TEXTE
87/2017

Discussion of the environmental limits of primary raw material extraction and development of a method for assessing the environmental availability of raw materials to further develop the criticality concept (ÖkoRess I)

A method for a site-related approach

For our Environment

Umwelt Bundesamt

TEXTE 87/2017

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Discussion of the environmental limits of primary raw material extraction and development of a method for assessing the environmental availability of raw materials to further develop the criticality concept (ÖkoRess I)

A methodology for a site-related approach

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List of abbreviations

AMAP	Arctic Monitoring and Assessment Programme
AMD	Acid Mine Drainage
AZE	Alliance for Zero Extinction
BREF	Best Available Techniques Reference Document
EHP	Environmental hazard potential
EIA	Environmental Impact Assessment
EITI	Extractive Industries Transparency Initiative
FPIC	Free, Prior and Informed Consent
GAR	Global Assessment Report on Disaster Risk Reduction
GARD	Global Acid Rock Drainage Guide
GRI	Global Reporting Initiative
GSHAP	Global Seismic Hazard Assessment Program
IAEA	International Atomic Energy Agency
IBA	Important Bird Area
ICCA	Indigenous and Community Conserved Areas
ICME	International Council on Metals and the Environment
ICMI	International Cyanide Management Code For the Manufacture, Transport and Use of Cyanide In the Production of Gold
ICMM	International Council on Mining and Metals
ICOLD	International Commission on Large Dams
INAP	International Network for Acid Prevention
IRMA	Initiative for Responsible Mining Assurance
IUCN	International Union for Conservation of Nature
TSM	Towards Sustainable Mining
UNEP	United Nations Environmental Program
UNISDR	United Nations International Strategy for Disaster Reduction
USGS	U.S. Geological Survey
WDPA	World Database on Protected Areas
WGI	World Governance Indicator
WSI	Water Stress Index

WTA	Withdrawal to availability
VF	Variation factor

1 Introduction

The report presented here 'Evaluation of the environmental hazard potentials involved in the extraction of abiotic primary raw materials – A method for a site-related approach' is a partial report within the ÖkoRess I[1] project prepared by the Öko-Institut, ifeu and Projekt-Consult on behalf of the Federal Environment Agency. It introduces the development of a method that can be used to evaluate and compare the environmental hazard potentials of mining sites.

The following (partial) reports have also been compiled and published within the ÖkoRess I project:

- 'Discussion of the environmental limits of primary raw material extraction and development of a method for assessing the environmental availability of raw materials to further develop the criticality concept' – ÖkoRess I Concept Volume
- 'Evaluation of the environmental hazard potentials involved in the extraction of abiotic primary raw materials – A method for a raw material-related approach'.[2]
- 'Mining residues' (This text does not exist as a Federal Environment Agency text, but has already been published as an independent report by the project team[3] in the course of ÖkoRess I).

Since the intention is for the documents to be read as stand-alone reports, it was necessary to incorporate some parts of the text into several reports. This was particularly the case for the reports on site-related evaluation and raw material-related evaluation, since the report on site-related evaluation presented here outlines the groundwork for the raw material-related evaluation method.

In addition to the above reports, environmental impacts at mining sites have also been described in 40 case studies, and their environmental hazard potentials assessed using the method outlined here. The most important case studies have also been published. The procedure for selecting, describing and assessing the case studies is, furthermore, described in the ÖkoRess I Concept Volume.

2 Background

The extraction of abiotic primary raw materials such as ores, coal, industrial minerals and building materials always constitutes intervention in the natural environment, and in many cases is associated with significant environmental impacts. Depending on the type and character of mining, they lead to a large-scale reshaping of the natural environment, the loss of ecosystems, changes in the water balance, and the pollution of soil, air and water.

The impacts of mining activities depend to a great extent on the basic conditions prevailing at the individual sites with respect to the geological site conditions, the technology used, and the natural and social environment conditions.

The method presented is designed to assist with 'roughly' assessing the most important aspects of this, even when there is no possibility of carrying out relevant surveys on site.

