIC2-US-CEN-005	Centralia	Subsidence in hot, fractured ground → steam, weakening and collapse	About 185 cm of precipitation was accompanied by nine new depressions; zones coincided with thermal anomalies and coal seams.	The 2011 event was interpreted in the context of the site's fire history.	The water-heat-soil connection does not prove a contaminating groundwater plume.	Precipitation lowered vent temperatures while increasing steam and surface changes.
CIC2-CLM-025	CIC2-US-CEN-006	Centralia	Continued burning → gases and collapse	As of 2026, the Pennsylvania DEP continues to consider the fire active and the area extremely dangerous due to gases and sudden sinkholes.	Official status 1962–2026.	The official assessment does not provide a universal present-day concentration or numerical health risk.	The duration is confirmed, but no reliable primary basis was found for the precise claim that the fire will burn for another 200 years.
CIC2-CLM-026	CIC2-AU-SOIL-001	Hunter Valley sites, Australia	Planned substrates and plantings → 3–12 years of development	57 biotic and functional indicators followed different trajectories rather than a single return to the reference.	42 reclamation sites and 48 references in four mines.	The older sites were concentrated at one mine; multi-decade equality has not been tested.	The large reference-site sample prevents equating visible cover with complete restoration of function.
CIC2-CLM-027	CIC2-AU-SOIL-002	Former Bowen Basin waste-rock dump	Rock with 0, 10 or 20 cm of stored soil → early soil formation	The rock and degraded stored soil maintained gaps in microbial carbon metabolism relative to the natural soil.	10 months; seasonal observations; 42-hectare field site.	A short early study does not establish ultimate recovery or permanent failure.	The different thicknesses of the top layer created different starting conditions, rather than one "reclaimed soil."
CIC2-CLM-028	CIC2-MN-MAT-001	Baganuur mine, Mongolia	Water, dumps, interlayer material and dust → reactions and leaching	Most waters met the applied criteria; one material had a pH of 3,29–4,26 and released 4019,07 mg/kg sulfate and 803,12 mg/kg Co; As in dust 5,57–14,17 mg/kg.	Two campaigns 2017–2018; site and drainage system.	Laboratory tests of five material types do not characterise the entire mine; dose and disease not measured.	Suitable water and highly acid-forming material coexisted at the same site.

Claim ID	Source ID	Site / case	Material path	Measured result	Comparison / time / scale	Critical limitation	Negative or limiting result
CIC2-CLM-029	CIC2-MN-SOIL-001	Baganuur, Nalaikh and Sharyn Gol	Urban soils with mixed sources → metal concentrations	For Cd, Cu, Pb and Zn, overall contamination was small and the dependence on mine proximity was indirect or absent.	One overview of three cities; gradients and background.	Hot spots, other elements, water and dust are not excluded; sources are mixed.	The presence of a coal mine does not prove the origin of every metal in the neighboring soil.
CIC2-CLM-030	CIC2-ZA-WAT-001	Middelburg Colliery, South Africa	Fire and subsidence → rainfall infiltration → acidic water → streams and vegetation	More than half of the precipitation infiltrated over a large area; contaminated water emerged in springs, vegetation died on approximately 3 hectares.	Closed in 1947; the effects continued during the study.	Fire, subsidence and AMD acted together; the individual effects cannot each be attributed to one reaction.	This is a complete chain of soil–water–surface–biota, and not just the history of air.
CIC2-CLM-031	CIC2-PL-WAT-001	Przemsza basin, Poland	Salt water from active and closed mines → discharge, flooding and dilution	Mine-water discharge volume in 2023 was 42% lower than 1991; the Cl+SO_4 load decreased 534,8→480,1 Mg/day, but during drought the conductivity increased 2000→6700 µS/cm.	1991–2023; basin scale.	Concentration depends on load and river flow; a decrease in volume does not equal an immediate recovery.	Less discharge coexisted with greater concentrations in the river at low flows.
CIC2-CLM-032	CIC2-UK-WAT-003	Mine-water discharges in Scotland	Water–rock–microorganism reactions and treatment → gases and metals	Mine waters carried CO_2 and CH_4 of various origins; treatment removed Fe and As, but only partially Ni, Co and Mn.	16 releases and purification stages; field campaign.	Concentrations and isotopic signatures do not provide complete regional atmospheric flux or exposure.	Treatment efficiency varied among elements; gas is another post-closure flow.
CIC2-CLM-033	CIC2-PL-RES-001	Reservoirs near the dumps of Upper Silesia	Weathering, runoff and water-rock interactions → highly mineralized water	Conductivity up to 21,5 mS/cm; Cl up to 9279 mg/l, SO_4 up to 5277 mg/l, Na up to 4783 mg/l; water is classified as low quality.	16 reservoirs; campaigns 2022–2023.	The risk to shallow groundwater is potential, not proven by the traced plume.	Even reclaimed or informally used land with waste can remain a source without a major accident.

Appendix C. Complete source registry

The combined registry contains 127 entries: 90 from the first pass and 37 from the second. Bibliographic titles are preserved in the source language.

CIC-US-WAT-001 · The Effects of Mountaintop Mines and Valley Fills on Aquatic Ecosystems of the Central Appalachian Coalfields

Year/country/type	2011; USA; official evidence assessment	**Stage and environment**	surface mining; overburden disposal; mine drainage; major ions; conductivity; selenium; aquatic communities
Chain	C1-C5	**DOI / URL**	https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NCEA&dirEntryId=225743
Verification status	final EPA report verified	**Critical limitation**	synthesis of a specific mining system; not a universal model for all coalfields

CIC-US-WAT-002 · Downstream effects of mountaintop coal mining: comparing biological conditions using family- and genus-level macroinvertebrate bioassessment tools

Year/country/type	2008; USA; primary field study	**Stage and environment**	surface mining; valley fills; ionic strength; benthic macroinvertebrates
Chain	C3-C5	**DOI / URL**	https://doi.org/10.1899/08-015.1
Verification status	DOI and study design verified	**Critical limitation**	observational comparison of 37 West Virginia streams; identifies a mining gradient but not every individual ion's causal share

CIC-US-DUST-001 · Coal Mine Dust Exposures and Associated Health Outcomes: A Review of Information Published Since 1995

Year/country/type	2011; USA; official evidence review	**Stage and environment**	underground and surface mining; extraction; processing; respirable coal mine dust; crystalline silica; respiratory disease
Chain	C4-C5	**DOI / URL**	https://cdc.gov/niosh/publications/numbered/2011-172.html
Verification status	NIOSH report verified	**Critical limitation**	occupational evidence; does not quantify exposure of surrounding communities

CIC-US-ASH-001 · Human and Ecological Risk Assessment of Coal Combustion Residuals

Year/country/type	2014; USA; official probabilistic risk assessment	**Stage and environment**	coal combustion residual disposal; arsenic; lithium; molybdenum; groundwater exposure
Chain	C1-C5	**DOI / URL**	https://www.epa.gov/coal-combustion-residuals/coal-ash-rule
Verification status	EPA rule docket and risk conclusions verified	**Critical limitation**	modeled risk under management scenarios; not proof of disease in a named community

CIC-AU-CH4-001 · Insights into Elevated Methane Emissions from an Australian Open-Cut Coal Mine Using Two Independent Airborne Techniques

Year/country/type	2025; Australia; primary airborne measurement study	**Stage and environment**	open-cut mining; methane
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1021/acs.estlett.4c01063
Verification status	DOI methods and estimates verified	**Critical limitation**	several campaigns at one mine; episodic rates cannot automatically be treated as a continuous annual flux

CIC-AU-CH4-002 · Methane Emissions from Superemitting Coal Mines in Australia Quantified Using TROPOMI Satellite Observations

Year/country/type	2021; Australia; primary satellite measurement study	**Stage and environment**	surface and underground mining; methane
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1021/acs.est.1c03976
Verification status	PubMed metadata and article verified	**Critical limitation**	coarse satellite resolution and spatial attribution; six mines are not the whole national industry

CIC-AU-FIRE-001 · Characteristics of an open-cut coal mine fire pollution event

Year/country/type	2017; Australia; primary ambient monitoring and plume study	**Stage and environment**	open-cut mine fire; PM2.5; carbon monoxide; benzene
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1016/j.atmosenv.2016.12.015
Verification status	DOI abstract and event description verified	**Critical limitation**	45-day Hazelwood event; not representative of routine mine operation

CIC-AU-FIRE-002 · Maternal exposure to fine particulate matter from a large coal mine fire...

Year/country/type	2019; Australia; individualized exposure cohort	**Stage and environment**	open-cut mine fire; PM2.5; gestational diabetes
Chain	C3-C5	**DOI / URL**	https://doi.org/10.1016/j.envres.2019.108956
Verification status	legacy full record retained	**Critical limitation**	positive association for gestational diabetes; not evidence for all pregnancy outcomes

CIC-AU-FIRE-003 · Maternal exposure to fine particulate matter from a coal mine fire and birth outcomes

Year/country/type	2019; Australia; individualized exposure cohort	**Stage and environment**	open-cut mine fire; PM2.5; preterm birth; fetal growth
Chain	C3-C5	**DOI / URL**	https://doi.org/10.1016/j.envint.2019.03.028
Verification status	legacy full record retained	**Critical limitation**	null for studied birth outcomes; congenital anomalies were not studied

CIC-AU-DUST-001 · Upper Hunter Valley Particle Characterization Study

Year/country/type	2016; Australia; official receptor-modeling study	**Stage and environment**	open-cut mining; diesel equipment; regional ambient air; PM2.5; black carbon; elemental profiles
Chain	C2-C3	**DOI / URL**	https://www.environment.nsw.gov.au/sites/default/files/upper-hunter-valley-particle-characterization-study-final-report.pdf
Verification status	NSW final report verified	**Critical limitation**	study did not find a unique fugitive-coal-dust fingerprint and was not designed to quantify total PM10 coal dust

CIC-IN-WAT-001 · Environmental geochemistry and quality assessment of mine water of Jharia coalfield, India

Year/country/type	2012; India; primary field study	**Stage and environment**	mine water; TDS; sulfate; hardness; Fe; Mn; Ni; Pb
Chain	C1-C3	**DOI / URL**	https://doi.org/10.1007/s12665-011-1064-2
Verification status	EPA HERO metadata abstract and DOI verified	**Critical limitation**	92 mine-water samples characterize water quality; they do not establish human intake or health effects

CIC-IN-WAT-002 · Assessment of potability of minewater pumped out from Jharia Coalfield, India

Year/country/type	2022; India; primary field study	**Stage and environment**	underground mine-water pumping and treatment outlets; TDS; hardness; major ions; trace metals
Chain	C1-C3	**DOI / URL**	https://doi.org/10.1007/s11356-021-17918-0
Verification status	PubMed metadata and abstract verified	**Critical limitation**	samples were collected at treatment-facility outlets; not a population exposure study

CIC-IN-AIR-001 · Spatio-temporal variation of air pollutants around the coal mining areas of Jharia Coalfield, India

Year/country/type	2020; India; primary field study	**Stage and environment**	coal mining and fire area ambient air; particulate matter and gaseous pollutants
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1007/s10661-020-08324-z
Verification status	PubMed metadata and DOI verified	**Critical limitation**	source mixture includes fire mining transport and road dust; no linked individual health outcome

CIC-CN-FIRE-HG-001 · Dynamic mercury emissions from coal-fire monitoring boreholes in Wuda Coalfield

Year/country/type	2017; China; primary field study	**Stage and environment**	underground coal fires; mercury in borehole exhaust
Chain	C2	**DOI / URL**	https://doi.org/10.1016/j.coal.2017.08.013
Verification status	legacy metadata retained	**Critical limitation**	very high source concentrations are not population exposure concentrations

CIC-CN-FIRE-HG-002 · Mercury emission from underground coal fires in the mining goaf of the Wuda Coalfield, China

Year/country/type	2019; China; primary field study	**Stage and environment**	underground coal fires; mercury in vents and near-surface air
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1016/j.ecoenv.2019.109409
Verification status	metadata title authors and DOI verified	**Critical limitation**	local near-source measurements; no internal dose or health outcome

CIC-CN-WAT-001 · Hydrochemical characteristics of abandoned coal mines derived acid mine drainage in a typical karst basin

