Reference concentrations of chemical elements in soils from global coal mining regions

Alexey V. Alekseenko[1], Maria M. Machevariani[2], Jaume Bech[3], and Daniel Karthe[1,4,5]

1 Institute for Integrated Management of Material Fluxes and of Resources, United Nations University (UNU-FLORES), Dresden, Germany
2 Technische Universität Bergakademie Freiberg, Freiberg, Germany
3 Faculty of Biology, University of Barcelona, Barcelona, Spain
4 Faculty of Environmental Sciences, Technische Universität Dresden, Dresden, Germany
5 Engineering Faculty, German-Mongolian Institute for Resources and Technology, Nalaikh, Mongolia

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United Nations University

A global think tank

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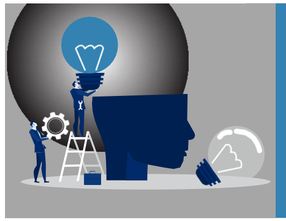
UNU System

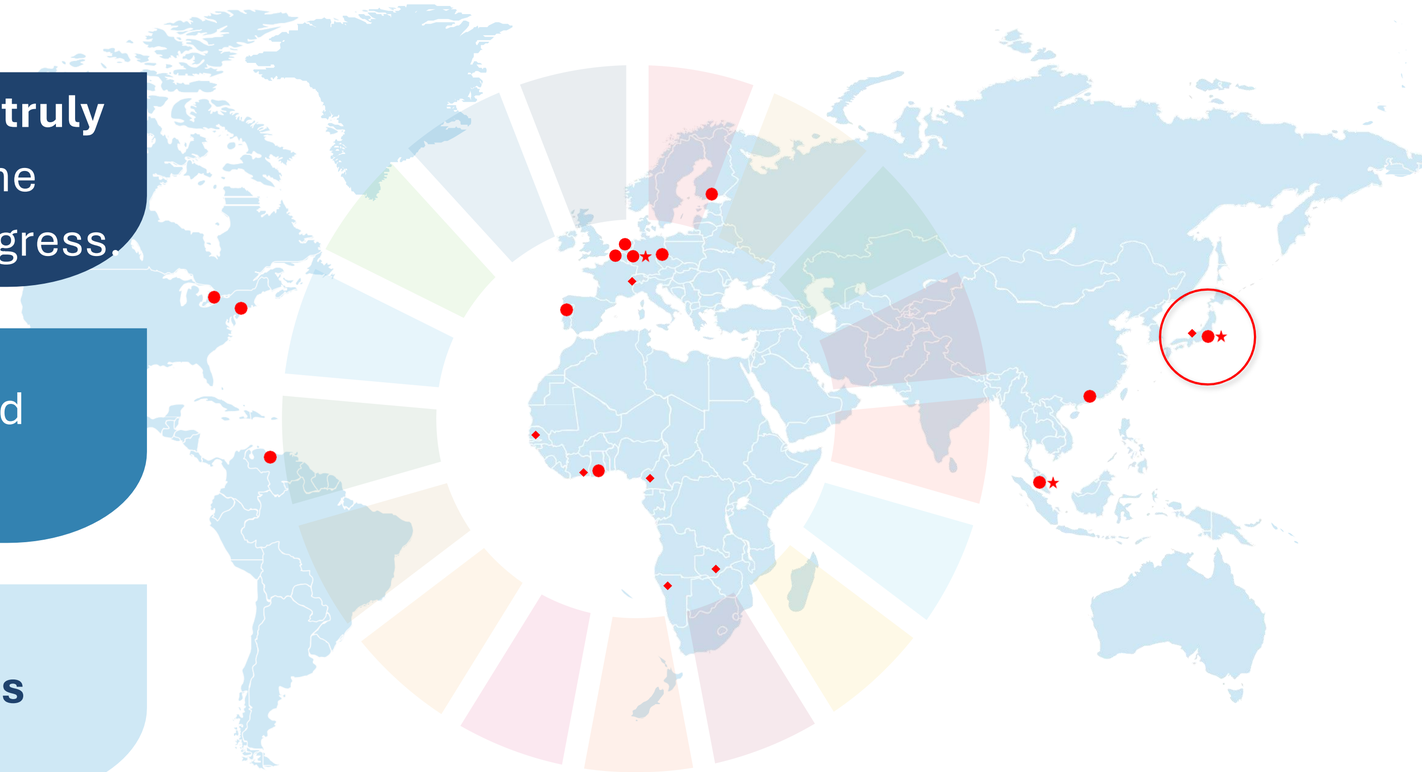
A global system of research and training institutes coordinated by UNU Centre in Tokyo

A university dedicated to being **“truly international”** and focused on the Charter’s goals of peace and progress.



A think tank for the UN System and Member States

13 **Institutes located in 12 countries**



- INSTITUTES
- OPERATING UNITS
- ADMINISTRATIVE & ACADEMIC SERVICE UNITS

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UNU Strategy 2025-2029

Knowledge: Enhancing knowledge and capacity through research and education

Partnerships: Strengthening partnerships, particularly in the Global South, and enhanced collaboration within the UN system

Impact: Greater visibility and impact through expansion and outreach, particularly in the Global South

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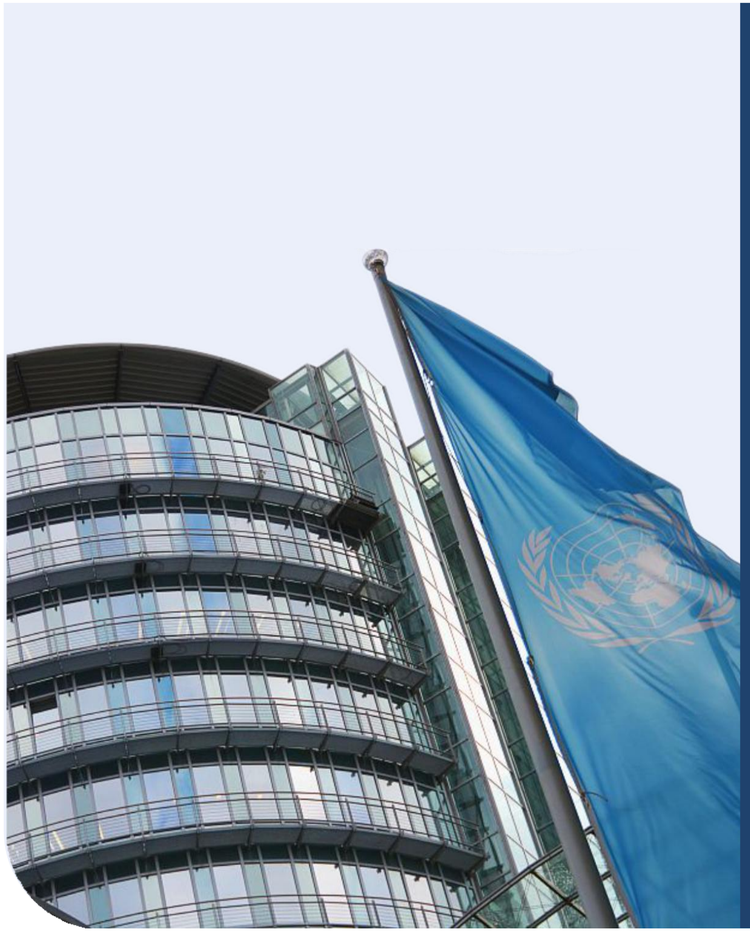
Advancing the Resource Nexus from Dresden



Mandate

The mandate of UNU-FLORES is to advance knowledge on the sustainable management of environmental resources through the Resource Nexus approach.

Strategic Approach

1. Research and Innovation Development
2. Education and Capacity Development
3. Outreach, Advocacy and Impact

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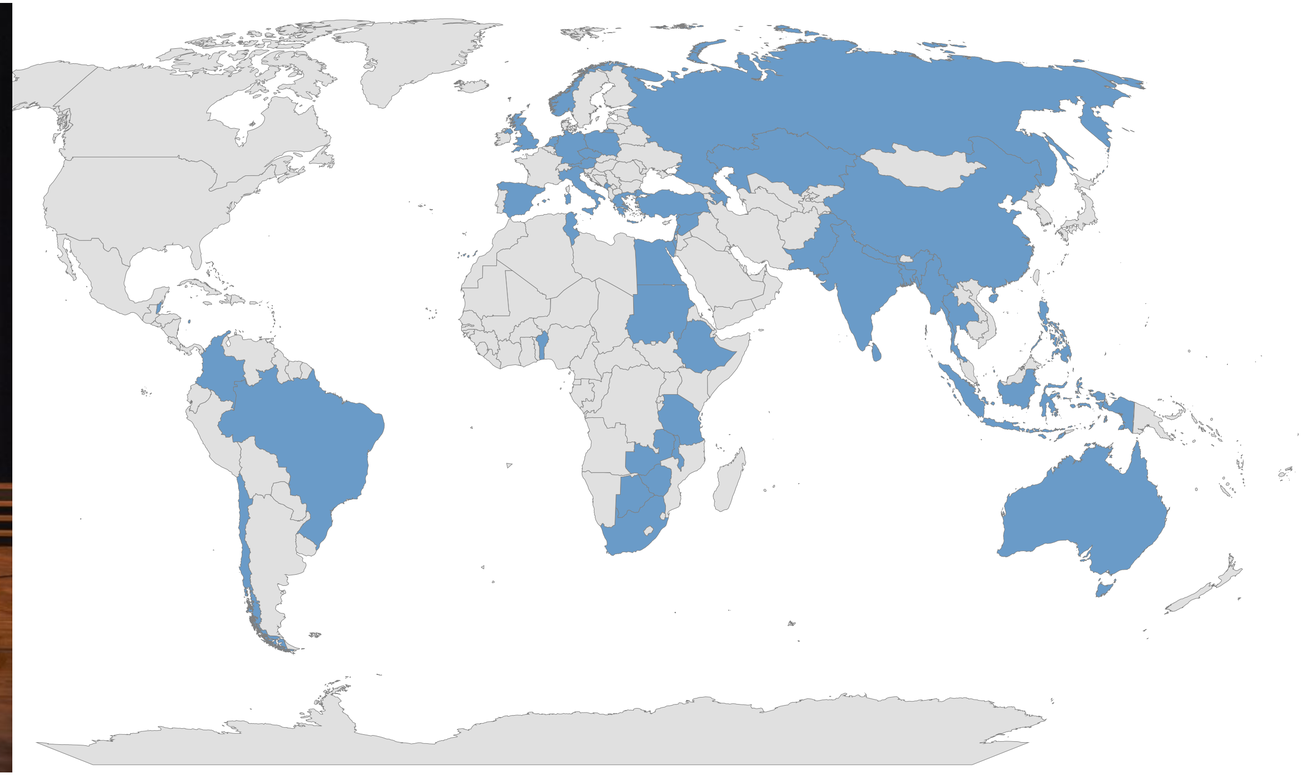
UNU-FLORES Team