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[1] Full title: 'Discussion of the environmental limits of primary raw material extraction and development of a method for assessing the environmental availability of raw materials to further develop the criticality concept', FKZ 3713 93 302

[2] Sources of the three ÖkoRess I texts: https://www.umweltbundesamt.de/umweltfragen-oekoress

[3] Source: https://www.umweltbundesamt.de/dokument/oekoress-teilbericht-bergbauliche-reststoffe-dr

3 Method for the site-related evaluation of environmental hazard potentials

As a rule, the evaluation of potential or manifest environmental impacts in the mining sector requires comprehensive methods and detailed analyses, including the consideration of local geological, hydrological and climatic conditions, the evaluation of site sensitivity with respect to the natural environment, as well as the preventative and remedial measures, both taken and planned.

An in-depth evaluation of the environmental impacts of an existing or planned mining project therefore requires very time-consuming and costly environmental impact assessments. Since decisions regarding planning and financing must be made in the run-up to such assessments, it seems appropriate to design a less complex test scheme that can provide reliable indications of environmental hazard potentials that may be very relevant. Such an initial assessment can by no means replace an in-depth environmental impact assessment, but it can, above all in the run-up to a project, be used to identify potential and likely hotspots, so that countermeasures can be taken at an early stage.

The evaluation scheme presented in the table below was developed within ÖkoRess I, and can be used for such an assessment. The evaluation scheme is essentially based on indicators (evaluated according to the simple traffic light rating system), each of which are assigned to an environmental goal (e.g. avoiding pollution risks) and a level of consideration. This double assignment to goals and consideration levels is designed to ensure easy manageability. The level of consideration, in particular, should facilitate the type of data collection by progressing from the general to the specific (Geology – Technology – Site).

Alongside the evaluation of individual mining projects – as took place within the case studies – such a scheme is also an important prerequisite for assessing the environmental hazard potentials of a raw material in general and, consequently, its limited availability, as the case may be. This is because, on the one hand, some of the indicators listed can be answered on the basis of raw material-specific considerations (e.g. typical paragenesis with heavy metals or radioactive substances); on the other hand, it is possible, via evaluations of the most important – in terms of quantity – regions where a raw material is extracted, to extrapolate to typical hotspots in general.

The evaluation scheme presented is primarily based on the experience gained during work on the 40 case studies within this project, in combination with the authors' expertise on evaluation issues.

For the use of the evaluation scheme, 'measurement instructions' were developed for each indicator, which are presented in this report.

Table 3-1: Evaluation scheme for environmental impacts from mining for individual mining examples – site-related evaluation

	Field	Goal	Indicator	Evaluation of environmental hazard potential		
				Low	**Medium**	**High**
Geology	Raw material-specific	Avoiding pollution risks	Preconditions for acid mine drainage (AMD)	Geochemical preconditions for AMD do not exist	Geochemical preconditions for AMD exist in part	Geochemical preconditions for AMD exist
			Paragenesis with heavy metals	The deposit has no elevated heavy metal concentrations	The deposit has slightly elevated heavy metal concentrations	The deposit has strongly elevated heavy metal concentrations
			Paragenesis with radioactive components	The deposit has low uranium and/or thorium concentrations	The deposit has slightly elevated uranium and/or thorium concentrations	The deposit has elevated uranium and/or thorium concentrations
	Deposit-specific	Limiting the direct impacts on ecosystems	Deposit size	Small	Medium	Large
		Limiting the effort for extraction	Specific ore grade	Rich	Medium	Poor
Technology	Mining-specific	Limiting the direct impacts on ecosystems	Mine type	Underground mining	Solid rock open pit mining	Alluvial or unconsolidated sediment mining
	Processing-specific	Avoiding pollution risks	Use of auxiliary substances	Without auxiliary substances	With auxiliary substances	With toxic reagents
	Management-specific	Minimising risks from mining waste	Mining waste management	Safe storage/deposition of tailings in the deposit	Among others, stable mine heaps, marketing of mine residues	Risky deposition, unstable tailings ponds, no tailings management system
		Minimising longevity of impacts	Remediation measures	Process-parallel rehabilitation	Financial accruals for rehabilitation	No provisions
Site (framework conditions)	Natural environment	Avoiding natural accident hazards	Accident hazard due to floods, earthquake, storms, landslides	All sub-indicators exhibit a low accident hazard (green)	At least one sub-indicator exhibits a medium accident hazard (yellow), none a high*	At least one sub-indicator exhibits a high accident hazard (red)
		Avoiding competition over water usage	Water Stress Index (WSI) and desert areas	Low water stress	Moderate water stress	Severe water stress or desert region
		Protecting/preserving valuable ecosystems	Protected areas and AZE sites	No relation to protected areas or AZE sites	AZE site or protected area (e.g. IUCN Cat. V-VI, national reserve)	Highly protected area (e.g. World Heritage Site, IUCN Cat. I-IV)
	Social environment	Avoiding environment-related conflicts in resource usage	Conflict potential with local population *(2 Worldwide Governance Indicators)*	Democratic rights existing; sound corruption control *(indicator values for 'Voice and Accountability' and 'Corruption Control' >65%)*	Moderate democratic rights and/or corruption control *(indicator values >45% <65%)*	Poor democratic rights and/or corruption control *(indicator values <45%)*