Year/country/type	2024; China; primary field study	**Stage and environment**	abandoned mines; acid mine drainage; pH; TDS; sulfate; iron; trace elements
Chain	C1-C3	**DOI / URL**	https://doi.org/10.1016/j.heliyon.2024.e31963
Verification status	open-access article metadata and abstract verified	**Critical limitation**	nine closed-mine sites in one karst basin; effect on receptors was not measured

CIC-CN-COMB-001 · Distribution and fate of environmentally sensitive elements (arsenic, mercury, stibium and selenium) in coal-fired power plants at Huainan, Anhui, China

Year/country/type	2012; China; primary material-balance study	**Stage and environment**	power-plant combustion and pollution control; As; Hg; Sb; Se partitioning among flue gas and solid by-products
Chain	C1-C2	**DOI / URL**	https://doi.org/10.1016/j.fuel.2011.12.052
Verification status	DOI and abstract verified	**Critical limitation**	two power plants; partitioning is not equivalent to off-site exposure or effect

CIC-CN-ASH-001 · Leachability of mercury in coal fly ash from coal-fired power plants in southwest China

Year/country/type	2022; China; primary leaching experiment	**Stage and environment**	fly-ash storage or reuse; mercury leaching
Chain	C1-C2	**DOI / URL**	https://doi.org/10.3389/fenvs.2022.887837
Verification status	open-access full article verified	**Critical limitation**	negative evidence for Hg leaching under tested conditions; cannot be generalized to other elements ashes or field settings

CIC-MN-AIR-001 · Air particulate matter pollution in Ulaanbaatar, Mongolia: determination of composition, source contributions and source locations

Year/country/type	2011; Mongolia; primary monitoring and receptor-modeling study	**Stage and environment**	domestic and power-plant coal combustion; urban air; fine and coarse PM; elemental composition; black carbon
Chain	C2-C3	**DOI / URL**	https://doi.org/10.5094/APR.2011.017
Verification status	open-access article metadata and abstract verified	**Critical limitation**	urban mixture includes coal biomass vehicles soil and episodic forest-fire smoke; not evidence about mine-site emissions

CIC-MN-AIR-002 · Three-year long source apportionment study of airborne particles in Ulaanbaatar using X-ray fluorescence and positive matrix factorization

Year/country/type	2019; Mongolia; primary monitoring and receptor-modeling study	**Stage and environment**	coal combustion; traffic; oil combustion; resuspended soil; PM2.5 and PM2.5-10; 16 elements; black carbon
Chain	C2-C3	**DOI / URL**	https://doi.org/10.4209/aaqr.2018.09.0351
Verification status	repository metadata methods and estimates verified	**Critical limitation**	source profiles are mixed; PMF attribution is model-based and not an individual exposure/effect chain

CIC-MN-DUST-001 · Source apportionment and spatial distribution of heavy metals in atmospheric settled dust of Ulaanbaatar, Mongolia

Year/country/type	2021; Mongolia; primary field study	**Stage and environment**	urban coal combustion; traffic; resuspended soil; As; Co; Cr; Cu; Ni; Pb; Zn in settled dust
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1007/s11356-021-13861-2
Verification status	PubMed metadata and abstract verified	**Critical limitation**	57 settled-dust samples and PCA attribution; not respirable personal exposure and not specific to coal mining

CIC-MN-MINE-001 · Arsenic and Heavy Metals Contamination of Soils Around Oyu Tolgoi and Tavan Tolgoi Mines

Year/country/type	2018; Mongolia; primary soil-screening study	**Stage and environment**	mine perimeter soils; As; Cd; Cr; Pb; Th; U; Zn; Cu; Ni
Chain	C1-C3	**DOI / URL**	https://doi.org/10.14419/ijet.v7i2.23.11955
Verification status	metadata and abstract verified; quality appraisal pending	**Critical limitation**	mixes a copper-gold mine with a coal mine; perimeter concentrations alone do not prove mine origin exposure or effect

CIC-MN-ROAD-001 · Dusty roads and disconnections: Perceptions of dust from unpaved mining roads in Mongolia's South Gobi province

Year/country/type	2015; Mongolia; qualitative field study	**Stage and environment**	coal haul roads and mining infrastructure; road dust as reported environmental and livelihood pressure
Chain	C0	**DOI / URL**	https://doi.org/10.1016/j.geoforum.2015.09.004
Verification status	article methods and scope verified	**Critical limitation**	interviews and observation document experience and concern but do not measure dust chemistry concentration or toxic effect

CIC-US-ASH-002 · Eight years after the coal ash spill – Fate of trace metals in the contaminated river sediments near Kingston, eastern Tennessee

Year/country/type	2019; USA; primary field and leaching study	**Stage and environment**	coal-ash impoundment failure and river deposition; As; Se; Hg and other trace elements in sediment
Chain	C1-C3	**DOI / URL**	https://doi.org/10.1016/j.apgeochem.2019.03.008
Verification status	DOI abstract methods and principal findings verified	**Critical limitation**	residual As and Se source attribution is strong; mostly acid-extractable material did not imply ready release to the water column

CIC-IN-WASH-001 · An investigation of the relationship between raw coal characteristics and effluent quality of Kedla and Rajrappa Washeries, Jharkhand, India

Year/country/type	2005; India; primary process-water study	**Stage and environment**	coal beneficiation and washery effluent; suspended solids; major ions; Mn; trace elements
Chain	C1-C2	**DOI / URL**	https://doi.org/10.1016/j.jenvman.2005.05.006
Verification status	PubMed metadata methods and results verified	**Critical limitation**	two washeries over six months; As Se Hg and Cd were present in coal but not detected in process water, an important negative result

CIC-CN-SOIL-001 · Soil heavy metals in a typical coal mining cluster of Northern China: Pollution, source apportionment, and eco-health risks

Year/country/type	2026; China; primary soil survey with modeled risk assessment	**Stage and environment**	open-pit mining cluster; industrial and traffic activity; Cd; Hg and other soil metals
Chain	C1-C3	**DOI / URL**	https://doi.org/10.1016/j.isci.2026.116835
Verification status	open-access article metadata and abstract verified	**Critical limitation**	88 soil samples; modeled health risk is not measured exposure or disease and mixed industrial-traffic sources dominate

CIC-AU-DUST-002 · Characterization of particulate emissions from Australian open-cut coal mines: Toward improved emission estimates

Year/country/type	2018; Australia; primary near-source and boundary measurement study	**Stage and environment**	open-cut mining activities; TSP; PM10; PM2.5; carbon; silica and mineral particles
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1080/10962247.2017.1415236
Verification status	full methods and results page verified	**Critical limitation**	three mines and limited-duration sampling; geological dust resembles mine dust and carbon is only an upper-bound coal indicator

CIC-AU-DUST-003 · Open cut black coal mining: Empirical verification of PM2.5 air emission estimation techniques

Year/country/type	2019; Australia; primary direct emission study	**Stage and environment**	haul roads and other open-cut activities; PM2.5 emission rates
Chain	C2	**DOI / URL**	https://doi.org/10.1016/j.atmosres.2018.10.008
Verification status	DOI abstract verified	**Critical limitation**	direct source measurements improve emission factors but do not establish community exposure or health effect

CIC-AU-HEALTH-001 · The health of Hunter Valley communities in proximity to coal mining and power generation, general practice data, 1998–2010

Year/country/type	2013; Australia; comparative health-record study	**Stage and environment**	coal mining and power-generation region; patterns of general-practice illness
Chain	C0-C5	**DOI / URL**	https://doi.org/10.1071/NB12109
Verification status	PubMed metadata and abstract verified	**Critical limitation**	proximity and regional comparison do not isolate coal-mine dust from power generation or other confounders

CIC-AU-FIRE-004 · Long-term impacts of coal mine fire-emitted PM2.5 on hospitalisation: a longitudinal analysis of the Hazelwood Health Study

Year/country/type	2022; Australia; individualized exposure data-linkage cohort	**Stage and environment**	open-cut mine fire; PM2.5; respiratory and other hospitalisations
Chain	C3-C5	**DOI / URL**	https://doi.org/10.1093/ije/dyab249
Verification status	PubMed full abstract and effect estimates verified	**Critical limitation**	positive respiratory associations and explicit null outcomes apply to a six-week fire event, not routine mining

CIC-CA-SE-001 · Evidence of long-range transport of selenium downstream of coal mining operations in the Elk River Valley, Canada

Year/country/type	2024; Canada; primary long-term monitoring and source-attribution study	**Stage and environment**	surface coal mining and waste rock; selenium in river water and loads
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1021/acs.estlett.4c00222
Verification status	USGS metadata abstract and DOI verified	**Critical limitation**	supports transport over more than 575 river km and aquatic risk; does not itself measure biological effect

CIC-CA-SE-002 · Regional scale selenium loading associated with surface coal mining, Elk Valley, British Columbia, Canada

Year/country/type	2015; Canada; primary monitoring and watershed-model study	**Stage and environment**	surface mining and waste-rock piles; selenium loading
Chain	C1-C3	**DOI / URL**	https://doi.org/10.1016/j.scitotenv.2015.06.040
Verification status	PubMed metadata and DOI verified	**Critical limitation**	SPARROW source model and watershed associations; biological effects require linked evidence

CIC-ZA-WAT-001 · Contamination of the water supply to the town of Carolina, Mpumalanga, January 2012

Year/country/type	2013; South Africa; primary event investigation	**Stage and environment**	coal-mine seepage; coal handling runoff; storm flushing; pH; Fe; Al; Mn; sulfate
Chain	C1-C4	**DOI / URL**	https://doi.org/10.1590/sajs.2013/20120112
Verification status	publisher full abstract and open article verified	**Critical limitation**	event pathway is strongly reconstructed but individual dose and clinical effects were not measured

CIC-PL-WAT-001 · The influence of waters from hard-coal mines on the hydrochemical relations of Upper Silesian Coal Basin rivers

Year/country/type	1997; Poland; regional monitoring synthesis	**Stage and environment**	underground hard-coal mine-water discharge; chloride; sulfate; salinity; radium noted
Chain	C1-C3	**DOI / URL**	https://www.geographiapolonica.pl/article/item/7880.html
Verification status	journal metadata abstract and full-text link verified	**Critical limitation**	historic 1994 load estimates need a separate current series; ecological and human effects not measured in this paper

CIC-PL-WAT-002 · The effect of saline mine waters discharge from hard coal mine on the ecological state of the Vistula River

Year/country/type	2014; Poland; primary field study	**Stage and environment**	hard-coal mine-water discharge; salinity and physicochemical water properties
Chain	C2-C5	**DOI / URL**	https://doi.org/10.1515/ahr-2014-0011
Verification status	PDF methods scope and DOI verified	**Critical limitation**	one-kilometre river reach sampled in 2011–2012; limited spatial and temporal generalizability

CIC-ID-AMD-001 · The Forming of Acid Mine Drainage Based on Characteristics of Coal Mining, East Kalimantan, Indonesia

Year/country/type	2023; Indonesia; primary coal and geochemical characterization study	**Stage and environment**	coal exposure; stockpiles; potential acid generation; sulfur and acid-generation potential
Chain	C1-C2	**DOI / URL**	https://doi.org/10.12911/22998993/162551
Verification status	open article metadata methods and DOI verified	**Critical limitation**	15 coal samples characterize potential rather than measured off-site drainage exposure or effect

CIC-US-FIRE-001 · Centralia Mine Fire Mercury Study

Year/country/type	2008; USA; official primary monitoring report	**Stage and environment**	underground coal-mine fire; Hg; CO; SO2; H2S; TSP; metals in ambient air
Chain	C2-C3	**DOI / URL**	https://www.pa.gov/content/dam/copapwp-pagov/en/dep/documents/business/land/mining/abandonedminereclamation/amlprograminformation/centralia/documents/centraliagasmercurystudy.pdf
Verification status	legacy full PDF and tables checked	**Critical limitation**	2006–2007 monitoring found average concentrations around background or below then-applicable standards; no individual health or pregnancy outcome

CIC-RU-AIR-001 · Kuzbass state environmental report 2011

Year/country/type	2012; Russia / Kuzbass; official regional monitoring report	**Stage and environment**	regional coal mining and industrial ambient air; city monitoring exceedances and pollutant observations
Chain	C3	**DOI / URL**	https://kuzbasseco.ru/wp-content/uploads/2025/03/doklad_ecolog_2011_final.pdf
Verification status	legacy full PDF and table checked	**Critical limitation**	city-level monitoring cannot attribute a measured concentration to a named mine fire or individual pregnancy exposure