111
Team Members

57
Female Colleagues

59
Colleagues from the Global South



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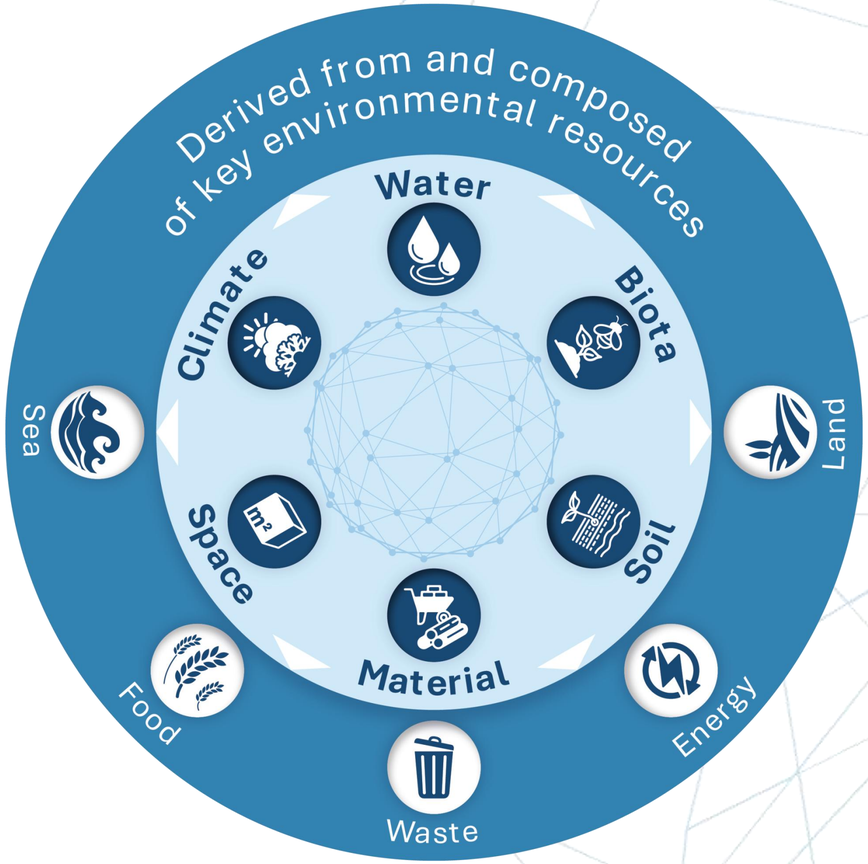
Resource Nexus Approach



An approach to consider the interplay and interlinkages between Resources, i.e., synergies as well as trade-offs

Rather than optimizing for a single resource, find the best overall solution

Include considerations around governance and financing

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Focus Areas

Advancing the Resource Nexus ...

Transformed Landscapes

Sustainable Buildings and Construction

Resilient Food, Forest and Ecosystems

Responsible Electronics

Circular Textiles

... to address the **triple planetary crisis** of climate change, biodiversity loss and pollution and to enable and empower people to sustainable **transform policies, businesses and societies** by respecting political, economic, societal, technological, environmental and legal contexts.

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Sustainability Nexus Analytics, Informatics, and Data (AID)

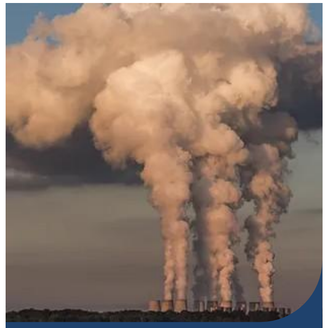
Air Pollution

Biological Invasions

Drought

Flood

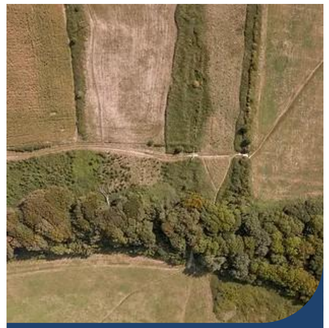
Food Security



Greenhouse Gas Emissions

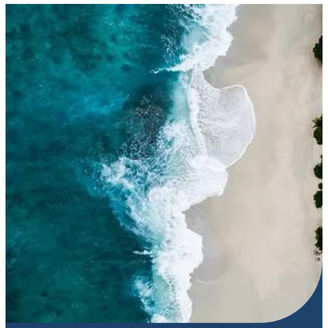
Groundwater

Infrastructure Resilience



Land Use Land Cover Change

Landslides and Land Subsidence



Sea Level Rise

Soil Health

Storms

Wetlands

Visit https://www.sustainabilityaid.net/

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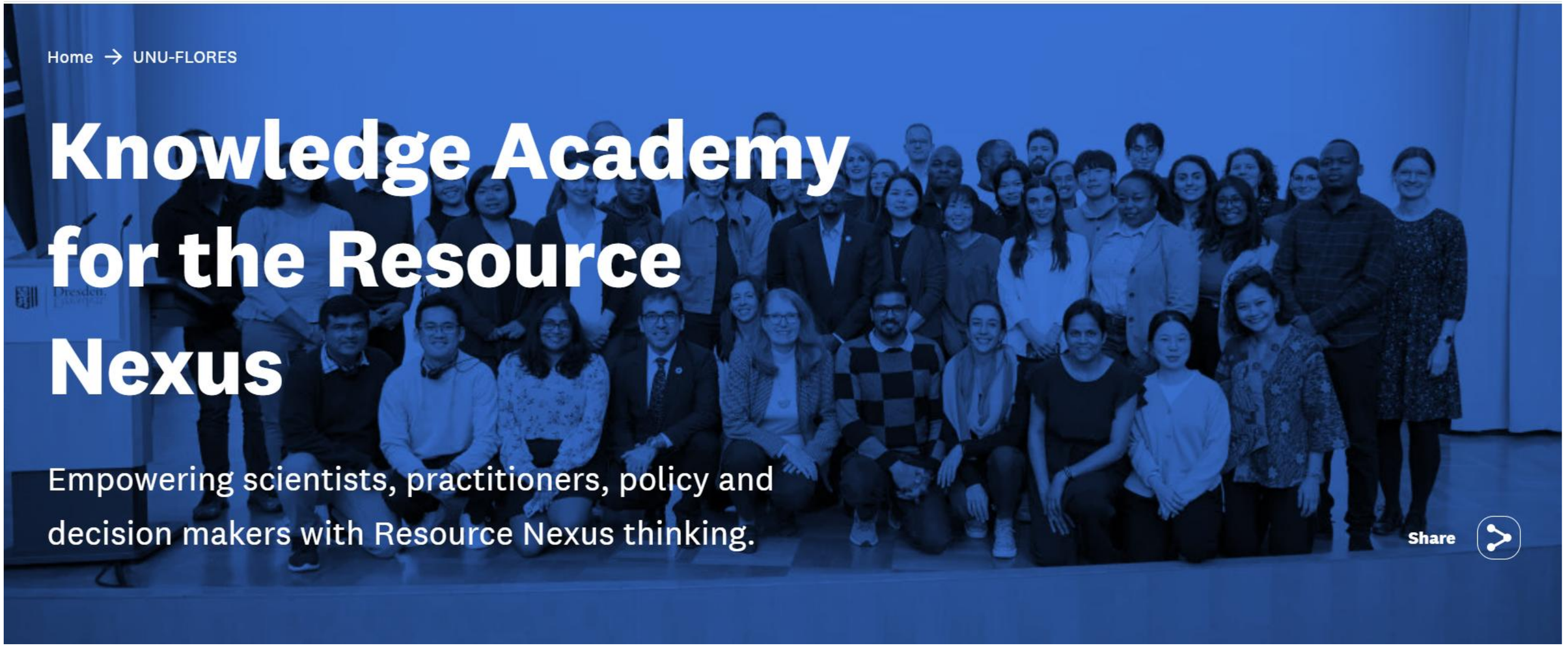

https://unu.edu/flores/knowledge-academy-resource-nexus-kare

UNU-FLORES Doctoral Programme

TECHNISCHE UNIVERSITÄT DRESDEN

Leibniz Institute of Ecological Urban and Regional Development

36
Doctoral researchers

32
Doctoral researchers are from the Global South

50%
Doctoral researchers are women

DAAD Deutscher Akademischer Austauschdienst
German Academic Exchange Service

BASF We create chemistry

IsDB Islamic Development Bank

KAAD Katholischer Akademischer Ausländer-Dienst

UNIDO

SMEKUL Sächsisches Staatsministerium für Energie, Klimaschutz, Umwelt und Landwirtschaft

DFG Deutsche Forschungsgemeinschaft

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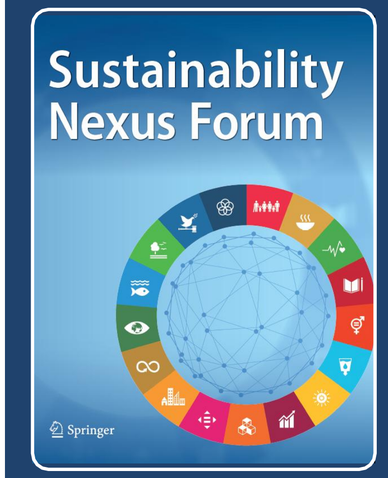
Sustainability Nexus Forum



A transdisciplinary journal which prioritises Nexus perspectives in the realm of Sustainability Transformation

Current Topical Collections

1. Nexus Perspectives for Sustainability Transformation
2. Nexus Perspectives for Sustainability, Just and Timely Transitions in the Era of Climate Change, Geopolitical Tension and Energy Insecurity
3. The Resource Nexus for New Modes of Science Policy Interaction
4. Sustainability Nexus Perspectives on Water Security and Climate Resilience
5. Data for Good: Promoting Data-Driven Nexus Approaches to Sustainability

Visit https://link.springer.com/journal/550

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2

REPOINT: Resource Nexus for Post-Mining Inclusive Transition

A living laboratory in Lusatia

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REPOINT - Resource Nexus for Post-Mining Inclusive Transition

1. Positioning the Lusatian lignite mining district as a model for coal transition regions worldwide

2. Sustainable and resource-effective transformation of industrial areas

3. Revitalization of post-coal landscapes

Office Strasse der Glasmacher 18, 02943 Weisswasser

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The only
UN staff member
with **Lusatia**
in the title

Alexey Alekseenko

Head of the Resource Nexus Laboratory in Lusatia

Education Dr.-Ing., Mining Engineering, TU Bergakademie Freiberg, Germany, 2018

Ph.D., Geoecology, Saint Petersburg Mining University, Russia, 2018

M.Sc., Environmental and Natural Resource Management, Lomonosov Moscow State University, Russia , 2014

Institute UNU-FLORES

Nationality Russian, Israeli

Contacts alekseenko@unu.edu

https://unu.edu/flores/about/expert/alexey-alekseenko

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Resource Nexus approach

The checklist to analyze **mining and processing legacies**

Climate:	greenhouse gas emissions
Water:	drainage, contamination
Biota:	biodiversity loss
Soil:	soil degradation
Material:	wasterock piles
Space:	extensive land use
Land:	landscape destruction
Waste:	slurry, tailings
Energy:	energy intensive extraction
Food:	deterioration of fertile landscapes

Image source:
Brouwer et al., 2024

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2024-2026: Resource Nexus Inventory of Post-Mining Legacies in Lusatia