* Natural accident hazards for the Arctic are generally evaluated conservatively with yellow (medium potential) for lack of hazard maps

Green = low EHP; yellow = medium EHP; red = high EHP

3.1 The 'Geology' level

3.1.1 The 'Geology' level, 'Raw material-specific' field, indicators for pollution risks resulting from the geochemical composition of the deposit

The geochemical composition of deposits is a key influencing factor when it comes to pollution risks related to mining. In particular with regard to ores, the pollution risks can essentially be subdivided as follows:

- Precondition for acid mine drainage (AMD)
- Paragenesis with heavy metals and arsenic
- Paragenesis with radioactive components

On top of this, there are pollution risks resulting from the auxiliary substances used in ore processing. These are addressed in Section 3.2.

Although targeted management measures are able to extensively reduce the emission of pollutants into the environment, the effectiveness of individual combinations of measures can generally only be gauged with the aid of labour-intensive and costly on-site analyses, meaning that in the initial assessment of environmental risks performed here, this dimension inevitably has to be disregarded.

3.1.1.1 Indicator: Preconditions for acid mine drainage (AMD)

Evaluation

Low (green):

Geochemical preconditions for AMD do not exist (raw material and ore companions are chemically inert; deposits are characterised by oxidic, carbonate or silicate parageneses; no presence of sulphide minerals; raw materials are lithophile)

Medium (yellow):

Geochemical preconditions for AMD exist in part (raw materials are siderophile, in pure form or mineralised as oxides)

High (red):

Geochemical preconditions for AMD exist (raw material is present in sulphidic form or in sulphide ore deposits).