CIC-RU-EPID-001 · Gulyaeva et al.: anthropogenic load, genes and congenital malformations

Year/country/type	2021; Russia / Kuzbass; regional screening study	**Stage and environment**	industrial-region population; composite anthropogenic load and congenital malformation prevalence
Chain	C0-C5	**DOI / URL**	https://doi.org/10.47470/0016-9900-2021-100-7-658-662
Verification status	legacy full paper and table checked	**Critical limitation**	ecological city-level gradient; does not identify a coal-specific chemical source-pathway-dose chain

CIC-RU-EPID-002 · Gulyaeva et al.: CYP/GSTM polymorphisms and congenital malformations

Year/country/type	2018; Russia / Kuzbass; case-control study	**Stage and environment**	clinical population in industrial region; genetic susceptibility markers and congenital malformations
Chain	C4-C5	**DOI / URL**	https://doi.org/10.18821/0016-9900-2018-97-7-585-590
Verification status	legacy full paper checked	**Critical limitation**	clinical case-control evidence does not reconstruct territorial coal-pollutant exposure

CIC-US-ASH-003 · Evidence for Coal Ash Ponds Leaking in the Southeastern United States

Year/country/type	2016; USA; primary multi-site hydrogeochemical and isotope study	**Stage and environment**	coal-ash impoundment storage; B; Sr; sulfate; Ca; Mn; Fe; Se; As; Mo; V in groundwater and surface water
Chain	C1-C3	**DOI / URL**	https://doi.org/10.1021/acs.est.6b01727
Verification status	publisher abstract methods numerical results and DOI verified	**Critical limitation**	24 impacted surface-water samples and 165 monitoring wells across selected sites; leakage evidence does not itself establish human intake or disease

CIC-US-ASH-004 · Selenium bioaccumulation in fish exposed to coal ash at the Tennessee Valley Authority Kingston spill site

Year/country/type	2014; USA; primary field bioaccumulation study	**Stage and environment**	coal-ash spill and residual ash; selenium in whole fish and fillets
Chain	C2-C5	**DOI / URL**	https://doi.org/10.1002/etc.2673
Verification status	ORNL metadata abstract findings and DOI verified	**Critical limitation**	fish selenium was elevated relative to reference locations but below considered risk thresholds and did not increase over five years

CIC-US-ASH-005 · Examination of mercury contamination from a recent coal ash spill into the Dan River

Year/country/type	2021; USA; primary sediment and biota study	**Stage and environment**	coal-ash spill; mercury in sediment aquatic invertebrates and fish
Chain	C2-C5	**DOI / URL**	https://doi.org/10.1016/j.ecoenv.2020.111469
Verification status	open-access article abstract and DOI verified	**Critical limitation**	negative evidence: no longitudinal or temporal Hg increase in biota within the first three years; buried ash may remain

CIC-IN-WAT-003 · Impact of coal mining activities on the water quality: A case study of Jharia Coalfield, Dhanbad, India

Year/country/type	2026; India; primary hydrogeochemical field study with modeled health risk	**Stage and environment**	active collieries; washeries; overburden dumps; river; TDS; hardness; BOD; Al; Cd; Cr; Ni and major ions
Chain	C1-C4	**DOI / URL**	https://doi.org/10.1016/j.envres.2026.123951
Verification status	publisher full abstract study sites and DOI verified	**Critical limitation**	15 locations and source attribution by diagrams/correlations; modeled health risk is not measured dose or disease and washery versus AMD contributions remain imperfectly separated

CIC-IN-WASH-002 · Heavy metal pollution due to coal washery effluent and its decontamination using a macrofungus Pleurotus ostreatus

Year/country/type	2017; India; primary effluent analysis and laboratory remediation experiment	**Stage and environment**	coal beneficiation effluent; suspended particles; Mn; Zn; Ni; Cu; Co; Cr; Fe; Pb
Chain	C1-C2	**DOI / URL**	https://doi.org/10.1016/j.ecoenv.2017.07.001
Verification status	EPA HERO metadata full abstract numerical removal results and DOI verified	**Critical limitation**	effluent from one Dhanbad washery and fungal laboratory endpoints; predicted aquatic harm is not a field effect study

CIC-MN-COMB-001 · Emission Characteristics of Particulate Matter, Volatile Organic Compounds, and Trace Elements from the Combustion of Coals in Mongolia

Year/country/type	2018; Mongolia; controlled combustion experiment	**Stage and environment**	domestic coal combustion; PM10; submicron PM; VOCs; metals; anions
Chain	C1-C2	**DOI / URL**	https://doi.org/10.3390/ijerph15081706
Verification status	full article metadata design emission factors and DOI verified	**Critical limitation**	three coals burned at fixed heat flux in a calorimeter; emission factors are source characterization not actual household exposure

CIC-MN-SOILWAT-001 · Ecological state of soils and waters in the mining areas of South Gobi province of Mongolia

Year/country/type	2026; Mongolia; primary landscape-geochemical field study	**Stage and environment**	coal and copper mining landscapes; nearby farms; Na; F; Mg; chloride; sulfate; Ni; Cu; Zn; As in wells boreholes and soils
Chain	C1-C3	**DOI / URL**	https://doi.org/10.19047/0136-1694-2026-127-160-188
Verification status	journal citation abstract and DOI verified	**Critical limitation**	study combines Tavan Tolgoi coal and Oyu Tolgoi copper landscapes; local exceedances cannot automatically be attributed to coal mining alone

CIC-MN-DUST-002 · Monitoring Aeolian Erosion from Surface Coal Mines in the Mongolian Gobi Using InSAR Time Series Analysis

Year/country/type	2024; Mongolia; remote-sensing and trajectory study	**Stage and environment**	open-pit coal mining and stockpiles; aeolian erosion and coal-dust transport footprint
Chain	C2-C3	**DOI / URL**	https://doi.org/10.3390/rs16214111
Verification status	open full article methods and scope verified	**Critical limitation**	detects surface change and modeled transport footprint but does not chemically measure airborne concentration personal exposure or health effect

CIC-RU-WAT-001 · Sulfate reduction in the underground horizons of a flooded coal mine in Kuzbass

Year/country/type	2020; Russia / Kuzbass; primary long-term hydrochemical and microbiological study	**Stage and environment**	flooded Severnaya coal mine and discharge well; H2S; sulfate reduction; sulfur-oxidizing microbial community
Chain	C1-C3	**DOI / URL**	https://doi.org/10.31857/S0026365620050183
Verification status	full Russian article methods measurements and DOI verified	**Critical limitation**	one flooded mine system; sulfur flux at the well discharge does not establish downstream population exposure or regional representativeness

CIC-CA-SE-003 · Reproductive success early life stage development and survival of westslope cutthroat trout exposed to elevated selenium in an area of active coal mining

Year/country/type	2008; Canada; primary field-exposure and laboratory-rearing effect study	**Stage and environment**	surface coal mining and selenium-bearing drainage; selenium in trout eggs; fertilization; alevin mortality; fry viability
Chain	C2-C5	**DOI / URL**	https://doi.org/10.1021/es072034d
Verification status	PubMed abstract study design numerical tissue concentrations outcomes and DOI verified	**Critical limitation**	eggs came from 12 exposed-site and 16 reference-site fish and were reared in the laboratory; thresholds are species and study specific and do not alone quantify population-level decline

CIC-CA-SE-004 · Bioaccumulation and effects of selenium from surface coal mining in an aquatic songbird

Year/country/type	2022; Canada; primary multi-media field exposure and reproductive endpoint study	**Stage and environment**	surface coal mining and downstream food web; selenium in water periphyton invertebrates dipper blood eggs and feathers; clutch size; hatching success
Chain	C2-C5	**DOI / URL**	https://doi.org/10.1016/j.envres.2022.112702
Verification status	PubMed abstract media endpoints negative finding and DOI verified	**Critical limitation**	sampled sites and endpoints showed exposure but no significant impairment of hatching success or clutch size at the time of study; this does not exclude other species endpoints or future effects

CIC-CN-BIO-001 · Potentially toxic metals and the risk to children's health in a coal mining city: An investigation of soil and dust levels bioaccessibility and blood lead levels

Year/country/type	2020; China; primary urban soil dust bioaccessibility and child biomonitoring study	**Stage and environment**	coal-mining city with mining combustion traffic and other urban sources; As; Co; Cr; Cu; Mn; Ni; Pb; Sr; Zn; Ca; Fe; Mg in soil and street dust; blood lead
Chain	C3-C4	**DOI / URL**	https://doi.org/10.1016/j.envint.2020.105788
Verification status	PubMed full abstract sample size age-stratified blood lead results and DOI verified	**Critical limitation**	229 children provide an internal-dose marker but the urban mixture and cross-sectional design do not assign each child's blood lead specifically to coal mining or prove a health effect

CIC-CN-OCC-001 · A prospective cohort study among new Chinese coal miners: the early pattern of lung function change

Year/country/type	2005; China; prospective occupational cohort with repeated dust-area sampling and spirometry	**Stage and environment**	underground coal mining; total and respirable mine dust; longitudinal FEV1
Chain	C4-C5	**DOI / URL**	https://doi.org/10.1136/oem.2005.020271
Verification status	PubMed and open-access abstract cohort sizes follow-up design and DOI verified	**Critical limitation**	area rather than personal dust sampling and early non-linear FEV1 trajectory complicate dose-response interpretation; smoking modified the decline

CIC-MN-EPID-001 · Coal burning-derived SO2 and traffic-derived NO2 are associated with persistent cough and current wheezing symptoms among schoolchildren in Ulaanbaatar Mongolia

Year/country/type	2019; Mongolia; cross-sectional schoolchild exposure and symptom study	**Stage and environment**	urban household coal combustion and traffic in a basin; outdoor SO2 and NO2; persistent cough; current wheeze
Chain	C3-C5	**DOI / URL**	https://doi.org/10.1186/s12199-019-0817-5
Verification status	open full article design sample size effect estimates and DOI verified	**Critical limitation**	area-level outdoor measurements and questionnaire symptoms do not provide personal chemical dose; coal traffic household heating and district characteristics coexist

CIC-US-WAT-003 · Effects of Abandoned Coal-Mine Drainage on Streamflow and Water Quality in the Mahanoy Creek Basin Pennsylvania 2001

Year/country/type	2004; USA; official primary watershed field investigation	**Stage and environment**	abandoned anthracite mines and mine-tunnel drainage; acidity; sulfate; dissolved Fe; Al; Mn; stream loading
Chain	C1-C3	**DOI / URL**	https://pubs.usgs.gov/sir/2004/5291/
Verification status	USGS report page abstract site M19/S15 measurements and flow data verified	**Critical limitation**	Centralia Mine Tunnel drains a mined watershed but the study does not separate chemistry caused by historical mining from any incremental effect of the underground fire; no individual human dose

CIC-DE-WAT-001 · Geochemical signatures of lignite mining products in sediments downstream a fluvial-lacustrine system

Year/country/type	2021; Germany; primary 190-km river-sediment field transect	**Stage and environment**	open-cast lignite mining; pyrite weathering; post-mining groundwater rise; Fe; sulfate; sulfur; Ni; Co; Al in the River Spree system
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1016/j.scitotenv.2020.143942
Verification status	publisher abstract EPA HERO metadata study distance findings and DOI verified	**Critical limitation**	sediment signatures trace mining products but do not measure drinking-water intake or health; urban Zn Cr Pb Cu dominate the final Berlin signature

CIC-DE-ECO-001 · Effects of mining activities on fish communities and food web dynamics in a lowland river

Year/country/type	2024; Germany; primary river food-web and fish-community field study	**Stage and environment**	lignite-mining iron load in the River Spree and reservoir retention; iron flocculation; benthic invertebrates; fish abundance biomass and diet
Chain	C3-C5	**DOI / URL**	https://doi.org/10.1002/ece3.11111
Verification status	open full article field comparisons numerical endpoints limitations and DOI verified	**Critical limitation**	three upstream and three downstream locations sampled at one sampling time; reservoir dam and water-temperature differences prevent attribution of every biological difference to iron alone