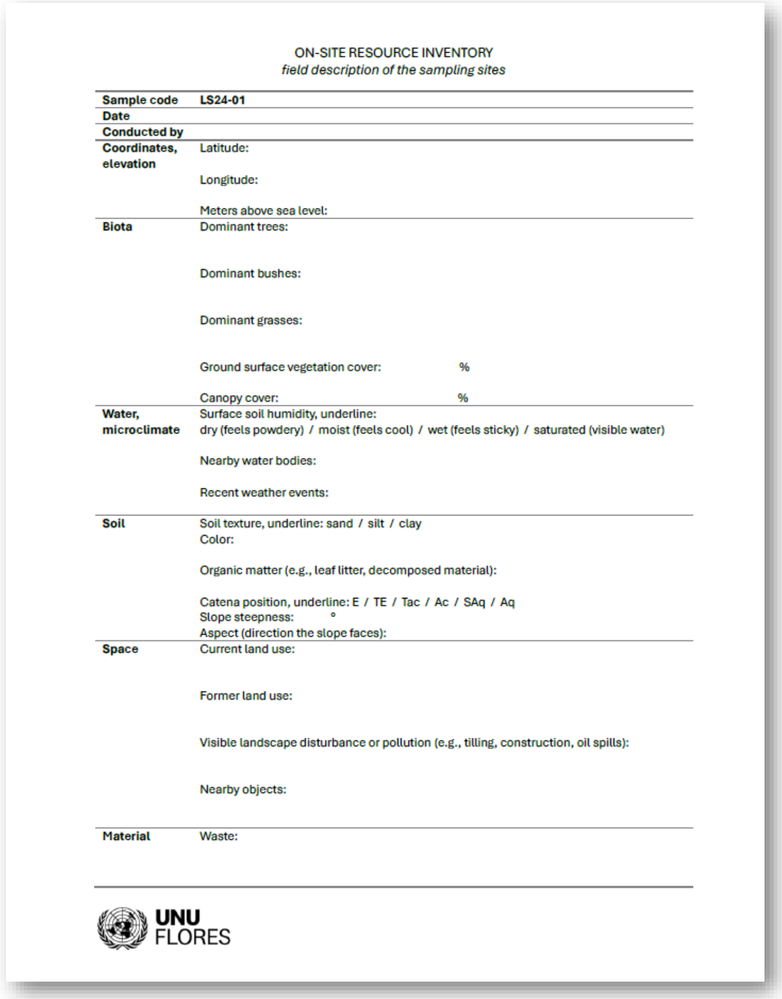
Field and lab studies of the mining-affected areas

Soils and bottom sediments of rivers and lakes

- Concentrations of trace elements
- Particle size distribution in soils
- Active soil acidity and organic carbon content

Air

- Dust fractions PM1, PM2.5, PM4, and PM10 on a regular grid



ON-SITE RESOURCE INVENTORY
field description of the sampling sites

Sample code	**LS24-01**
Date	
Conducted by	
Coordinates, elevation	Latitude: Longitude: Meters above sea level:
Biota	Dominant trees: Dominant bushes: Dominant grasses: Ground surface vegetation cover: % Canopy cover: %
Water, microclimate	Surface soil humidity, underline: dry (feels powdery) / moist (feels cool) / wet (feels sticky) / saturated (visible water) Nearby water bodies: Recent weather events:
Soil	Soil texture, underline: sand / silt / clay Color: Organic matter (e.g., leaf litter, decomposed material): Catena position, underline: E / TE / Tac / Ac / SAq / Aq Slope steepness: ° Aspect (direction the slope faces):
Space	Current land use: Former land use: Visible landscape disturbance or pollution (e.g., tilling, construction, oil spills): Nearby objects:
Material	Waste:

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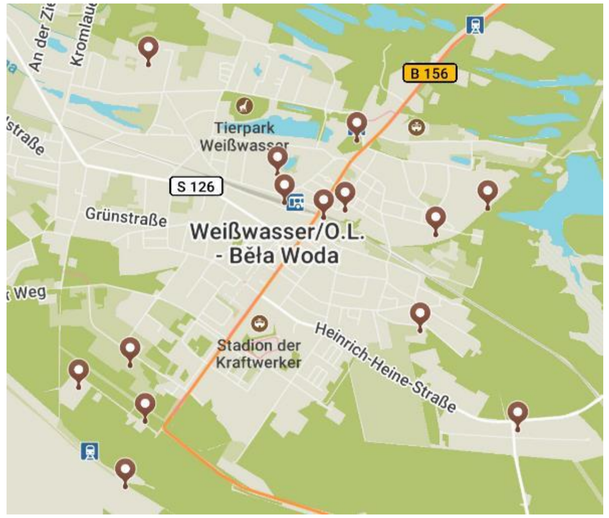
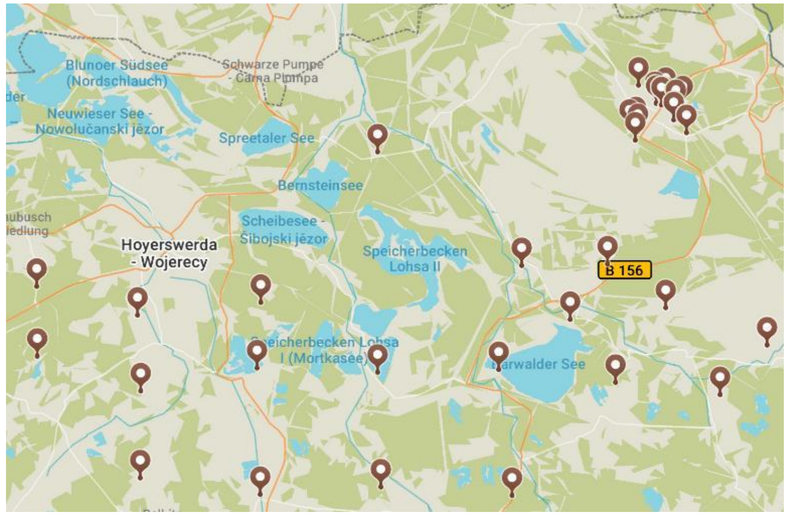
Soil pollution in Lusatia

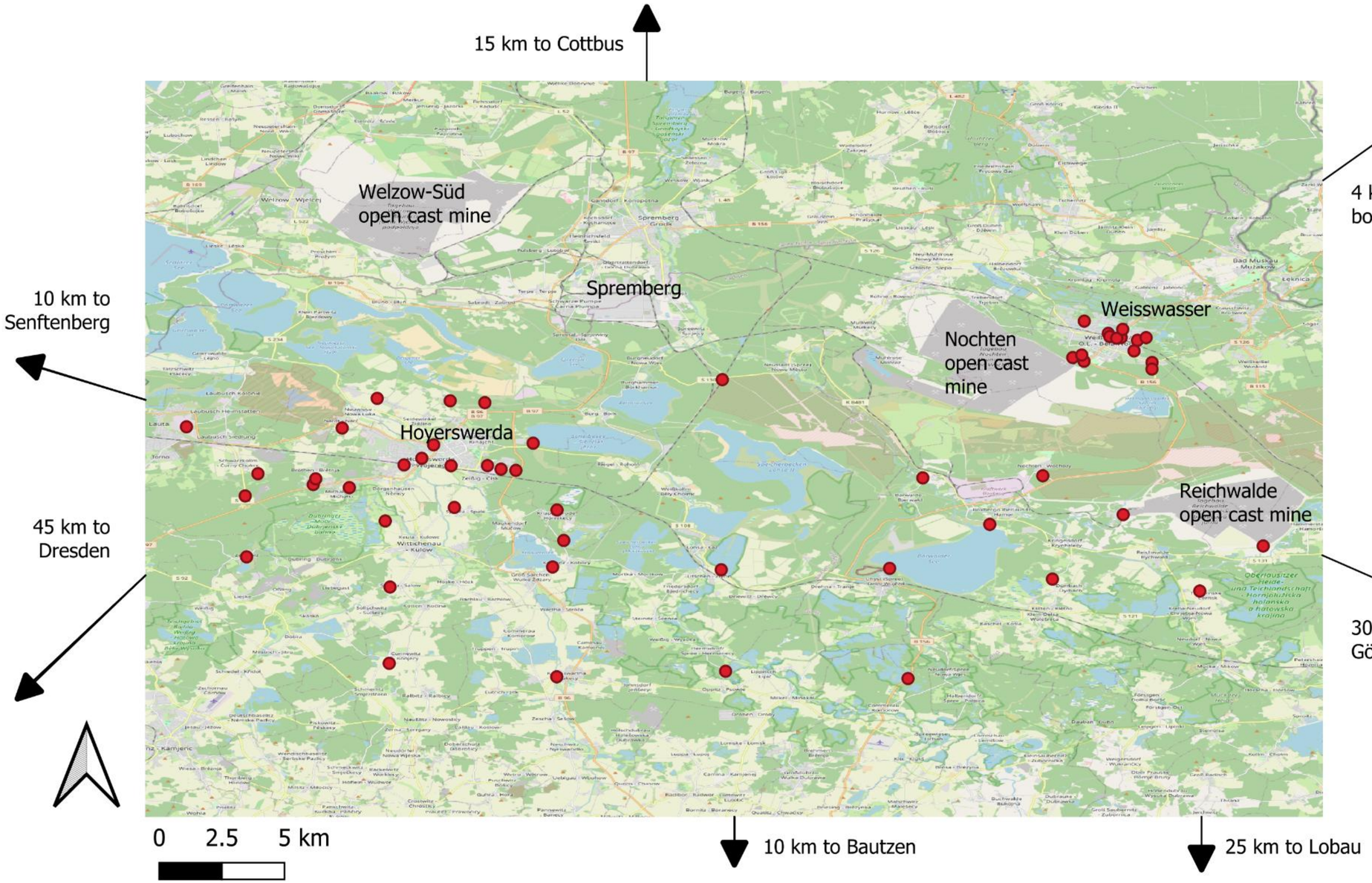
Soil pollution was reported as a critical issue in the Black Triangle: such observed pollutants as Zn, Pb, Cu, Cr, Cd, Co, and Ni pose risks to human health and the environment.

Contamination hotspots were found between the Schwarze Pumpe and Boxberg power plants, where **petrochemical plants, refineries, textile manufactures, and glasswork industry were active** (Som et al., 2002; Spiteri et al., 2005).

Rachwał et al. (2017) revisited old soil samples and revealed different levels of pollution, up to moderately contaminated. These sites are located near emission sources, notably power plants near Hoyerswerda and Weisswasser.