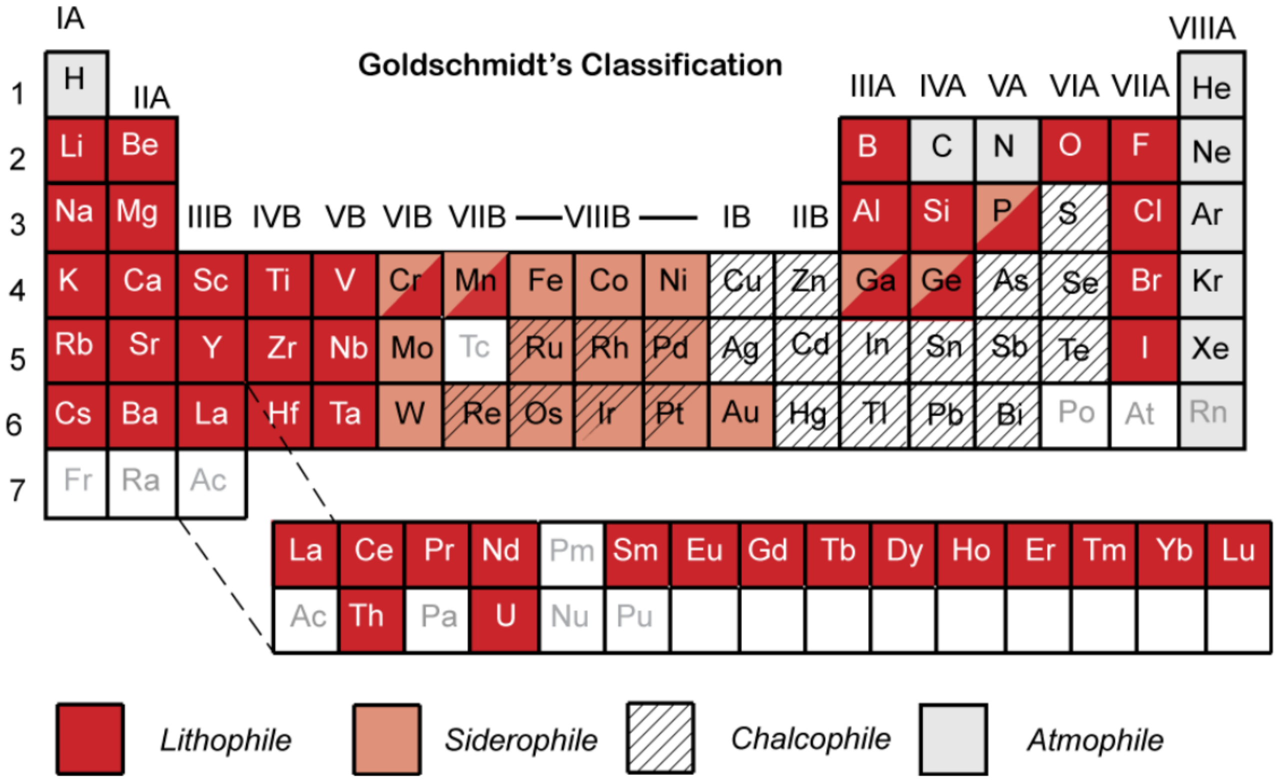
Acid mine drainage is regarded as one of the major environmental problems in mining. It refers to the formation of acidic leachates whose escape in most cases entails serious environmental consequences for groundwater and surface water in the relevant drainage area. The formation of acidic leachates is dependent on a variety of factors such as the particle size and particle size distribution of tailings and overburden, the moisture and the temperature regime (Akcil, Koldas 2006). A key factor, however, is the chemical composition of tailings and overburden. Generally, a prerequisite for AMD is the presence of sulphidic minerals. If these minerals are exposed to moisture and (atmospheric) oxygen, then – via a chain of chemical reactions – oxidation and hydrolysis occur, resulting in the formation of acidic leachates. These acidic leachates can in turn dissolve heavy metals out of the rock and hence further aggravate the environmental problem (Udayabhanu, Prasad 2010). Although the magnitude of the environmental problem originating from AMD depends strongly on the individual situation in a mining area and on the countermeasures taken, characteristic geochemical compositions provide indications of general hazards nonetheless.

The tendency of the ores and mining residues towards autoxidation can be derived from the preferred formation conditions of the ore minerals for the extracted metals or valuable elements and their accompanying minerals. The geochemical conditions for formation differ according to the type of elements; according to Goldschmidt's classification, these are characterised as either siderophile (iron-loving), lithophile (silicate-loving) or chalcophile (sulphur-loving) (see Figure 3-1[4]). This classification, which provides initial guidance, is based on the typical accumulation of elements in the geosphere: whereas siderophile elements have accumulated predominantly in the planet's iron core, lithophile elements are more likely to occur in elevated concentrations in the earth's crust. The latter elements are characterised by the high bond energies of the element oxides, which prevent the element from occurring naturally in pure form or from dissociating easily (White 2013). Chalcophile elements, on the other hand, are more likely to occur in sulphidic conditions. From this classification it is possible, in turn, to derive raw material-specific preconditions for acid mine drainage:

- Lithophile elements are generally extracted from oxidic deposits
- Chalcophile elements are generally extracted from sulphidic deposits
- Siderophile elements are often present in sulphidic form, but are also extracted from oxidic deposits. This applies, above all, to deposits that were exposed to atmospheric weathering for a long time.

Particularly when considering this from the perspective of economic geology, it is necessary – for the purposes of classification or evaluation – to consider in each case the paragenetic conditions of the ores in deposits where extraction is economical. This may, in the case of siderophile elements, frequently result in them being classed in the group composed of lithophile elements. On this point, see Figure 3-2 and the text below.

Figure 3-1: Illustration of Goldschmidt's classification of the elements



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[4] Atmophile (gas-loving) elements, also shown in the figure, are not relevant in this context.

Source: White (2013)

From the perspective of deposit geology, these element-specific properties are transferred to ore minerals and mineral parageneses, which are illustrated in Figure 3-2 for the different geological conditions of rock formation according to Cissarz (1965).