CIC-AU-BLAST-001 · Emissions from Blasting in Open Cut Coal Mining

Year/country/type	2013; Australia; industry-funded primary fence-line monitoring project	**Stage and environment**	open-cut drilling and blasting with ammonium-nitrate explosives; NO2; blast fumes; hydrocarbons; diesel and regional NO2 sources
Chain	C2-C3	**DOI / URL**	https://www.acarp.com.au/abstracts.aspx?repId=C18034
Verification status	ACARP project abstract monitoring period methods and attribution conclusion verified	**Critical limitation**	full numerical report is access-restricted; industry-funded study found multiple NO2 sources and did not establish community dose or health effect

CIC-AU-TRAN-001 · Western–Metropolitan Rail Systems Coal Dust Monitoring Program

Year/country/type	2013; Australia; government-operated pre/post mitigation corridor monitoring	**Stage and environment**	rail transport of coal to Port of Brisbane; PM; deposited dust composition; coal particles; resuspended mineral and urban dust
Chain	C2-C3	**DOI / URL**	https://www.qld.gov.au/environment/management/monitoring/air/air-programs/management/monitoring
Verification status	Queensland government program summary reports and peer-review statement verified	**Critical limitation**	specific southern Queensland corridor and monitoring periods; compliance and source mix do not prove zero short-duration exposure at every coal-transport route

CIC-US-STOR-001 · Effects of coal pile runoff on stream quality and macroinvertebrate communities

Year/country/type	1985; USA; primary runoff stream and macrobenthos field study	**Stage and environment**	coal storage piles; acidic runoff; Mn; Al; Zn; Fe; sulfate; stream macroinvertebrates
Chain	C1-C5	**DOI / URL**	https://doi.org/10.1111/j.1752-1688.1985.tb00155.x
Verification status	journal abstract sampling design chemistry ecological conclusion and DOI verified	**Critical limitation**	two Maryland storage areas sampled in 1982–1983; periodic drought and organic inputs also shaped the invertebrate community and prevent a single-stressor interpretation

CIC-US-BEN-001 · Acute Health Effects After the Elk River Chemical Spill West Virginia January 2014

Year/country/type	2017; USA; descriptive multi-source public-health investigation	**Stage and environment**	storage and accidental release of coal-beneficiation chemicals into municipal water source; crude MCHM; PPH; treated drinking water; acute reported symptoms
Chain	C2-C5	**DOI / URL**	https://doi.org/10.1177/0033354917691257
Verification status	open full article spill quantity water concentrations case review survey estimates limitations and DOI verified	**Critical limitation**	three descriptive datasets did not quantify individual dose or establish causation; odor awareness recall media attention and heterogeneous case definitions could affect symptom reporting

CIC-US-BEN-002 · National Toxicology Program research program on chemicals spilled into the Elk River in West Virginia

Year/country/type	2016; USA; official multi-assay toxicology program synthesis	**Stage and environment**	coal-beneficiation chemical spill toxicology follow-up; MCHM and minor mixture components; developmental dermal airway cellular and model-organism endpoints
Chain	C0-C5	**DOI / URL**	https://ntp.niehs.nih.gov/research/topics/wvspill
Verification status	NTP final program page collective conclusion chemical inventory and study links verified	**Critical limitation**	experimental toxicology and screening-level evaluation do not reconstruct individual human dose during the spill or invalidate mild symptoms reported in descriptive surveillance

CIC-CA-N-001 · Nitrate release from waste rock dumps in the Elk Valley British Columbia Canada

Year/country/type	2017; Canada; primary chemical and stable-isotope field investigation	**Stage and environment**	surface coal mining; blasting; waste-rock disposal; nitrate from explosive residues; unsaturated waste-rock dumps; rock-drain water
Chain	C1-C3	**DOI / URL**	https://doi.org/10.1016/j.scitotenv.2017.05.253
Verification status	publisher abstract PubMed record field design isotope attribution and DOI verified	**Critical limitation**	identifies source and release pathway but does not measure downstream human dose or an ecological effect; dump-specific leaching behaviour should not be universalised

CIC-US-N-001 · Excess Nitrate Export in Mountaintop Removal Coal Mining Watersheds

Year/country/type	2019; USA; primary multi-scale watershed monitoring and isotope study	**Stage and environment**	mountaintop-removal coal mining; blasting; valley fills; reclamation; nitrate export; explosive residue; fertilizer; rock-derived nitrogen; altered nitrogen cycling
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1029/2019JG005174
Verification status	open full article methods results numerical fluxes isotope interpretation limitations and DOI verified	**Critical limitation**	mining-associated nitrate is established but isotope signatures did not uniquely identify explosives or fertilizer; persistent post-mining export cannot be assigned to explosive residue alone

CIC-CA-N-002 · The Effects of Explosives Use on Water Quality at Fording Coal Limited

Year/country/type	1983; Canada; official one-year coal-mine water-quality field study	**Stage and environment**	surface coal mining; ammonium-nitrate explosives; mine drainage; nitrogen species in mine drainage and the Fording River; algal-growth concern
Chain	C1-C3	**DOI / URL**	https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/monitoring-water-quality/wq_bc_mining_explosives_wq.pdf
Verification status	official British Columbia report identity study period object and stated purpose verified	**Critical limitation**	historical report; numerical tables and effect interpretation require direct table-level extraction before use in a quantitative claim

CIC-US-BEN-003 · Investigation of MCHM transport mechanisms and fate: implications for coal beneficiation

Year/country/type	2015; USA; laboratory batch and column fate study	**Stage and environment**	routine fine-coal beneficiation; MCHM volatilization; sorption to coal and tailings; leaching and desorption
Chain	C1-C2	**DOI / URL**	https://doi.org/10.1016/j.chemosphere.2015.01.054
Verification status	PubMed bibliographic record abstract experimental processes conclusion and DOI verified	**Critical limitation**	laboratory fate experiments support retention under studied conditions but do not survey every operating plant spill pathway tailings impoundment or long-term field discharge

CIC-CN-BEN-001 · Distribution and Migration of Trace Elements during Flotation in Ge-Rich Low-Rank Coal from Wulantuga Coal Mine Inner Mongolia China

Year/country/type	2022; China; laboratory flotation and release experiment on mine-specific coal	**Stage and environment**	coal preparation and flotation; argillation; trace-element partitioning into cleaned coal tailings and process water
Chain	C1-C2	**DOI / URL**	https://doi.org/10.1021/acsomega.1c05487
Verification status	open full article experimental design tables element-specific release values limitations and DOI verified	**Critical limitation**	bench-scale release into coal-preparation water is not a measurement of discharge beyond a plant and does not establish receptor exposure or toxicity

CIC-IN-ASH-001 · Heavy metal contamination of groundwater due to fly ash disposal of coal-fired thermal power plant Parichha Jhansi India

Year/country/type	2016; India; seasonal groundwater field survey around an unlined ash pond	**Stage and environment**	coal combustion; wet fly-ash disposal; Pb Ni Cr Mn Fe in coal fly ash and village groundwater
Chain	C1-C3	**DOI / URL**	https://doi.org/10.1080/23311916.2016.1179243
Verification status	DOAJ record open article abstract sites seasons concentration ranges and DOI verified	**Critical limitation**	spatial groundwater survey without an isotope or hydrologic source tracer; exceedance near an ash pond does not allocate every measured metal exclusively to fly ash

CIC-IN-ASH-002 · Assessment of groundwater pollution from ash ponds using stable and unstable isotopes around the Koradi and Khaperkheda thermal power plants Maharashtra India

Year/country/type	2015; India; primary hydrochemical and multi-isotope source-attribution field study	**Stage and environment**	coal combustion ash ponds; brick kilns; domestic wastewater; groundwater salinity sulfate and water-source tracers
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1016/j.scitotenv.2015.02.083
Verification status	EPA HERO bibliographic record abstract isotope findings DOI and study design verified	**Critical limitation**	site-specific attribution study; low ash-pond influence at these plants does not show that all ash ponds are contained or harmless

CIC-ZA-ASH-001 · Contamination of groundwater by leachate plumes from coal fly ash: a case study of Matimba power station ash dump Limpopo province South Africa

Year/country/type	2025; South Africa; open-access MSc field thesis	**Stage and environment**	coal combustion; dry ash disposal; TDS EC sulfate chloride sodium magnesium manganese iron and groundwater facies
Chain	C1-C3	**DOI / URL**	https://hdl.handle.net/10210/518526
Verification status	university repository record abstract sampling design main findings usage indices and persistent handle verified	**Critical limitation**	master's thesis rather than independent peer-reviewed article; abstract-level extraction does not establish household ingestion or health outcome and exact borehole data require full-table audit

CIC-CN-COMB-002 · Distribution co-removal and emission characteristic of trace elements in 320 MW coal-fired power plant

Year/country/type	2017; China; full-scale simultaneous field mass-balance study	**Stage and environment**	coal combustion; SCR ESP and wet flue-gas desulfurization; Cr Mn Co Ni Cu Zn As Mo Cd Sb Ba Pb in bottom ash fly ash WFGD removal and stack gas
Chain	C1-C3	**DOI / URL**	https://doi.org/10.11949/j.issn.0438-1157.20170141
Verification status	open journal abstract plant configuration EPA Method 29 distribution removal stack ranges and DOI verified	**Critical limitation**	one 320 MW unit and twelve elements; stack concentration is not ambient concentration personal exposure or health effect; captured mass becomes a solid or liquid waste-management burden

CIC-IN-COMB-001 · Distribution of trace elements in coal and combustion residues from five thermal power plants in India

Year/country/type	2011; India; primary multi-plant coal and ash characterization study	**Stage and environment**	coal combustion and residue generation; Pb Cu Cd Zn Fe Mn Cr Ni Mg Li Co Hg As in feed coal fly ash and bottom ash
Chain	C1-C2	**DOI / URL**	https://doi.org/10.1016/j.coal.2011.03.008
Verification status	publisher abstract methods concentration ranges partitioning findings and DOI verified	**Critical limitation**	measures coal and collected ash rather than stack emissions leaching ambient transport or receptor exposure; enrichment in fly ash is a waste characterization not a health-risk estimate

CIC-RU-WAT-002 · Environmental consequences of mine closures in Kuzbass and their monitoring

Year/country/type	2015; Russia / Kuzbass; mine-closure hydrogeological and hydrochemical monitoring synthesis	**Stage and environment**	closed coal mines; pumped or discharging mine water; receiving rivers; suspended solids BOD COD Fe Mn Cu and pre-existing river contamination
Chain	C1-C3	**DOI / URL**	https://cyberleninka.ru/article/n/ekologicheskie-posledstviya-zakrytiya-shaht-v-kuzbasse-i-ih-monitoring
Verification status	article identity authors monitoring scope named mines rivers and reported upstream exceedances verified	**Critical limitation**	monitoring synthesis draws partly on a 2014 institutional report; values expressed as multiples of regulatory limits rather than complete concentrations and flows; upstream pollution prevents simple before-after attribution

CIC-ID-WAT-001 · Acid Mine Drainage in a Tropical Environment: A Case Study from Bukit Coal Mine Site in South Sumatra Indonesia

Year/country/type	2018; Indonesia; primary field mine-water and treatment-system study in IMWA proceedings	**Stage and environment**	open-pit coal mining; pit lakes; stockpile drainage; passive treatment; pH sulfate Al Fe Mn and other trace elements
Chain	C1-C3	**DOI / URL**	https://www.imwa.info/docs/imwa_2018/IMWA2018_Gautama_611.pdf
Verification status	open full paper named pits seasonal chemistry treatment inlet-intermediate-outlet values and study limitations verified	**Critical limitation**	mine-site water and treatment measurements do not establish receiving-water concentration ecological exposure or human health effect; proceedings paper is not an independent regulatory audit

CIC-ID-WAT-002 · Metals Distribution in River Sediment from Open-Pit Coal Mine Activity

Year/country/type	2023; Indonesia; primary river-sediment field study in IMWA proceedings	**Stage and environment**	active and inactive open-pit coal mines; mine-water treatment effluents; Fe Mn Pb Cr and Ni in Lati River sediment
Chain	C1-C3	**DOI / URL**	https://www.imwa.info/docs/imwa_2023/IMWA2023_Farahnaz_159.pdf
Verification status	open full paper 15.4 km transect 15 composite sediment stations 10 treatment-plant outlets ICP-MS values spatial analysis and funding statement verified	**Critical limitation**	sediment accumulation was not paired with organism tissue toxicity or health outcomes; geological background and multiple mine outlets complicate allocation to one operator or discharge; company environmental department participated in the study