Map of soil and sediment sampling sites in Lusatia

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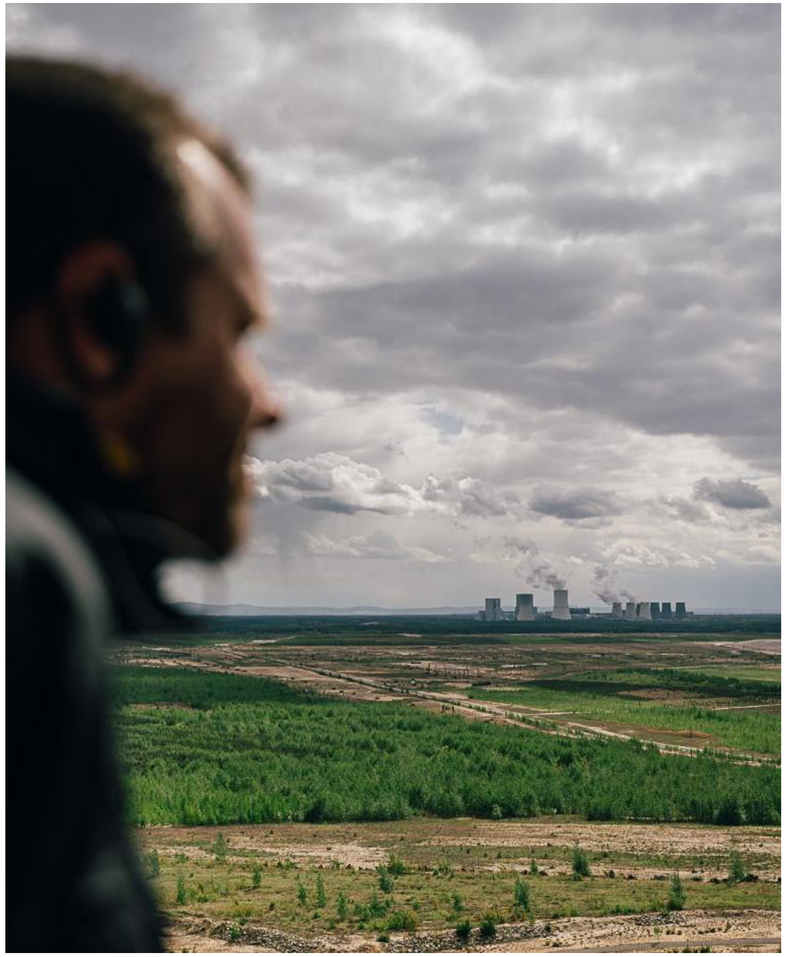
Post-mining landscape restoration: Hands-on workshops



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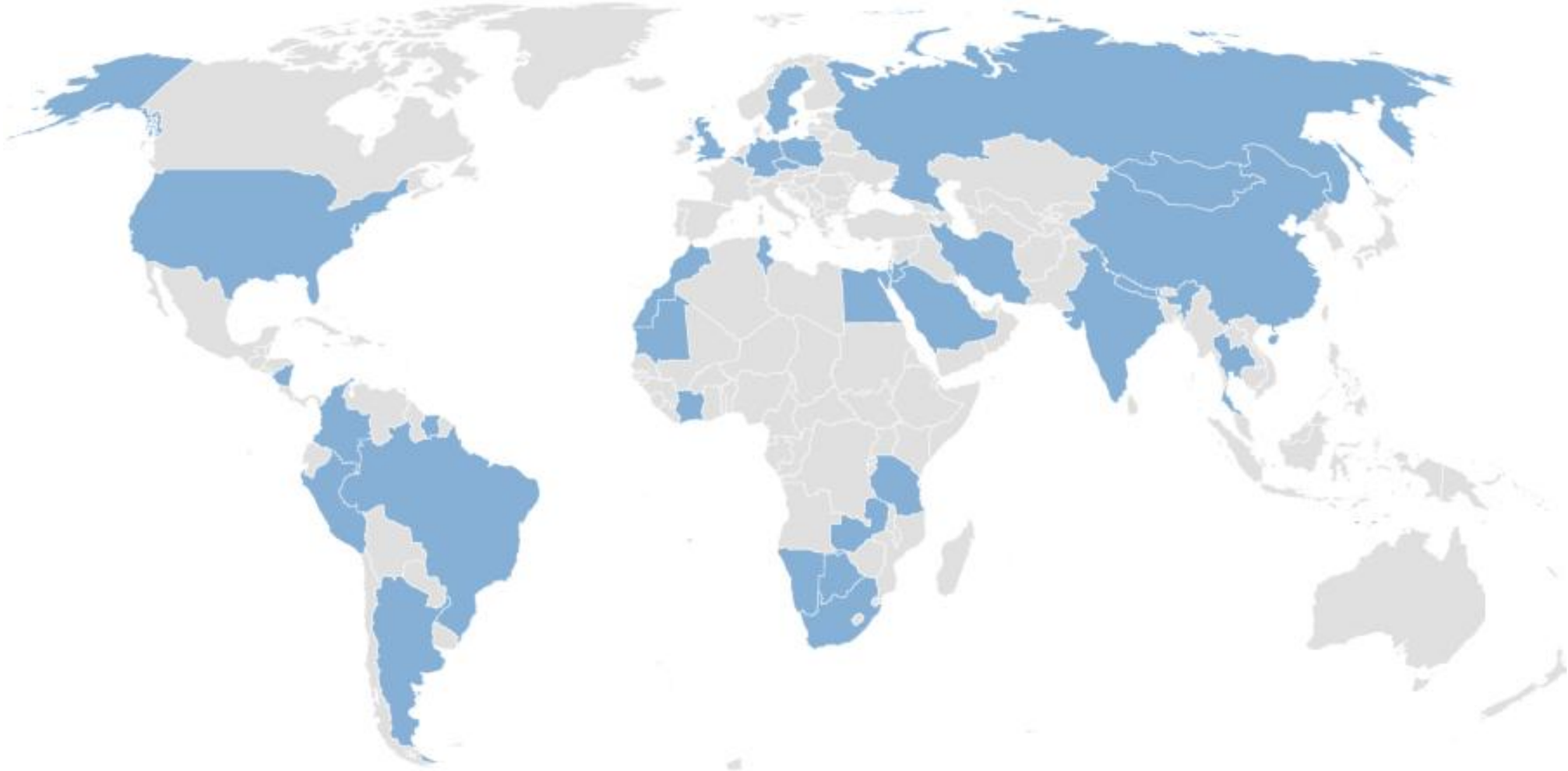
United Nations Convention to Combat Desertification

G20 GLOBAL LAND INITIATIVE

Workshop participants and speakers: Countries represented



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United Nations Convention to Combat Desertification

G20 GLOBAL LAND INITIATIVE

Hands-on training

Post-Mining Landscape Restoration Workshop

Saxony, Germany

April 2024

Key facts:

- 50 participants, more than a half from the Global South
- 2 days of classwork
- 2 days of field trips

Donor: G20 Global Land Initiative, UNCCD

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United Nations Convention to Combat Desertification

G20 GLOBAL LAND INITIATIVE

Field trips

Restored and active lignite mining areas

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United Nations Convention to Combat Desertification

G20 GLOBAL LAND INITIATIVE

Post-mining landscape restoration: Hands-on workshops

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United Nations Convention to Combat Desertification

G20 GLOBAL LAND INITIATIVE

Post-mining landscape restoration: Webinars

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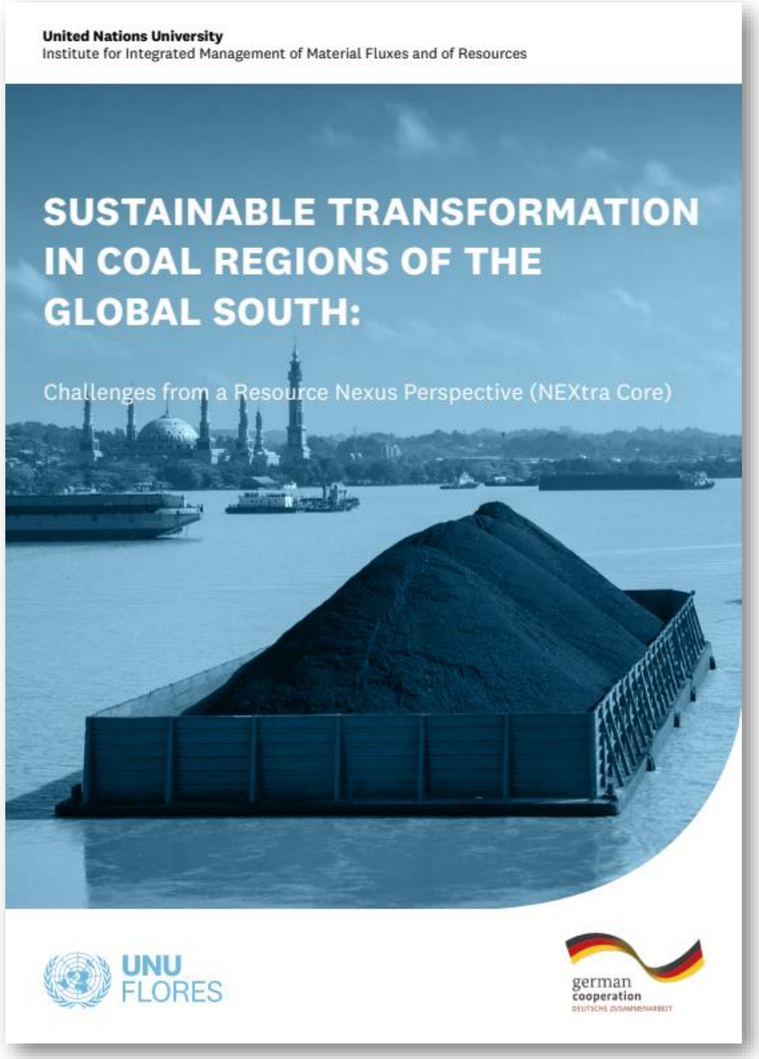
Resource Nexus approach



Post-coal challenges in **Colombia, Mozambique, South Africa, and Indonesia**:

- Environmental legacies
- Energy transition
- Economic restructuring
- Social implications

Download the report:

https://rue.bmz.de/resource/blob/157250/2023-06-20-nextra-core-final-report-finalversion.pdf

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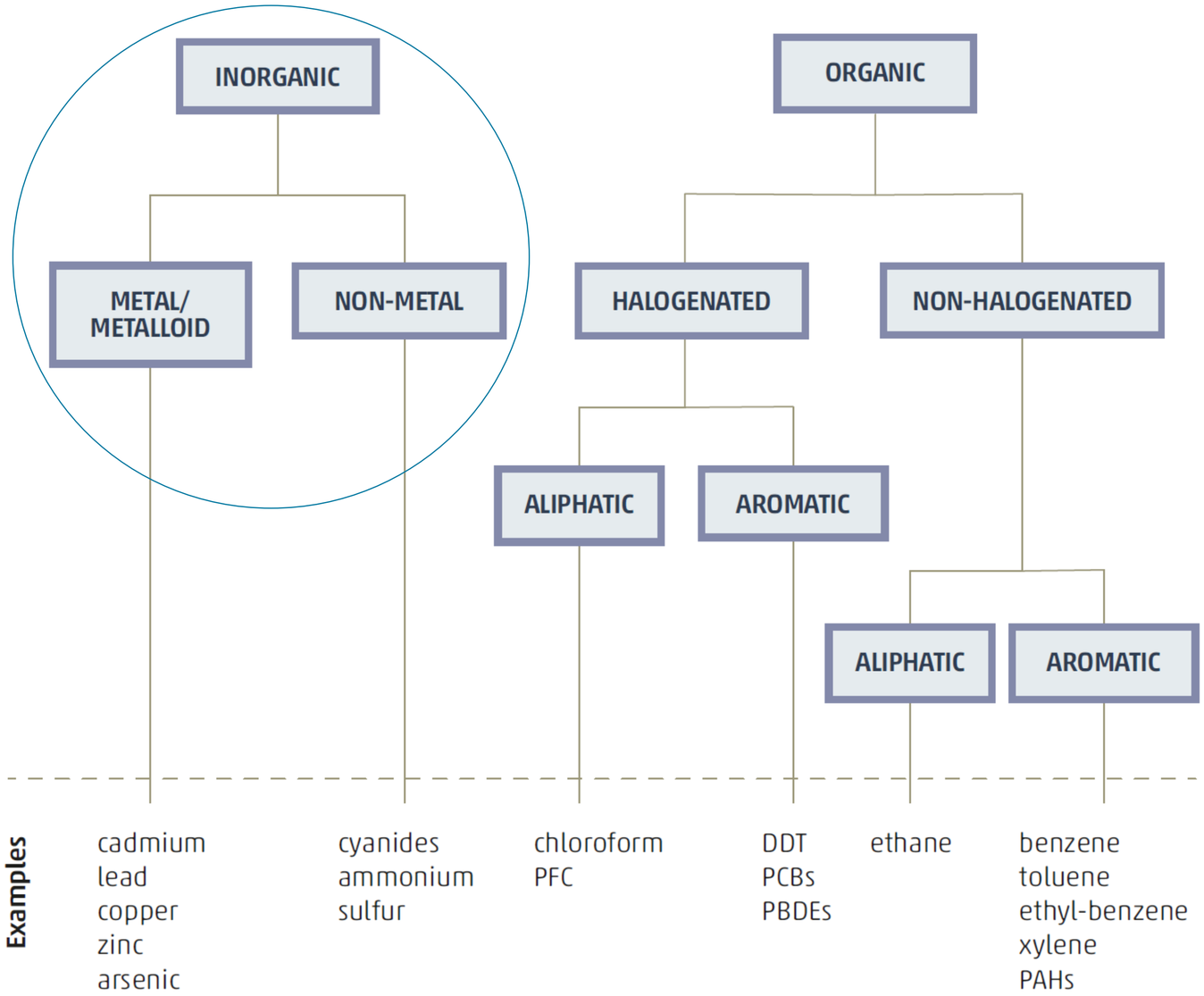
3