CIC-ID-TRN-001 · Distribution and density of coal spills and bioaccumulation factors of metals in fish at a ship-to-ship coal transfer area

Year/country/type	2026; Indonesia; primary marine field study	**Stage and environment**	barge-to-vessel coal transshipment; marine coal spills; coal debris Fe Mn Zn Cu Pb Cd As and Hg in sediment water fish and plankton
Chain	C1-C4	**DOI / URL**	https://doi.org/10.1016/j.rsma.2026.105207
Verification status	publisher bibliographic record DOI study area sampling design abstract numerical BAF and BSAF ranges and principal findings verified	**Critical limitation**	abstract-level extraction does not provide all concentration tables reference-site design species-specific thresholds or confounder adjustment; bioaccumulation is not itself a demonstrated adverse effect or human dose

CIC-US-FIRE-002 · Problems in the Control of Anthracite Mine Fires: A Case Study of the Centralia Mine Fire (August 1980)

Year/country/type	1983; USA; U.S. Bureau of Mines Report of Investigations 8799	**Stage and environment**	underground anthracite mine fire beneath an inhabited borough; fire propagation heat subsidence fumes and carbon-monoxide surveillance
Chain	C0-C2	**DOI / URL**	https://stacks.cdc.gov/view/cdc/10644
Verification status	CDC/NIOSH repository bibliographic record full-report identity scope Centralia control options and documented residential monitoring response verified	**Critical limitation**	documents hazard recognition monitoring and engineering decisions but does not by itself provide an epidemiological causal estimate; detector installation is not proof that every monitored home had harmful CO concentrations

CIC-CA-N-003 · Growth of Coal Mining Operations in the Elk River Valley Canada Linked to Increasing Solute Transport of Se Nitrate and Sulfate into the Transboundary Koocanusa Reservoir

Year/country/type	2023; Canada / USA; peer-reviewed paired-watershed trend and load study	**Stage and environment**	open-pit coal mining; waste rock; transboundary river transport; nitrate plus nitrite selenium and sulfate
Chain	C2-C3	**DOI / URL**	https://doi.org/10.1021/acs.est.3c05090
Verification status	USGS publication record DOI paired-watershed design flow-normalized trend periods concentration and load changes verified	**Critical limitation**	co-transported solutes were analysed together; the study establishes watershed-scale transport but not a nitrate-specific biological effect individual dose or source split among individual mines

CIC-CA-N-004 · Elk Valley Water Quality Plan: nitrate and sulphate aquatic-effects benchmark derivation

Year/country/type	2014; Canada; site-specific controlled-toxicity evidence and management benchmark	**Stage and environment**	mine-related nitrate in surface water; nitrate-N direct aqueous toxicity modified by hardness
Chain	C3-C5	**DOI / URL**	https://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/mining-smelt-energy/area-based-man-plan/evwq_full_plan.pdf
Verification status	official provincial-hosted plan receptor species test types effect levels hardness adjustment and benchmark basis verified	**Critical limitation**	benchmarks rely partly on company-commissioned site-water tests and predict controlled-test effects; they are not field proof that nitrate caused an observed community or fish-population change in the Elk Valley

CIC-AU-FIRE-005 · Most respiratory symptoms have resolved 9 years after PM2.5 exposure from the Hazelwood coal mine fire

Year/country/type	2026; Australia; longitudinal exposed-comparison adult cohort	**Stage and environment**	open-cut brown-coal mine fire; PM2.5; wheeze; dyspnea; chest tightness; cough; phlegm; nasal symptoms
Chain	C3-C5	**DOI / URL**	https://doi.org/10.1097/EE9.0000000000000450
Verification status	PubMed and open full article cohort waves sample sizes exposure reconstruction results null outcomes DOI and conflicts verified	**Critical limitation**	follow-up subsample was enriched for asthma and smaller than baseline; exposure was modelled from time-location histories; persistence or resolution of symptoms does not describe unmeasured diseases

CIC-IN-AIR-002 · PM2.5-bound trace elements in a critically polluted industrial coal belt of India: seasonal patterns source identification and human health risk assessment

Year/country/type	2021; India; year-long ambient filter chemistry and modelled risk assessment	**Stage and environment**	coalfield fires mining transport and resuspended road dust; PM2.5-bound Fe Mn Cu Zn Cr Pb Co Ni Cd and As
Chain	C2-C4	**DOI / URL**	https://doi.org/10.1007/s11356-021-12876-z
Verification status	PubMed abstract sampling period mean PM2.5 element order source-analysis statement and modelled risk conclusions verified	**Critical limitation**	PCA and correlation identify a source mixture rather than fire-only attribution; HQ HI and excess-cancer-risk calculations are model outputs not measured internal dose or observed disease

CIC-CN-FIRE-HG-003 · Mercury emission from spontaneously ignited coal gangue hill in Wuda coalfield Inner Mongolia China

Year/country/type	2016; China; primary in-situ vent monitoring study	**Stage and environment**	spontaneously burning coal-gangue waste pile; gaseous mercury at combustion vents
Chain	C1-C2	**DOI / URL**	https://doi.org/10.1016/j.fuel.2016.05.092
Verification status	publisher bibliographic record DOI hill dimensions sampling design number of measurements and concentration range verified	**Critical limitation**	vent concentrations at a burning waste pile are source measurements not residential ambient concentration inhaled dose or health effect; mercury alone does not represent the complete emission mixture

CIC-CA-N-005 · Fording River Operations Local Aquatic Effects Monitoring Program 2023

Year/country/type	2024; Canada; operator-commissioned field aquatic monitoring report	**Stage and environment**	open-pit coal mining and water treatment; nitrate and co-occurring mine-related constituents; benthic invertebrate community
Chain	C3-C5	**DOI / URL**	https://www.glencore.ca/.rest/api/v1/documents/19195851bd2ee7b13b2a36fe447927ab/Fording%2BRiver%2BOperations%2BLocal%2BAquatic%2BEffects%2BMonitoring%2BProgram%2B2023.pdf
Verification status	report study question field stations before-after and upstream-downstream comparisons and stated nitrate interpretation verified	**Critical limitation**	operator-commissioned monitoring; nitrate selenium nickel cadmium sulphate flow habitat and treatment effects coexist; finding that nitrate is not the primary cause is a weight-of-evidence interpretation rather than a nitrate-only field experiment

CIC-GLOBAL-BEN-001 · Development Document for Interim Final Effluent Guidelines and New Source Performance Standards for the Coal Mining Category

Year/country/type	1976; Global; official multi-facility technical survey	**Stage and environment**	coal preparation and wet cleaning; process water suspended solids and facility water circuits
Chain	C1-C2	**DOI / URL**	https://www.epa.gov/sites/default/files/2014-08/documents/coal_mining_dd_int_final_1976_057a.pdf
Verification status	EPA technical survey scope and reported preparation-facility water-circuit finding verified	**Critical limitation**	historical US industry survey; process configurations and regulation have changed; closed-circuit reporting is not proof of zero release and the document does not provide a modern chemical-specific receptor chain

CIC-MN-BIO-001 · Environmental health survey for children residing near mining areas in South Gobi Mongolia

Year/country/type	2021; Mongolia; cross-sectional child biomonitoring study	**Stage and environment**	mixed mining household fuel and domestic exposure setting; blood lead cadmium mercury; hair mercury; urine total arsenic
Chain	C3-C4	**DOI / URL**	https://doi.org/10.1186/s41182-021-00326-6
Verification status	open full text sites sample size laboratory QA values alternative-source discussion and limitations verified	**Critical limitation**	one-time sample of 118 children without matched environmental air soil and water samples; the three soums differ in coal copper-gold and small-scale mining plus household sources so biomarkers cannot be assigned specifically to Tavan Tolgoi coal dust

CIC-RU-DUST-002 · Spatial Patterns of Dust Deposition and PAH Accumulation in Snow near an Open-Pit Coal Mine: The Roles of Topography and Wind Direction in Kuzbass Russia

Year/country/type	2026; Russia / Kuzbass; primary snow-deposition particle chemistry study	**Stage and environment**	open-pit overburden and pre-mining stage; PM10 PM0.1 mineral phases and PAHs in snow
Chain	C2-C3	**DOI / URL**	https://doi.org/10.3390/su18115679
Verification status	full article design particle fractions XRD HPLC values spatial directions and conclusions verified	**Critical limitation**	snow-deposited mass is not breathing-zone PM concentration or personal dose; no health endpoint; lack of a monotonic distance gradient and mixed supporting activities limit simple mine-only attribution

CIC-ID-WAT-003 · Kajian kualitas lingkungan air sungai Lati dan sosial ekonomi masyarakat desa Sembakungan akibat aktivitas penambangan batubara PT Berau Coal

Year/country/type	2004; Indonesia; university master's thesis field survey available at abstract level	**Stage and environment**	coal-mine waste discharge to Lati River; pH TDS TSS Fe Mn and plankton diversity
Chain	C2-C5	**DOI / URL**	https://etd.repository.ugm.ac.id/penelitian/detail/25320
Verification status	university repository abstract methods key water values plankton-index values and dilution statement verified	**Critical limitation**	full thesis is not publicly displayed; purposive sampling and abstract-level extraction prevent audit of station-level tables seasonal replication co-contaminants and causal allocation to individual discharges

CIC-TR-AIR-001 · Biomonitoring of metals in the vicinity of Soma coal-fired power plant in western Anatolia Turkey using the epiphytic lichen Xanthoria parietina

Year/country/type	2011; Turkey; primary spatial lichen biomonitoring study	**Stage and environment**	coal-fired power generation and atmospheric deposition; As Cd Co Cr Cu Fe Hg Ni Pb Se Th U V and Zn in lichens
Chain	C2-C4	**DOI / URL**	https://doi.org/10.1080/10978526.2011.609075
Verification status	PubMed DOI 44-station grid 2004-2006 period ICP-MS element list wind-direction pattern and conclusions verified	**Critical limitation**	lichen concentration integrates deposition but is not human internal dose or a direct ecological-effect endpoint; traffic industry soil and regional sources were not eliminated by an experimental source tracer

CIC-BG-WAT-001 · Impact of Coal-Fired Power Plant Activities on the Ecological Status of River Ecosystems: Case Study of Sokolitsa River Bulgaria

Year/country/type	2026; Bulgaria; primary upstream-downstream river chemistry and biological-community study	**Stage and environment**	coal-fired power plant wastewater and adjacent energy complex; temperature conductivity hardness calcium sulfate nitrogen nutrients phytobenthos and macrozoobenthos
Chain	C2-C5	**DOI / URL**	https://doi.org/10.3390/environments13040191
Verification status	DOI authors 2013-2022 monitoring 2023-2024 sampling upstream-downstream design chemical variables and community results verified	**Critical limitation**	the Sokolitsa lies within a wider lignite mining and power complex; wastewater hydromorphology temperature nutrients salts and other pollutants co-vary so a single chemical cannot be assigned as the sole cause

CIC-GLOBAL-CH4-001 · 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 Chapter 4 Fugitive Emissions

Year/country/type	2006; Global; international inventory methodology	**Stage and environment**	surface underground and post-mining coal; methane emission factors activity data and mine-specific measurements
Chain	C0-C2	**DOI / URL**	https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html
Verification status	IPCC tier equations documentation requirements and relative status of direct mine-specific measurement versus emission-factor methods verified	**Critical limitation**	inventory methodology is not an independent atmospheric measurement; uncertainty depends on gas-content representativeness activity data mine type and temporal variability and cannot validate a named mine by itself

CIC2-US-CEN-001 · Divergent extremes but convergent recovery of bacterial and archaeal soil communities to an ongoing subterranean coal mine fire

Year/country/type	2017; USA; primary field chronosequence	**Stage and environment**	underground coal fire; soil chemistry and microbiome
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1038/ismej.2017.1
Verification status	full article verified	**Critical limitation**	space-for-time fire history is not repeated measurement of every site; near-complete community convergence does not establish recovery of every soil function

CIC2-US-CEN-002 · Arrive and wait: Inactive bacterial taxa contribute to perceived soil microbiome resilience after a multidecadal press disturbance

Year/country/type	2024; USA; primary seven-year field study	**Stage and environment**	underground coal fire; soil microbiome
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1111/ele.14393
Verification status	full article verified	**Critical limitation**	microbial community resilience does not equal restoration of soil profile vegetation geology or human safety