Global pollutant concentrations
in coal mine soils

Photo credits: A. Dollmeyer

Protocol for meta-study: Which pollutants?



Systematic categorization of the main pollutants in soils according to IUPAC

DOI: 10.4060/cb4827en

Data gathering

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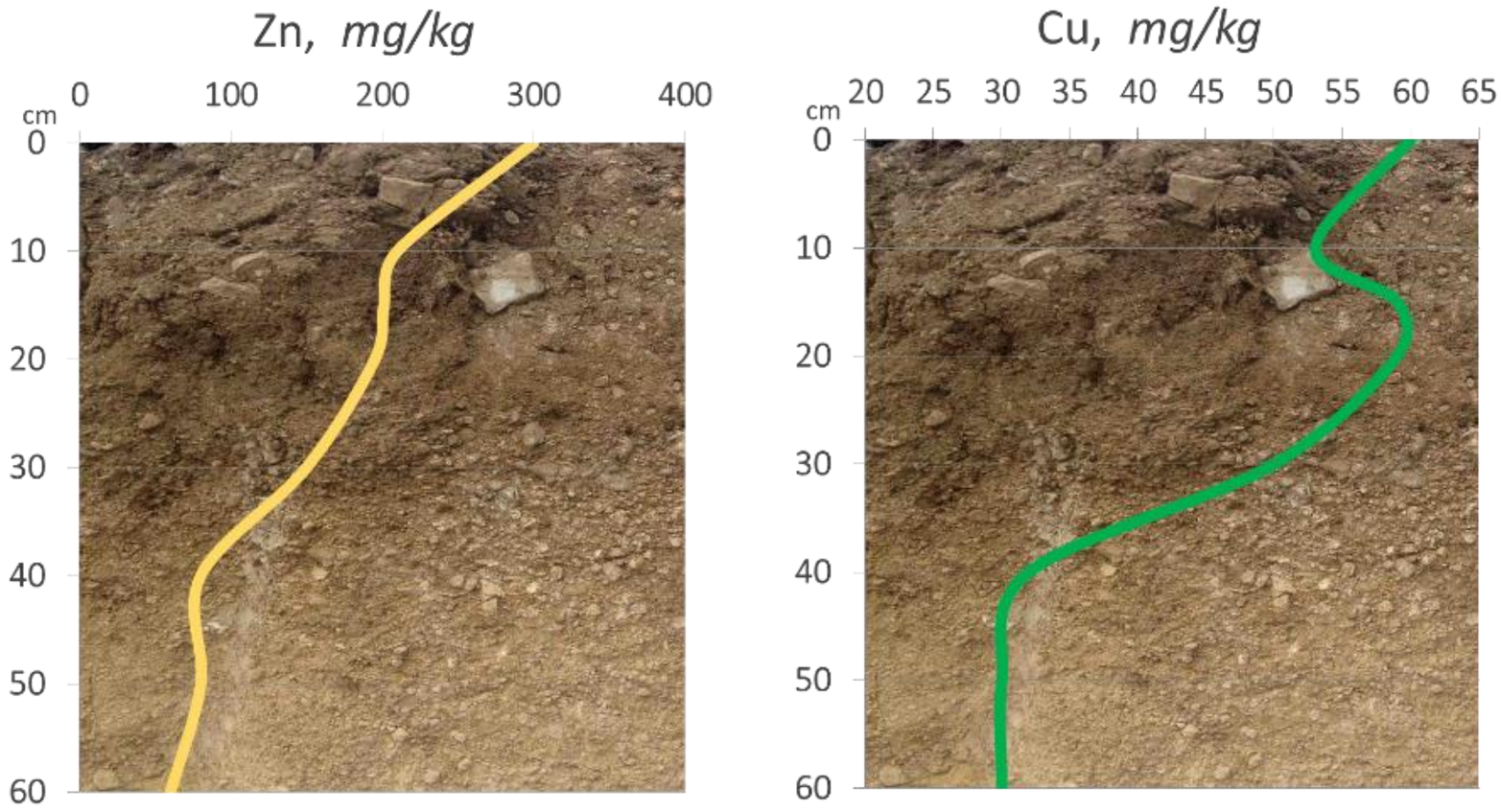
Data collection: meta-study and own samples

Soil type:
Technosols (WRB)

Topsoil sampling



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Protocol for meta-study: Keywords

What to look for?

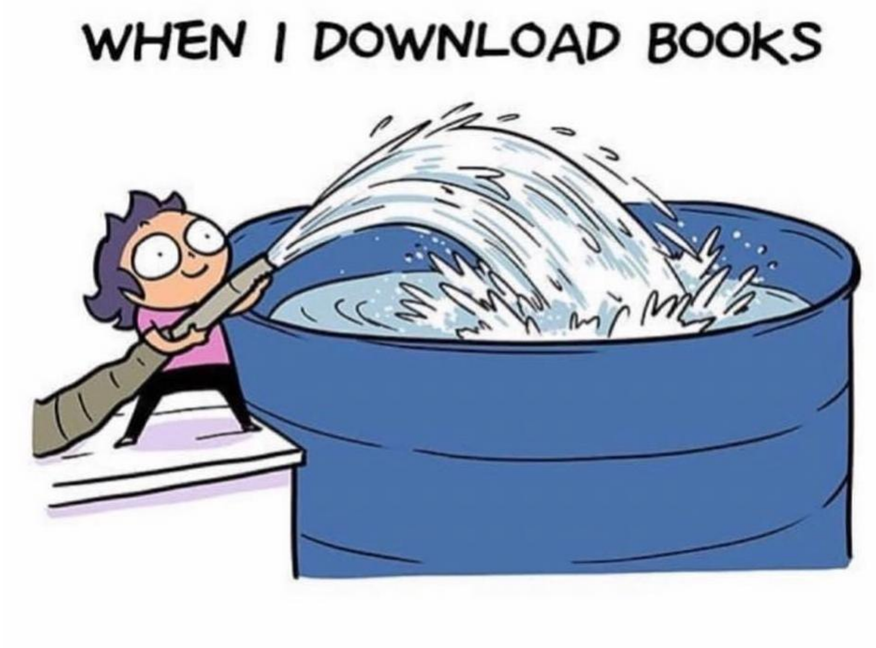
The typical set of **keywords**: “coal mine”, “soil/dumps”, “pollution/contamination”, and “elements/metals”

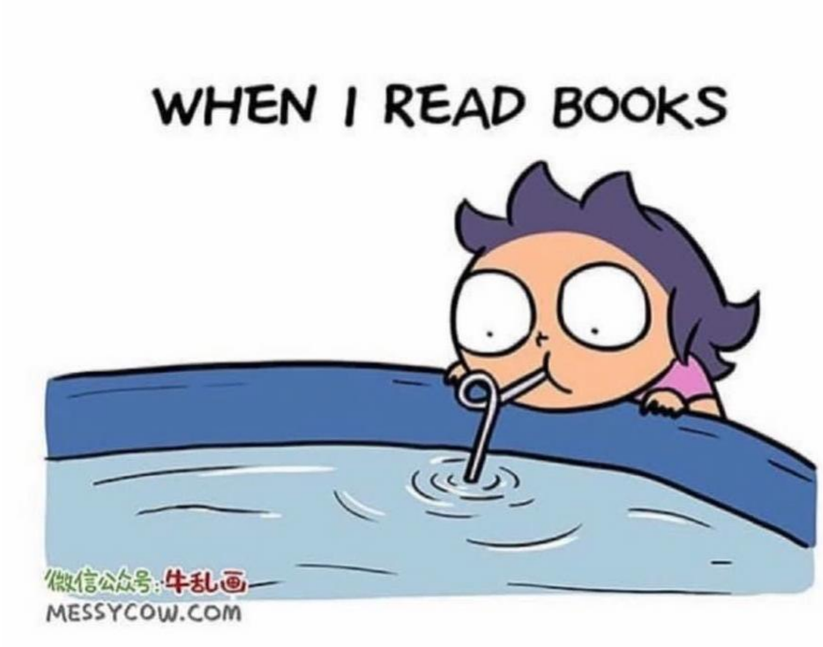
The **variations** like “colliery”, or “wasterock”, or “brownfield”, or “geochemical transformation” were applied too but gave fewer search results

Where?

Search engines: Google Scholar, Science Direct, Springer Link, MDPI, and SciELO

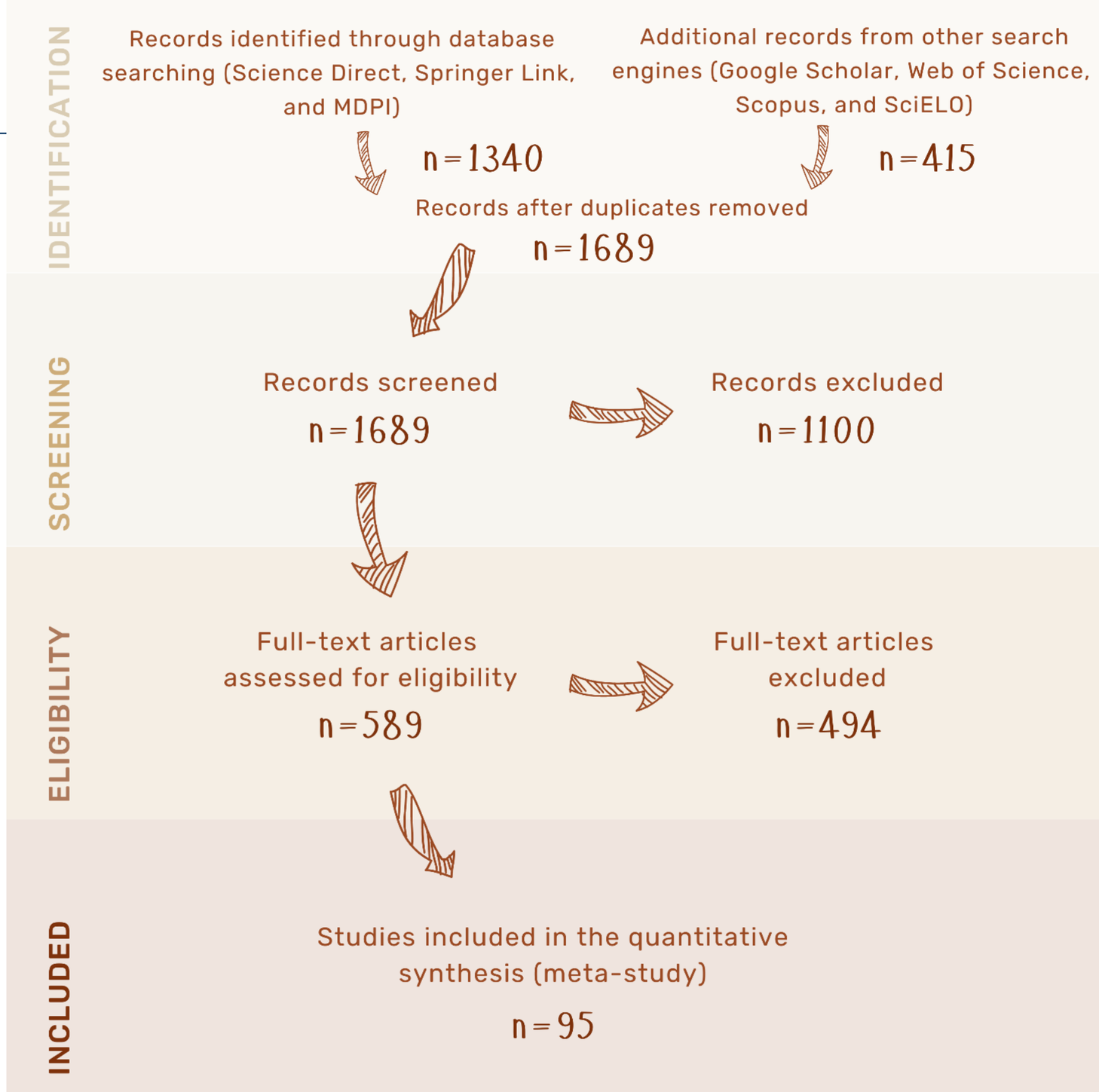
Data gathering





Workflow chart

The steps of the meta-study taken to collect the statistically reliable dataset on the concentrations of chemical elements in the coal mine soils



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Coal mining regions reviewed

One coal field (coal basin) was considered as a single sample

≠

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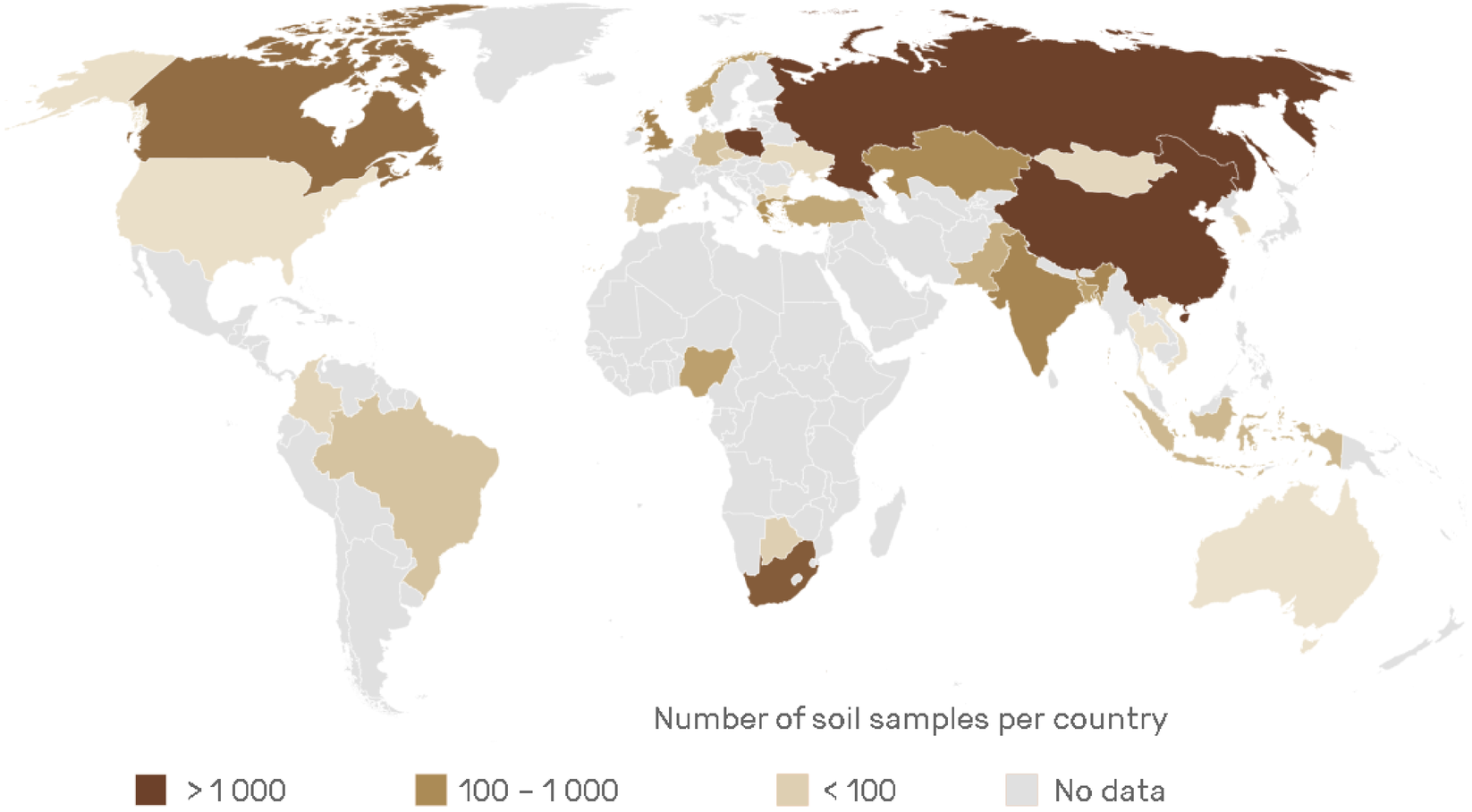
Countries

Papers published in peer-reviewed journals **from the year 2000**

Covering **29 major coal-producing countries** of Eurasia, Africa, Australia, and the Americas

No.	Country	Articles	Samples
1	Australia	1	27
2	Bangladesh	6	92
3	Botswana	1	27
4	Brazil	2	42
5	Bulgaria	1	22
6	Canada	1	260
7	China	15	8 512
8	Colombia	4	30
9	Czechia	1	29
10	Germany	3	58
11	Greece	2	110
12	India	8	252
13	Indonesia	1	20
14	Kazakhstan	1	190
15	Korea	4	59
16	Mongolia	2	30
17	Nigeria	2	104
18	North Macedonia	1	52
19	Poland	3	1 299
20	Portugal	2	19
21	Russia	28	1 322
22	South Africa	3	723
23	Spain	1	24
24	Thailand	1	17
25	Turkey	2	76
26	UK	2	45
27	Ukraine	2	15
28	USA	5	78
29	Vietnam	1	31
	Total	**106**	**13 565**

Coal mining regions reviewed



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Global pollutant concentrations in coal mine soils, mg/kg

No.	Element	Content
1	Al	96330
2	Ca	3643
3	Fe	35550
4	K	369136
5	Mg	3516
6	Na	2704
7	P	1619
8	S	4082
9	Si	211074
10	Ti	5727

No.	Element	Content
11	Ag	0.2
12	As	95.3
13	Ba	444.2
14	Bi	5.8
15	Cd	3.6
16	Co	15.0
17	Cr	137.7
18	Cs	7.7
19	Cu	44.7
20	Ga	15.7
21	Ge	1.6
22	Hf	3.1
23	Hg	12.3
24	Mn	604.0
25	Mo	2.3
26	Nb	11.7

No.	Element	Content
27	Ni	104.2
28	Pb	70.8
29	Rb	104.6
30	Sb	6.3
31	Sc	12.4
32	Se	0.9
33	Sn	23.0
34	Sr	284.0
35	Ta	0.8
36	Th	10.3
37	U	2.6
38	V	106.6
39	Y	19.4
40	Zn	134.3
41	Zr	246.8
42	∑REE	311.2

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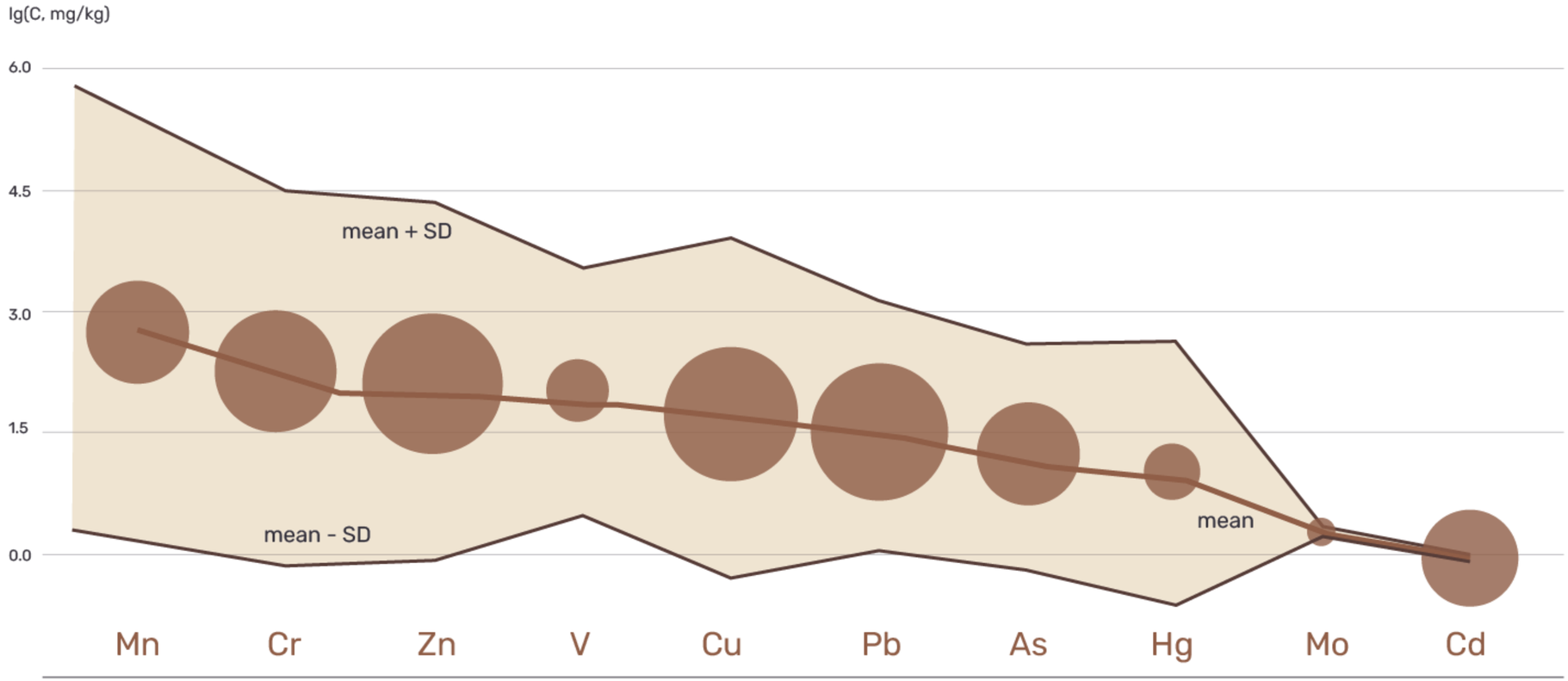
10 most studied elements in the soils of coal mines worldwide



The central line shows the mean contents of each element, the top and bottom lines indicate the spread of values, i.e., mean $\pm$ standard deviation. The sizes of circles are proportional to the number of coal fields where each of the elements was analyzed.