CIC2-US-CEN-003 · Seven years of microbial community metagenomes from temperate soils affected by an ongoing coal seam fire

Year/country/type	2024; USA; primary dataset announcement	**Stage and environment**	underground coal fire; soil metagenome
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1128/mra.00198-24
Verification status	methods and dataset verified	**Critical limitation**	dataset paper supplies sequence resources rather than an independent ecological-effect estimate

CIC2-US-CEN-004 · Nitrogen Changes and Domain Bacteria Ribotype Diversity in Soils Overlying the Centralia Pennsylvania Underground Coal Mine Fire

Year/country/type	2005; USA; primary field study	**Stage and environment**	underground coal fire; soil chemistry and bacteria
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1097/00010694-200503000-00005
Verification status	DOI and abstract/full-text lead verified	**Critical limitation**	site-specific early study; chemistry was heterogeneous and cannot be generalized to the whole borough

CIC2-US-SOIL-001 · Soil Microbial Community Recovery in Reclaimed Soils on a Surface Coal Mine Site

Year/country/type	2012; USA; primary field chronosequence	**Stage and environment**	surface-coal-mine reclamation; soil microbial community
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.2136/sssaj2011.0288
Verification status	abstract and journal record verified	**Critical limitation**	chronosequence substitutes space for time; biomarker recovery does not establish recovery of all soil properties

CIC2-CA-SOIL-001 · Microbial composition and function in reclaimed mine sites along a reclamation chronosequence become increasingly similar to undisturbed reference sites

Year/country/type	2024; Canada; primary field chronosequence	**Stage and environment**	mine reclamation; soil bacterial and fungal communities
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.scitotenv.2024.170996
Verification status	PubMed metadata and abstract verified	**Critical limitation**	mine type and full site characteristics require full-text extraction; increasing similarity is not identity

CIC2-DE-SOIL-001 · Relationship between soil organic carbon and microbial biomass on chronosequences of reclamation sites

Year/country/type	1988; Germany; primary field chronosequence	**Stage and environment**	open-pit mine reclamation; soil carbon and microbial biomass
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1007/BF02011711
Verification status	PubMed metadata and abstract verified	**Critical limitation**	historic chronosequence; carbon values depend on land use and do not alone define full soil recovery

CIC2-ES-SOIL-001 · Reclamation of lignite mine areas with Triticum aestivum: The dynamics of soil functions and microbial communities

Year/country/type	2014; Spain; primary field chronosequence	**Stage and environment**	lignite-mine reclamation; soil microbes and enzymes
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.apsoil.2014.03.009
Verification status	journal abstract verified	**Critical limitation**	microbial abundance and enzyme convergence coexisted with different community structure after 20 years

CIC2-IN-SOIL-001 · Soil development in 2-21 years old coalmine reclaimed spoil with trees: A case study from Sonepur-Bazari opencast project Raniganj Coalfield India

Year/country/type	2015; India; primary field chronosequence	**Stage and environment**	opencast-coal spoil reclamation; soil properties microbial activity biomass and plant community
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.ecoleng.2015.09.043
Verification status	journal metadata and abstract verified	**Critical limitation**	space-for-time design; tree-covered spoil and selected soil properties do not prove recreation of the original soil profile

CIC2-CN-SOIL-001 · The development of topsoil properties under different reclaimed land uses in the Pingshuo opencast coalmine of Loess Plateau of China

Year/country/type	2017; China; primary multi-land-use field study	**Stage and environment**	opencast-coal reclamation; topsoil texture carbon nitrogen nutrients and CEC
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.ecoleng.2016.12.028
Verification status	abstract and methods summary verified	**Critical limitation**	OC and N became comparable under some land uses; other properties differed and chronosequence convergence is not whole-profile restoration

CIC2-CN-GW-001 · Evolution mechanism of a groundwater system in the opencast coalmine area in the typical prairie

Year/country/type	2019; China; primary hydrogeochemical field comparison	**Stage and environment**	active opencast coal mining; groundwater chemistry and flow
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.16030/j.cnki.issn.1000-3665.2019.01.22
Verification status	full HTML abstract and methods verified	**Critical limitation**	multiple simultaneous hydrological changes complicate attribution of every analyte to one reaction

CIC2-PL-DUMP-001 · Mineralogy and geochemistry of coal wastes from the Starzykowiec coal-waste dump Upper Silesia Poland

Year/country/type	2014; Poland; primary field mineralogical and geochemical study	**Stage and environment**	old self-heating coal-waste dump; solid waste mineralogy organic matter and trace elements
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.coal.2014.02.007
Verification status	publisher abstract methods and conclusions verified	**Critical limitation**	original input material was poorly documented; history and mass change therefore rely partly on inference

CIC2-PL-DUMP-002 · Preservation of coal-waste geochemical markers in vegetation and soil on self-heating coal-waste dumps in Silesia Poland

Year/country/type	2016; Poland; primary field soil vegetation and organic-geochemistry study	**Stage and environment**	self-heating coal-waste dumps; migrating biomarkers alkyl aromatics PAHs and phenols
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.chemer.2016.04.001
Verification status	publisher abstract verified	**Critical limitation**	surface fingerprints demonstrate migration to sampled soil and plant surfaces but not dose disease or a universal dump composition

CIC2-PL-DUMP-003 · Organic contaminants of coal-waste dump water in the Lower- and Upper Silesian Coal Basins Poland

Year/country/type	2020; Poland; primary field water organic-geochemistry study	**Stage and environment**	coal-waste dumps and self-heating; organic compounds PAHs and organophosphate esters in temporary and permanent waters
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.apgeochem.2020.104690
Verification status	publisher abstract verified	**Critical limitation**	mixed biogenic geogenic self-heating and external anthropogenic sources require compound-specific attribution

CIC2-PT-DUMP-001 · Assessment of mobile mercury concentration in soils of an abandoned coalfield waste pile in Douro region: the Fojo waste pile study case

Year/country/type	2024; Portugal; primary field soil and sequential-extraction study	**Stage and environment**	abandoned partly burnt coal-waste pile; pseudo-total and operationally mobile mercury fractions in waste and nearby soil
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1007/s11368-024-03786-x
Verification status	full article verified	**Critical limitation**	local geology is naturally Hg-enriched and downhill spread is described as possible; sequential fractions are operational mobility indicators not measured uptake

CIC2-US-REFUSE-001 · Hydrogeology and Simulation of Groundwater Flow at the Green Valley Reclaimed Coal Refuse Site near Terre Haute Indiana

Year/country/type	2011; USA; official primary hydrogeological investigation	**Stage and environment**	reclaimed coarse and fine coal refuse; groundwater flow seeps acid mine drainage and receiving waters
Chain	second pass material flow	**DOI / URL**	https://pubs.usgs.gov/sir/2011/5116/
Verification status	USGS report verified	**Critical limitation**	reclamation altered flow and runoff but site-specific groundwater paths and imported cap materials limit transfer

CIC2-UK-WAT-001 · Long-term changes in the quality of polluted minewater discharges from abandoned underground coal workings in Scotland

Year/country/type	1999; United Kingdom; primary multi-site long-term monitoring synthesis	**Stage and environment**	abandoned underground coal mines; mine-water pH alkalinity iron sulfate and discharge evolution
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1144/GSL.QJEG.1999.032.P1.05
Verification status	journal repository abstract verified	**Critical limitation**	iron commonly declined toward an asymptote but did not vanish; discharge behavior depended on water-table fluctuation and geology

CIC2-UK-WAT-002 · Flow dependent water quality impacts of historic coal and oil shale mining in the Almond River catchment Scotland

Year/country/type	2013; United Kingdom; primary catchment monitoring and spatial hydrochemistry	**Stage and environment**	abandoned coal and oil-shale sites; river Fe sulfate major ions and cumulative point-plus-diffuse loading
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.apgeochem.2013.06.001
Verification status	journal repository abstract verified	**Critical limitation**	coal and oil-shale sources coexist with urban inputs; catchment evidence cannot assign every ion to a single site

CIC2-US-ECO-001 · Abandoned coal mine drainage and its remediation: impacts on stream ecosystem structure and function

Year/country/type	2012; USA; primary comparative field ecosystem study	**Stage and environment**	abandoned coal-mine drainage; water chemistry macroinvertebrates primary production respiration nutrient uptake and decomposition
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1890/11-1735.1
Verification status	publisher abstract verified	**Critical limitation**	two mining regions showed different ecological responses; no single AMD phenotype can be generalized

CIC2-US-ECO-002 · Impact of mine drainage on a mountain stream in Pennsylvania

Year/country/type	1978; USA; primary upstream-downstream field study	**Stage and environment**	coal-mine drainage; ferric hydroxide deposition water chemistry fish and benthic macroinvertebrates
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/0013-9327(78)90055-1
Verification status	publisher abstract verified	**Critical limitation**	historic single-stream study; alkaline receiving water held pH at 6.5-8 so effects cannot be described as acid toxicity alone

CIC2-US-SED-001 · Mineralogical and geochemical variation in stream sediments impacted by acid mine drainage is related to hydro-geomorphic setting

Year/country/type	2018; USA; primary streambed cores porewater and hydraulic-gradient study	**Stage and environment**	abandoned-coal-mine drainage; iron oxyhydroxide deposits Al Mn Cu and porewater Fe Mn
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1525/elementa.286
Verification status	full open article verified	**Critical limitation**	field data show spatially variable storage and porewater but do not quantify whole-watershed remobilization during an extreme flood

CIC2-US-COMB-001 · Partitioning of Mercury Arsenic Selenium Boron and Chloride in a Full-Scale Coal Combustion Process Equipped with SCR ESP and FGD Systems

Year/country/type	2009; USA; full-scale simultaneous material-balance field study	**Stage and environment**	coal combustion and air-pollution control; Hg As Se B and chloride across gas ash gypsum and wastewater
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1021/ef900293u
Verification status	publisher abstract and numerical partitioning verified	**Critical limitation**	one plant one operating state; percentages are element- and configuration-specific and are not ambient exposure estimates

CIC2-US-COMB-002 · Partitioning of selected trace elements in coal combustion products from two coal-burning power plants in the United States

Year/country/type	2013; USA; primary two-plant solid-stream mass-balance study	**Stage and environment**	coal combustion; As Cr Hg Pb and Se in feed coal bottom ash economizer ash and fly ash
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.coal.2012.08.010
Verification status	USGS publication record and abstract verified	**Critical limitation**	mass balance excluded FGD and does not represent final disposal leaching or ambient exposure

CIC2-NL-USE-001 · Verification of laboratory-field leaching behavior of coal fly ash and MSWI bottom ash as a road base material

Year/country/type	2000; Netherlands; primary decade-scale field verification	**Stage and environment**	beneficial use in road construction; element release percolation water and soil-profile accumulation
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/S0956-053X(99)00322-0
Verification status	publisher abstract verified	**Critical limitation**	mixed material types and site-specific construction; release behavior cannot be generalized to every fly ash or use

CIC2-US-USE-001 · Water Quality Risk Assessment from Roadway Substructures Employing Fly Ash

Year/country/type	2016; USA; primary multi-site field monitoring synthesis	**Stage and environment**	beneficial use in road substructures; trace elements in groundwater and surface water
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1061/9780784480144.099
Verification status	publisher abstract verified	**Critical limitation**	reported no water-quality impact for tested applications; does not prove safety for unencapsulated fills other ashes or unmonitored pathways

CIC2-CN-BEN-001 · Migration and Distribution of Fifteen Toxic Trace Elements during the Coal Washing of the Kailuan Coalfield Hebei Province China

Year/country/type	2009; China; primary process partitioning study	**Stage and environment**	coal washing; 15 trace elements across raw coal clean coal middlings slime and tailings
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1260/0144-5987.27.2.143
Verification status	publisher abstract verified	**Critical limitation**	partitioning into wastes is not evidence of release beyond the facility or receptor exposure

CIC2-US-BEN-001 · Environmental Contaminants in Coal Slurry Intended for Underground Injection in the State of West Virginia

Year/country/type	2015; USA; primary multi-site slurry characterization	**Stage and environment**	coal preparation slurry; 177 organic and inorganic constituents in liquid and solids
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1061/(ASCE)EE.1943-7870.0000874
Verification status	publisher abstract verified	**Critical limitation**	composition above guidelines in slurry does not establish migration to groundwater; source-to-receptor attribution requires separate hydrogeology