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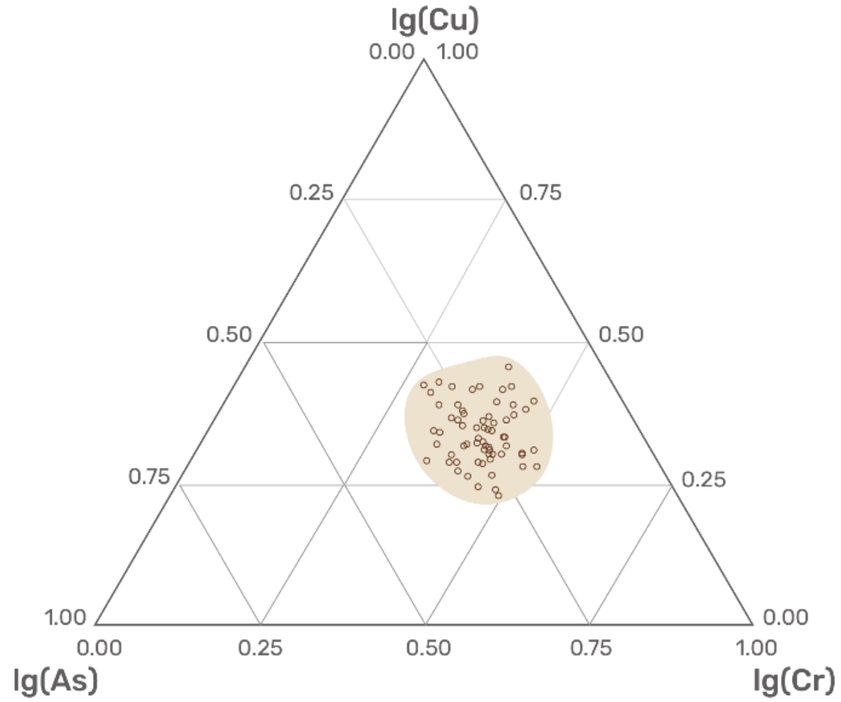
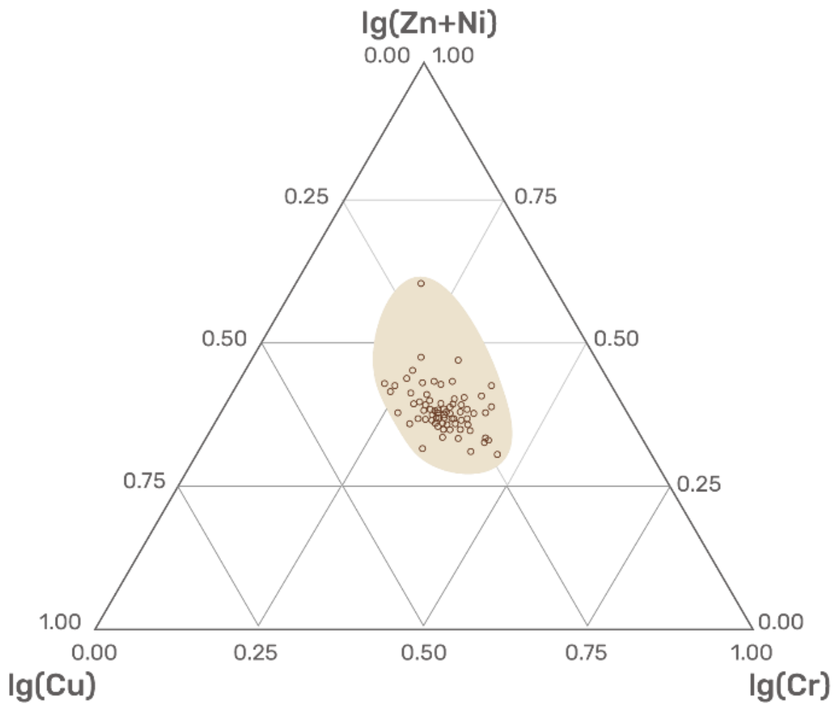
10 most studied elements in the soils of coal mines worldwide





As, Cr, and Cu demonstrate significant positive dependence between each other (left graph), similarly to Cr, Cu, and Zn+Ni (right). These large-scale global dependencies are similar to those found in case studies of natural and anthropogenic soils.

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Elements typically accumulated by coals

(a) non-coalphile elements: I, Cl, Mn, Br, Rb, and Cs;

(b) weakly or moderate coalphile elements: Ti, Zr, F, Cd, V, Ta, Cr, Y, Li, and P;

(c) coalphile elements: Ni, Hf, Sn, La, Co, Ba, Sc, Nb, Sr, Th, Ga, Cu, REE, Zn, Au, In, Pb, U, B, and Be;

(d) highly coalphile elements: Ag, Sb, Tl, As, Mo, Ge, Hg, Bi, and Se.

DOI: 10.1016/j.coal.2009.01.002

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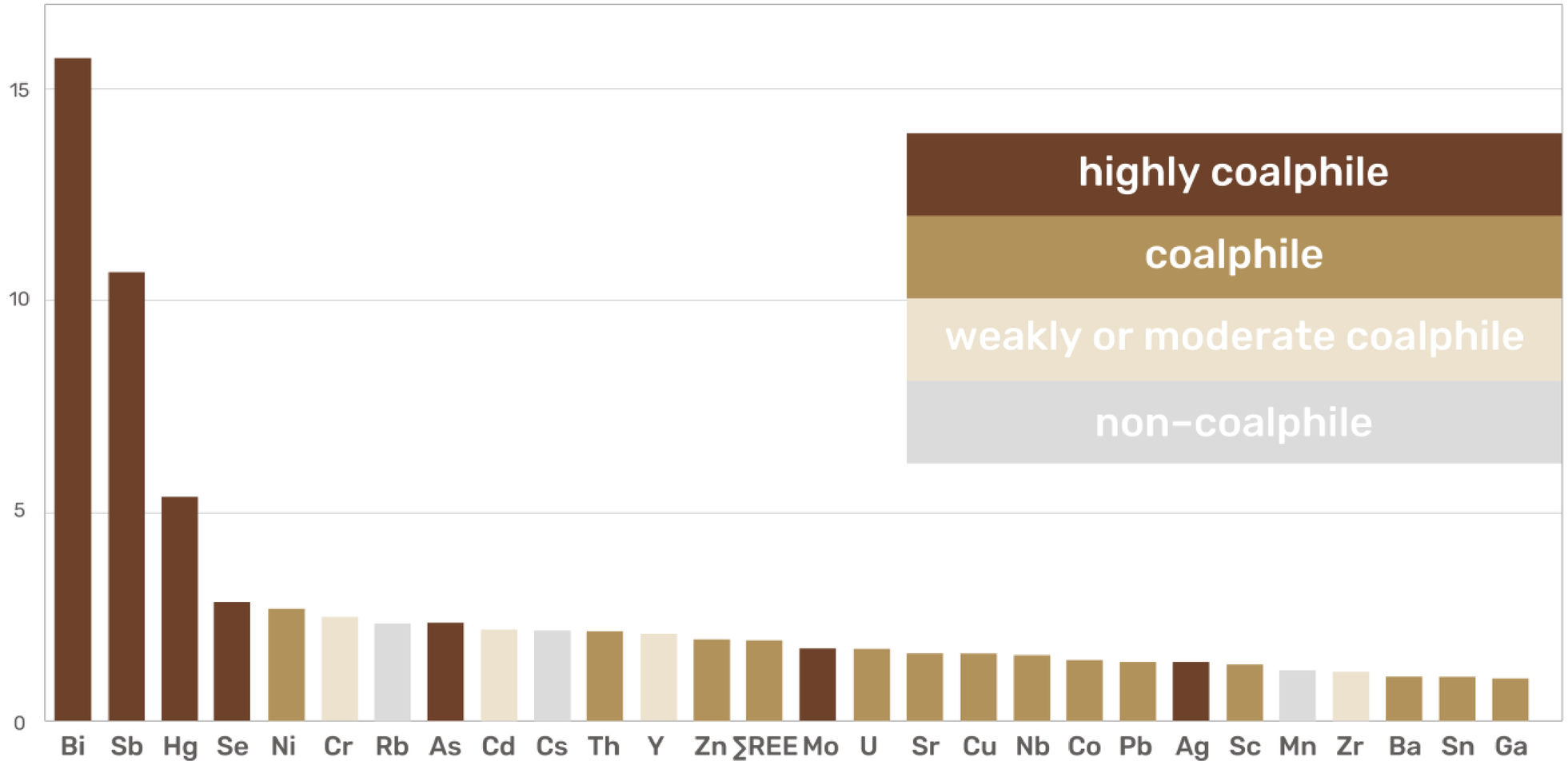
Priority pollutants in coal mine soils: excess factor over natural levels