CIC2-US-CEN-005 · The effect of abundant precipitation on coal fire subsidence and its implications in Centralia PA

Year/country/type	2013; USA; primary field mapping thermal-imagery and precipitation study	**Stage and environment**	underground coal fire; infiltration steam heat fractures sinkholes and surface subsidence
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.coal.2012.10.004
Verification status	publisher full preview verified	**Critical limitation**	links precipitation fire heat and new subsidence spatially and mechanistically but does not quantify groundwater contamination

CIC2-US-CEN-006 · Centralia Mine Fire Resources

Year/country/type	2026; USA; current official status and hazard page	**Stage and environment**	underground coal fire; official current fire status dangerous gases and collapse hazard
Chain	second pass material flow	**DOI / URL**	https://www.pa.gov/agencies/dep/programs-and-services/mining/abandoned-mine-reclamation/aml-program-information/centralia-mine-fire-resources
Verification status	current Pennsylvania DEP page verified	**Critical limitation**	official hazard/status source rather than a chemical field study; no claim about specific present-day concentrations

CIC2-AU-SOIL-001 · Temporal dynamics in biotic and functional recovery following mining

Year/country/type	2022; Australia; primary multi-mine reference comparison	**Stage and environment**	open-cut coal-mine rehabilitation; vegetation attributes soil-surface condition and landscape function
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1111/1365-2664.14172
Verification status	full methods and article record verified	**Critical limitation**	older sites were unevenly distributed among mines and 12 years is not a full long-term endpoint

CIC2-AU-SOIL-002 · Identification of Metabolic Gaps in the Microbial Cycling of Carbon Limiting Soil Formation in Coal Mine Spoil and Degraded Topsoil

Year/country/type	2025; Australia; primary field rehabilitation experiment	**Stage and environment**	coal-mine waste-rock dump rehabilitation; spoil topsoil chemistry and microbial carbon metabolism
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1111/sum.70099
Verification status	full open methods verified	**Critical limitation**	short monitoring window describes constraints and early trajectories not mature ecosystem recovery

CIC2-MN-MAT-001 · Environmental Sustainability of Open-Pit Coal Mining Practices at Baganuur Mongolia

Year/country/type	2020; Mongolia; primary field water-soil sampling plus laboratory leaching	**Stage and environment**	active open-pit coal mining; dewatering water discharged water sump water waste soil interburden and dust
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.3390/su12010248
Verification status	full open article verified	**Critical limitation**	only five soil material samples and laboratory leaching; potential release is not a demonstrated regional plume or health outcome

CIC2-MN-SOIL-001 · The impacts of mining on soil pollution with metal(loid)s in resource-rich Mongolia

Year/country/type	2023; Mongolia; primary urban-soil survey plus evidence synthesis	**Stage and environment**	coal-mining towns and mixed urban sources; Cd Cu Pb Zn and other metal(loid)s in topsoil
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1038/s41598-023-29370-w
Verification status	full open article and DOI verified	**Critical limitation**	urban heating traffic geology and industry confound simple mine-distance attribution

CIC2-ZA-WAT-001 · Environmental impacts associated with an abandoned mine in the Witbank Coalfield South Africa

Year/country/type	2001; South Africa; primary integrated post-closure case study	**Stage and environment**	abandoned underground coal mine and fire; subsidence fractures recharge acid mine drainage groundwater seepage surface water and vegetation
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/S0166-5162(00)00033-1
Verification status	publisher full preview verified	**Critical limitation**	historic site-specific case; multiple coupled mechanisms prevent assigning every change to combustion alone

CIC2-PL-WAT-001 · Multi-Decadal Impact of Mine Waters in Przemsza River Basin Upper Silesian Coal Basin Southern Poland

Year/country/type	2024; Poland; primary long-term discharge and river synthesis	**Stage and environment**	active and abandoned underground coal mines; mine-water quantity chloride sulfate load river conductivity and flow
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.3390/w16213147
Verification status	full open article verified	**Critical limitation**	regional drought and changing river flow strongly affect concentration even as mine-water volume declines

CIC2-UK-WAT-003 · Sources and controls of greenhouse gases and heavy metals in mine water: A continuing climate legacy

Year/country/type	2024; United Kingdom; primary multi-site field chemistry and isotope study	**Stage and environment**	abandoned coal-mine water; CO2 methane Fe As Ni Co Mn and source signatures
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.1016/j.scitotenv.2023.167371
Verification status	open publisher abstract and dataset link verified	**Critical limitation**	outflow concentrations and isotopic source apportionment do not directly equal atmospheric flux or human exposure

`CIC2-PL-RES-001` · **Characteristics of the chemical composition of water in reservoirs under the influence of coal mine waste in the Upper Silesian Coal Basin southern Poland**

Year/country/type	2025; Poland; primary multi-reservoir field study	**Stage and environment**	post-mining waste landfills; chloride sulfate sodium conductivity and shallow-aquifer concern
Chain	second pass material flow	**DOI / URL**	https://doi.org/10.7163/GPol.0299
Verification status	full article metadata and abstract verified	**Critical limitation**	adjacency and reservoir chemistry establish influence but shallow-groundwater risk is potential unless hydraulic source attribution is measured

Appendix D. Search log

The log records 47 search packets from both passes. Status `gap-open` means a fixed gap, and not the absence of a process in reality.

Search ID	Pass	Module	Platform	Search string	Filters	Result / exclusion	Status
SLOG-000	I	coal fires	legacy archive	inventory of existing 11-file corpus	none	11 files; preservation and SHA-256 confirmed	complete
SLOG-001	I	mining dust; coal combustion; mine water	web search	Mongolia Tavan Tolgoi coal mine dust heavy metals primary study DOI; Ulaanbaatar coal combustion source apportionment	primary studies and official reports preferred	12 candidate records; mining and urban-combustion branches must remain separate	screened
SLOG-002	I	Appalachian water; occupational dust; coal ash	web search	Appalachian coal mining stream chemistry selenium sulfate conductivity; coal mine dust silica exposure; coal ash groundwater risk	official or peer-reviewed	16 candidate records; final EPA report distinguished from 2009 draft	screened
SLOG-003	I	open-cut methane; mine dust; mine water; Hazelwood	web search	Australia open cut coal mine methane aircraft; Upper Hunter particle characterization; coal mine wastewater	primary measurements or government monitoring	18 candidate records; regional PM attribution is complicated by bushfire smoke and windblown dust	screened
SLOG-004	I	Jharia air; mine water; coal-fire areas	web search	Jharia coalfield mine water trace metals 92 samples; spatio-temporal air pollutants	primary field studies	8 candidate records; ambient air has mixed fire mining transport and road-dust sources	screened
SLOG-005	I	Wuda fires; abandoned mine drainage; power-plant element partitioning; ash leaching	web search	China coal mining acid mine drainage trace metals; coal combustion fly ash leaching; Wuda mercury	primary field or experimental studies	11 candidate records; emission and leaching measurements do not by themselves establish receptor harm	screened

Search ID	Pass	Module	Platform	Search string	Filters	Result / exclusion	Status
SLOG-006	I	coal ash; beneficiation; mine dumps; South Gobi	web search	coal ash spill trace metals; coal washery effluent; Ordos waste dump; Tavan Tolgoi monitoring	primary field studies preferred	17 candidate records; company self-monitoring retained only as a lead until independently checked	screened
SLOG-007	I	routine open-cut dust; occupational dust; community health; Hazelwood follow-up	web search	Australian coal mine particulate characterization; Hunter Valley health; Hazelwood hospitalisation	primary measurements and linked cohorts	17 candidate records; routine mining and exceptional mine fire treated as separate exposures	screened
SLOG-008	I	selenium; acid mine drainage; saline mine water; pit lakes	web search	coal mining selenium Elk Valley; Mpumalanga water; Poland mine-water salinity; Indonesia AMD	primary field studies and official data	18 candidate records; second-ring countries added to test whether chemistry differs across geological and regulatory settings	screened
SLOG-009	I	coal-ash pond leakage; spill sediment; fish bioaccumulation	web search	coal ash groundwater isotope tracer; Dan River mercury; Kingston selenium fish	primary field studies and official datasets	17 candidate records; retained both demonstrated leakage and null/limited biological findings	screened
SLOG-010	I	washery effluent; Mongolian coal combustion; South Gobi soil and water; Kuzbass flooded mine	web search	coal washery metals; Mongolia coal VOC PM trace elements; Tavan Tolgoi water metals; Kuzbass mine water sulfur	primary measurement studies	15 candidate records; mine extraction and end-use combustion kept as separate pathways	screened
SLOG-011	I	C4 internal dose; C5 biological and health effects; null findings	web search	Elk Valley selenium reproduction; Yulin blood lead; Chinese miner lung function; Ulaanbaatar child symptoms; Jharia resident biomonitoring	primary longitudinal biomonitoring or linked-endpoint studies	16 candidate records; retained direct and null endpoints; Jharia self-reported proximity surveys not treated as complete chemical causal chains	screened
SLOG-012	I	Centralia ambient air and mine drainage	web and legacy-corpus verification	Centralia mercury gas monitoring; Centralia Mine Tunnel water chemistry; Mahanoy Creek AMD	official primary measurements with site and date	8 candidate records; air fire monitoring kept separate from mine-tunnel AMD; water chemistry not attributed to the fire without source separation	screened
SLOG-013	I	Lusatian lignite post-mining water chemistry; Spree transport; ecological effects	web search	lignite sulfate iron Spree; sediment mining signature; fish food web iron flocculation	primary field transects and ecological endpoints	12 candidate records; retained long-range chemistry and paired biological findings; dam and water-temperature confounding recorded	screened
SLOG-014	I	blasting explosives; coal rail transport; stockpile runoff; beneficiation reagents	web search	ANFO NO2 fence line; rail coal dust; coal pile runoff macroinvertebrates; MCHM fate; nitrogen leaching	primary field or official monitoring with source separation	19 candidate records; retained measured and negative transport/storage results; conference nitrogen study and MCHM chemistry held for deeper source-event verification	screened

Search ID	Pass	Module	Platform	Search string	Filters	Result / exclusion	Status
SLOG-015	I	coal-beneficiation reagents and accidental drinking-water exposure	web search	Elk River MCHM spill water concentrations acute symptoms toxicology birthweight	primary public-health surveillance official toxicology and measured water chemistry	15 candidate records; human surveillance retained as descriptive not causal; NTP negative screening-level interpretation kept beside reported symptoms	screened
SLOG-016	I	nitrate and ammonium associated with blasting and coal-mine wastewater	web search	Fording Coal explosives water quality; Elk Valley waste-rock nitrate isotopes; Appalachian mountaintop-removal nitrate persistence	identifiable coal-mine field datasets with measured chemistry isotope attribution or watershed flux	14 candidate records; retained two modern primary studies and one historical official coal-mine report; non-coal explosive leaching cases excluded from central claims; long-term nitrate not assigned to explosives alone	screened
SLOG-017	I	routine coal-beneficiation reagents process water tailings and discharge	web search	MCHM sorption and leaching; Wulantuga flotation element migration; MIBC plant-circuit retention; preparation-plant blackwater	primary process-specific experiments or field measurements distinguishing in-plant partitioning from environmental discharge	18 candidate records; retained MCHM negative transport experiment and mine-specific flotation release experiment; historical blackwater and restricted ACARP material held as supporting leads; no claim of environmental harm from process-water detection alone	screened
SLOG-018	I	coal-combustion ash disposal leachate groundwater and source attribution outside USA-China	web search	Parichha groundwater; Koradi-Khaperkheda isotopes; Matimba plume; Silesian dump waters	field chemistry with spatial comparison isotope source attribution or named disposal facility	21 candidate records; retained positive and negative attribution results for India plus South African field thesis; laboratory-only leachability kept as supporting evidence; Poland dump water is coal waste rather than combustion ash and remains in its own lifecycle class	screened
SLOG-019	I	combustion transformation and partitioning among stack gas fly ash bottom ash and FGD products	web search	Huainan As Hg Sb Se; 320 MW field mass balance; Guizhou Hg leaching; five Indian power plants trace-element residues	simultaneous full-scale mass balance multi-plant residue characterization and element-specific leaching	20 candidate records; retained four complementary claims; air capture kept distinct from destruction and from safe disposal; ash concentration kept distinct from mobile fraction and receptor dose	screened
SLOG-020	I	Tavan Tolgoi coal-haul road PM chemistry personal exposure livestock and groundwater	web search	Tavan Tolgoi road dust; Tsagaan Khad coal handling; South Gobi herder reports; aeolian erosion; mine-perimeter soil and groundwater	direct filter chemistry gravimetric roadside monitoring personal sampling livestock biomarkers or mine-specific tracers	24 candidate records; no direct personal PM chemistry or livestock biomarker study specific to the Tavan Tolgoi coal road was verified in this search; retained qualitative evidence and remote-sensing transport evidence only with explicit C0 and C2-C3 limits; Ulaanbaatar combustion studies not substituted for South Gobi haul-road exposure	gap-recorded
SLOG-021	I	named closed mines mine-water chemistry discharge routes and receiving rivers	web search	Severnaya flooded mine sulfate reduction; Sudzhenskaya Yagunovskaya Pionerka Dimitrova Smychka Shushtalepskaya river monitoring	named mine plus measured chemistry pathway comparator or monitoring section	17 candidate records; retained one direct borehole-process study and one multi-mine monitoring synthesis; upstream river contamination preserved as negative attribution evidence; generic Kuzbass groundwater and company publicity excluded from strong claims	screened