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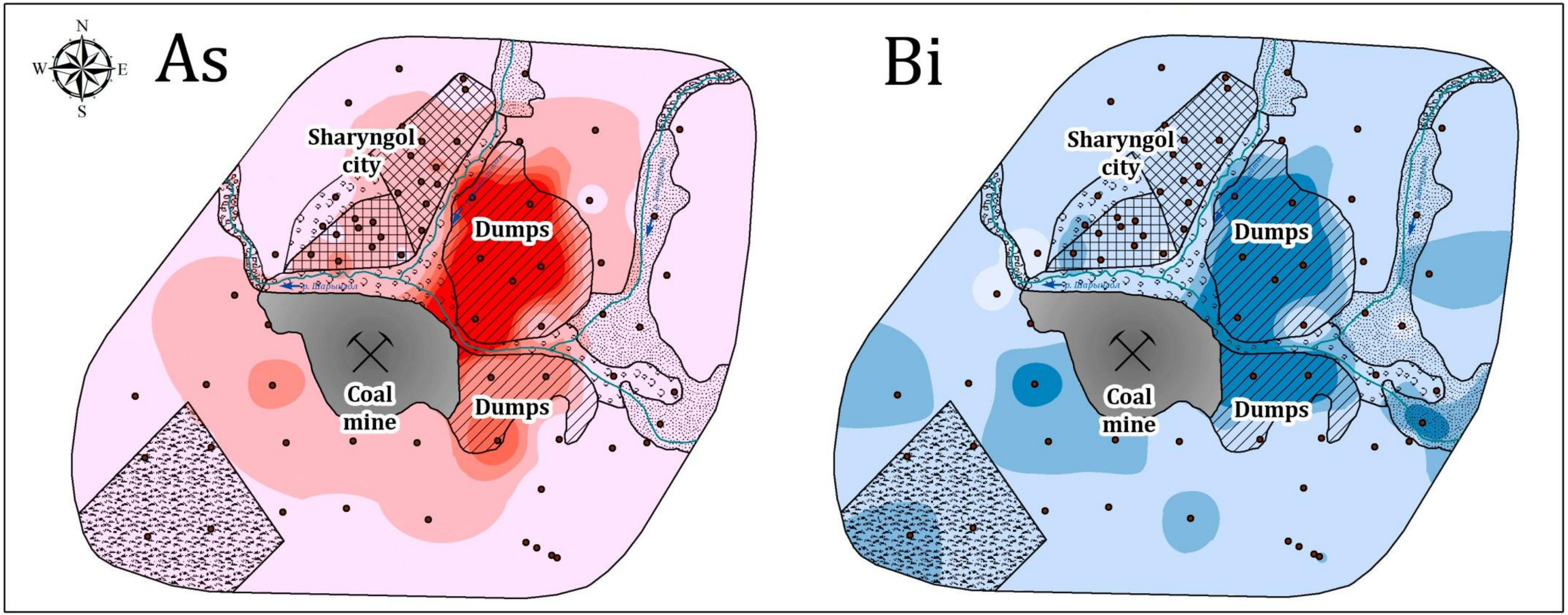
Polluted Technosols



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4

What to do?

Converting the fundamental data
into policy action

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FROM

META-ANALYSIS

Peer-reviewed studies in **2000–2022**

All continents, **32 countries**

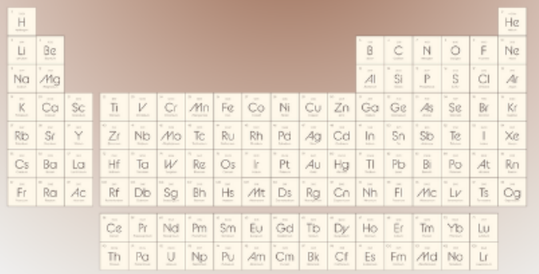
Chemical analyses of **13,925 samples**

Soils of coal mines before reclamation

TO

GLOBAL REFERENCE DATASET

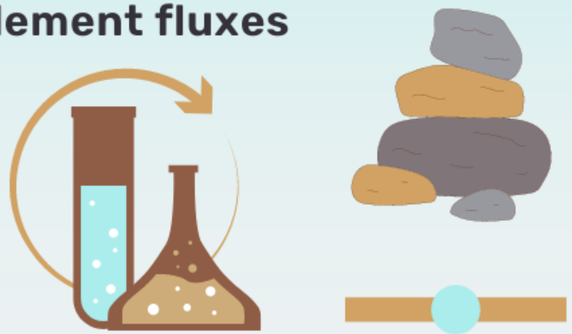
Concentrations of **41 chemical elements**, ∑REE, and TOC in soils of coal mines worldwide



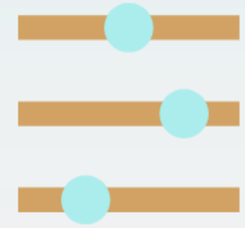
FOR

SCIENCE & PRACTICE

Basic research of **chemical element fluxes**



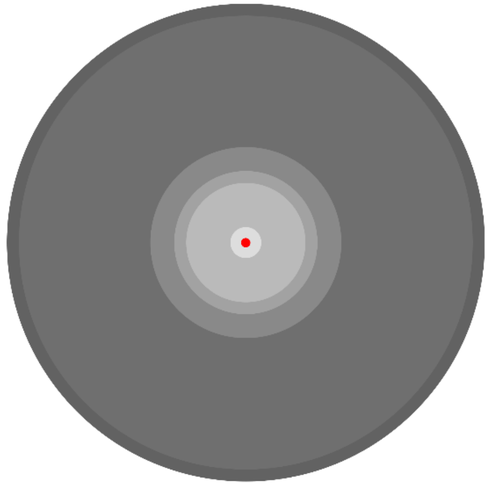
Reference levels for future case studies of coal mines



Prediction of contamination for potential new mines

Revealed priority pollutants **for remediation**

Screening against the national soil quality guidelines of six regions

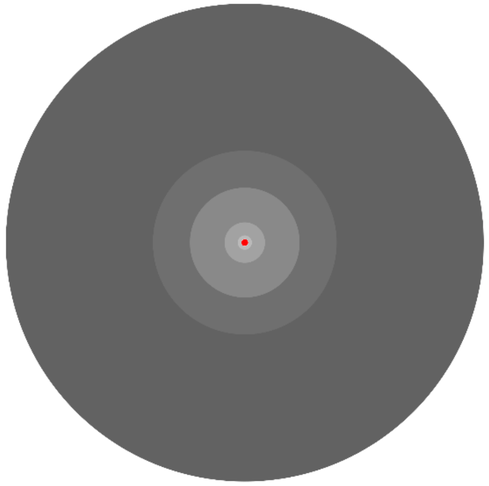


Pb, mg/kg

39

Reference levels in coal mine soils

Threshold levels	
130	Russia
500	China
600	Canada
800	USA
1900	South Africa
2000	Germany

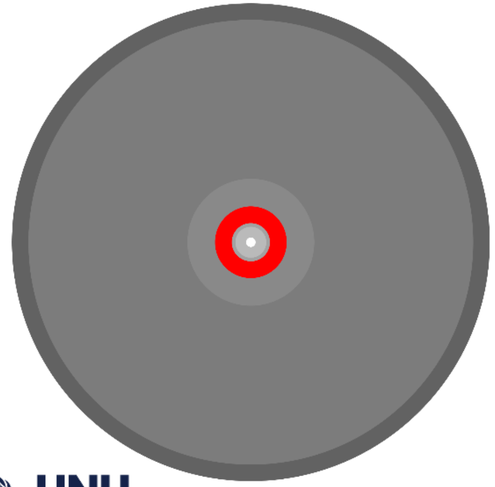


Cd, mg/kg

0.9

Reference levels in coal mine soils

Threshold levels	
1	China
2	Russia
22	Canada
60	Germany
100	USA
260	South Africa



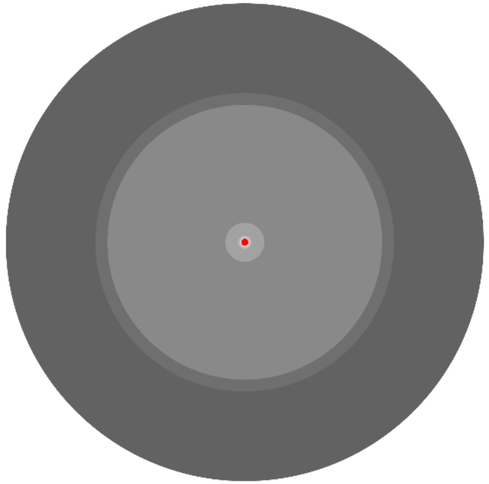
As, mg/kg

Threshold levels	
3	USA
10	Russia
12	Canada

16

Reference levels in coal mine soils

Threshold levels	
40	China
140	Germany
150	South Africa



Hg, mg/kg

0.4

Reference levels in coal mine soils

Threshold levels	
1,5	China
2,1	Russia
6,5	South Africa
46	USA
50	Canada
80	Germany

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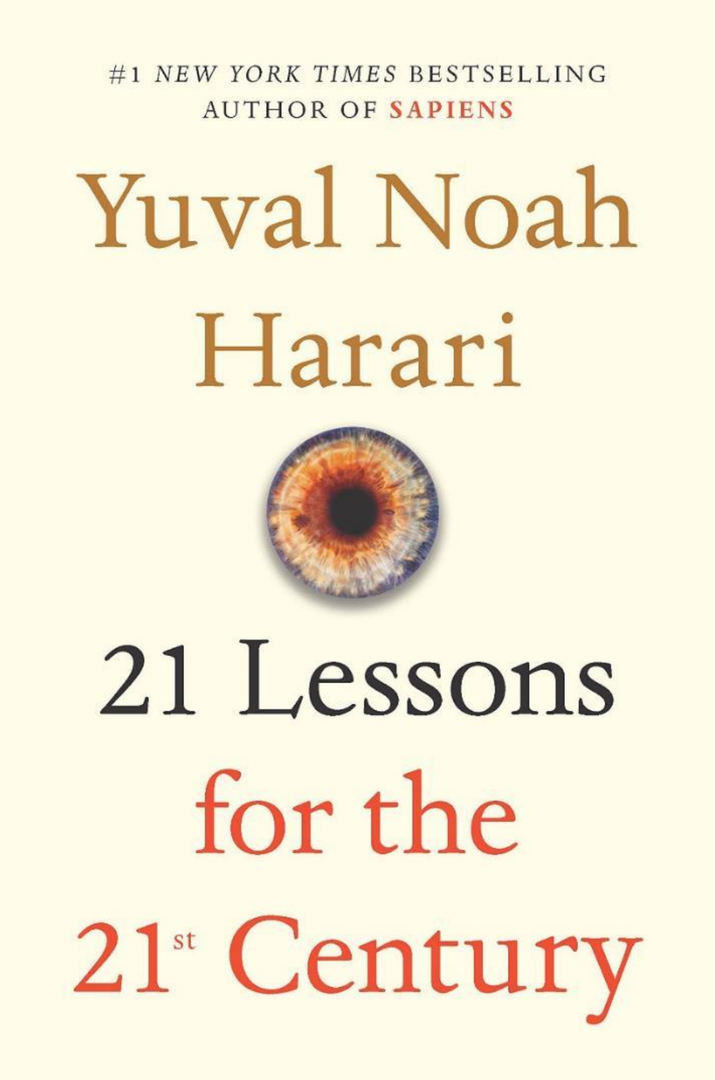
Limitations of use



The figures reflect the combined impact of technogenic and natural processes occurring during a certain time period: the end of the XX century – the beginning of the XXI century.

With advancing technology, the numbers may gradually change.

The rate of these changes is still poorly predictable.

https://www.amazon.com/-/es/Yuval-Noah-Harari/dp/0525512179

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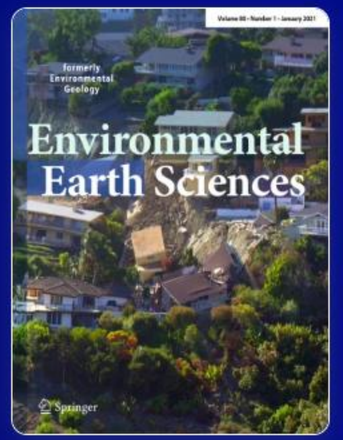

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https://doi.org/10.1007/s12665-025-12160-0

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alekseenko@unu.edu