Search ID	Pass	Module	Platform	Search string	Filters	Result / exclusion	Status
SLOG-022	I	field transport and receptors beyond laboratory acid-generation potential	web search	Tanjung Enim pit lakes and treatment; Lati River sediments; Muara Berau coal transshipment; Kintap River; Kalimantan pit lakes	named field object with measured concentration spatial or inlet-outlet comparator and where available biological uptake	27 candidate records; retained three primary studies producing four claims; laboratory cover-system tests reviews perception studies and unrelated gold-mine pits excluded from strong coal claims; receptor-effect gap remains explicit	screened
SLOG-023	I	historical residential interface subsidence gas surveillance and direct measurements at Centralia	web search	RI 8799; residential CO detectors; weekly seepage tests; fire-control options; current mine-fire hazard guidance	official primary or government technical material separating recognized hazard monitoring from measured exposure and health outcome	18 candidate records; retained RI 8799 for the lived-under-fire context; press anecdotes and retrospective unsourced health claims excluded; late 2006-2007 ambient monitoring remains separate negative evidence	screened
SLOG-024	I	nitrate source transport and nitrate-specific receptor effects separated from selenium sulfate salinity and metals	web search	Fording explosives report; waste-rock nitrate; Elk-Kootenay paired watershed; nitrate toxicity benchmarks; aquatic monitoring	long-term flow-normalized transport plus controlled or field receptor endpoints with nitrate-specific comparator	23 candidate records; retained one independent paired-watershed transport study and one site-water controlled-toxicity benchmark; no clean field study attributing an observed population effect to nitrate alone was verified; co-contaminant limitation retained	screened
SLOG-025	I	international coal-fire source exposure and health comparison	web search	Hazelwood ambient plume pregnancy birth respiratory follow-up; Jharia fire versus non-fire air and PM2.5 metals; Wuda underground fire and gangue Hg; Centralia historical and late ambient monitoring	primary ambient measurement individual exposure cohort longitudinal outcome or named fire-source measurement with explicit comparator	37 candidate records; retained eight new claim blocks including three negative or mixed results; modelled risk not treated as observed disease; vent concentration not treated as community dose; four fire systems remain separate	screened
SLOG-026	I	nitrate and ammonium receptor effects in coal-mine receiving waters	web search	Fording River nitrate benthic fish field effect; explosives nitrate aquatic receptor; mine ammonia nitrate EEM	field upstream-downstream or before-after endpoint with nitrate-specific attribution and reported chemistry	31 candidate records; retained 2023 Fording LAEMP as field negative/limiting evidence; nitrate was not judged the primary cause of observed BIC structure; no clean nitrate-only population endpoint verified	screened
SLOG-027	I	routine coal-beneficiation reagents and receiving-water receptors	web search	coal washery influent effluent mass balance; flotation reagent environmental concentration; preparation plant receiving stream fish benthos	independent field mass balance with named reagent and downstream receptor endpoint	34 candidate records; no independent modern chain from named routine reagent through plant discharge to receptor effect verified; retained historical EPA facility survey to bound process-water architecture; accident evidence remains separate	screened-gap
SLOG-028	I	coal ash and combustion-to-receptor pathways outside USA and China	web search	ash plume groundwater receptor; power-plant metal deposition lichen; wastewater upstream downstream macrozoobenthos phytobenthos	primary named-site field chemistry plus biomonitoring or ecological endpoint and explicit comparator	42 candidate records; retained Soma lichen biomonitoring and Sokolitsa upstream-downstream ecological study; Matimba full-table access remained incomplete; co-pollutant and multi-source limits preserved	screened

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SLOG-029	I	Tavan Tolgoi coal-road particulate chemistry personal exposure and livestock biomarkers	web search	Tavan Tolgoi PM10 PM2.5 chemical composition; coal-road dust personal exposure; South Gobi child biomonitoring; livestock metals	direct filters personal monitors or biological markers with mine-specific attribution	29 candidate records; retained South Gobi child biomonitoring as C4 evidence that fails coal-specific attribution; direct Tavan Tolgoi coal-road PM chemistry and livestock effect chain still not verified	screened-gap
SLOG-030	I	Kuzbass source-specific dust and waste chemistry plus Indonesian receptor replication	web search	Kuzbass pit snow PM quartz PAH; active discharge loads; burning waste dump chemistry; Lati River plankton; Muara Berau replication	named source field chemistry comparator and receptor endpoint where available	38 candidate records; retained Kuzbass snow particle mineralogy and PAH transport plus Lati water-plankton thesis; Muara Berau remained a first report without independent replication	screened
SLOG-031	I	open-cut coal-mine methane measurement and inventory comparison	web search	surface mine methane emission factor direct ground downwind aircraft satellite inverse modelling temporal variability attribution	official methods and primary cross-platform mine-scale estimates	36 candidate records; retained IPCC tier framework; Hail Creek aircraft and satellite claims cross-linked; episodic plume measurement not converted into continuous annual flux and inventory factors not treated as direct observation	screened
SP-S-001	II	soil chronosequences	web discovery plus journal/PubMed	coal mine reclaimed soil reference chronosequence 30 years soil carbon microbial enzymes primary study DOI	primary field chronosequences with reference sites	6 viewed; included CIC2-US-SOIL-001; CIC2-CA-SOIL-001; CIC2-DE-SOIL-001; CIC2-ES-SOIL-001; chronosequence is space-for-time and must not be called longitudinal	active
SP-S-002	II	overburden weathering	web discovery plus primary repositories	coal mine overburden field sulfide oxidation secondary minerals drainage long term primary study	coal-specific material transformation with field priority	5 viewed; included none; first result set was dominated by laboratory columns; retained only as leads pending field verification	gap-open
SP-S-003	II	old spoil and refuse piles	web discovery	coal waste rock pile 30 years leachate groundwater vegetation field study coal mine	post-closure field time series	4 viewed; included none; results insufficiently object-specific; targeted country searches required	gap-open
SP-S-004	II	Centralia whole system	web discovery plus primary journals	Centralia Pennsylvania mine fire soil chemistry microbiome vegetation subsidence primary studies	soil chemistry microbiome vegetation and geomorphology	11 viewed; included CIC2-US-CEN-001; CIC2-US-CEN-002; CIC2-US-CEN-003; CIC2-US-CEN-004; soil and microbiome evidence strong; mineral condensate vegetation and groundwater modules remain open	active
SP-S-005	II	spoil heaps and self-heating	web discovery plus primary journals	coal waste dump spontaneous combustion mineralogy soil water field study Upper Silesia DOI	field mineralogy soil vegetation water and post-closure evidence	18 viewed; included CIC2-PL-DUMP-001; CIC2-PL-DUMP-002; CIC2-PL-DUMP-003; CIC2-PT-DUMP-001; CIC2-US-REFUSE-001; object-specific studies show heterogeneous mineral transformations and multiple pathways; no universal dump chemistry	included
SP-S-006	II	flooded and abandoned mine water	web discovery plus NERC and primary journals	flooded abandoned coal mine water rebound long term chemistry field study UK DOI iron sulfate decades	long records and field discharges prioritized	16 viewed; included CIC2-UK-WAT-001; CIC2-UK-WAT-002; long-term decline and persistent residual loading both documented; German and Polish deep-mine stratification remains a targeted gap	included

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SP-S-007	II	sediment and stream ecosystem	web discovery plus primary journals	coal mine drainage sediment secondary source remobilization field study pH redox DOI	field sediment porewater and biological response	17 viewed; included CIC2-US-SED-001; CIC2-US-ECO-001; CIC2-US-ECO-002; field evidence supports storage and ecological effects; extreme-event remobilization evidence remains incomplete	included
SP-S-008	II	combustion material balance	web discovery plus ACS and USGS	coal combustion trace element mass balance power plant mercury arsenic selenium fly ash bottom ash FGD wastewater primary study DOI	simultaneous full-scale stream sampling	16 viewed; included CIC2-US-COMB-001; CIC2-US-COMB-002; partitioning is element- and plant-specific; capture transfers mass to solids/liquids rather than destroying it	included
SP-S-009	II	beneficial use	web discovery plus primary field studies	field study coal fly ash concrete leaching beneficial use groundwater road base structural fill DOI	field exposure and monitoring prioritized over batch leach alone	13 viewed; included CIC2-NL-USE-001; CIC2-US-USE-001; negative field evidence retained; concrete and mine-backfill scenarios still require separate treatment	included
SP-S-010	II	coal preparation and tailings	web discovery plus primary journals	coal preparation tailings impoundment seepage groundwater field study pyrite trace elements DOI	process partitioning slurry composition and field migration	18 viewed; included CIC2-CN-BEN-001; CIC2-US-BEN-001; good evidence for transfer into tailings/slurry; causal groundwater plume evidence remains weaker and must not be inferred from composition alone	included
SP-S-011	II	global soil and groundwater	web discovery plus primary journals	surface coal mining reclaimed soil reference chronosequence India China opencast groundwater field DOI	India China Australia Mongolia leads; primary field comparisons	18 viewed; included CIC2-IN-SOIL-001; CIC2-CN-SOIL-001; CIC2-CN-GW-001; India and China added; Australia overburden evidence found mainly in reviews/management reports and remains open for direct field studies	active
SP-S-012	II	Centralia geology and current status	web discovery plus Pennsylvania DEP	Centralia Pennsylvania mine fire soil chemistry minerals vents groundwater vegetation primary study DOI	system components beyond ambient air	15 viewed; included CIC2-US-CEN-005; CIC2-US-CEN-006; soil heat microbiome vegetation succession and subsidence now evidenced; direct fire-attributed groundwater chemistry not located	included
SP-S-013	II	Australia coal rehabilitation	web discovery plus primary journals	Australia coal mine overburden spoil field weathering acid drainage soil water DOI coal	field rehabilitation and reference sites	15 viewed; included CIC2-AU-SOIL-001; CIC2-AU-SOIL-002; strong early rehabilitation comparisons; direct multi-decade spoil-to-water mass balance remains open	included
SP-S-014	II	Mongolia coal material flow	web discovery plus open primary studies	Mongolia open pit coal mine soil water contamination field study DOI Baganuur	field soil water and negative attribution results	18 viewed; included CIC2-MN-MAT-001; CIC2-MN-SOIL-001; Baganuur material-specific risk and broader low/ambiguous soil signal both retained	included
SP-S-015	II	post-closure mine water Europe and South Africa	web discovery plus primary journals	Ruhr Upper Silesia Witbank abandoned coal mine water long term chemistry field DOI	long-term field chemistry coupled groundwater–surface-water pathways	19 viewed; included CIC2-ZA-WAT-001; CIC2-PL-WAT-001; CIC2-UK-WAT-003; CIC2-PL-RES-001; long-term and coupled pathways added; exact Ruhr flooded-mine chemical series remains less accessible than Scottish and Polish evidence	included

CONCLUSION

The coal industry does not create a single pollution stream. It moves masses of rock and coal, and the substances they contain change form, environmental medium and pathway.

Some pathways weaken. Some controlled systems retain matter. Certain soil properties recover. Negative results are real and inevitable.

But the end date of production, flue-gas treatment, or the disappearance of a substance from one measured medium does not mean that the chemical process is complete.

Only for humans does coal end in the furnace. For chemistry, it continues.