In Figure 3-2, the economically significant ore minerals are marked with a black spot. For the respective ore minerals, minerals of associated parageneses[5] that could also be responsible for the formation of AMD, particularly in the case of sulphide minerals, are listed in the same column of the figure.

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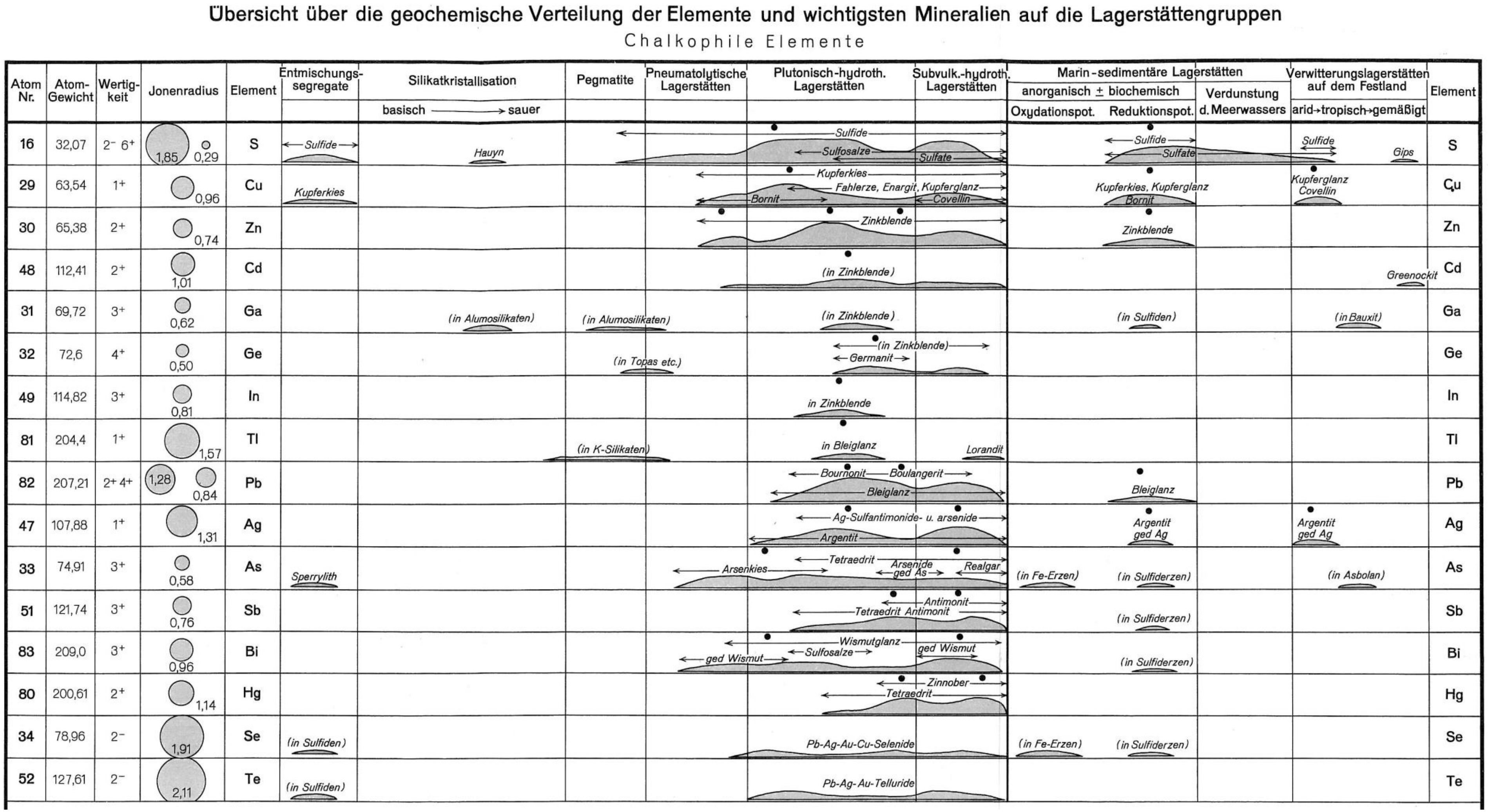
[5] For example: nickel from the ore mineral pentlandite from segregation deposits occurs jointly as a paragenesis with chalcopyrite (likewise in the column of segregated minerals), sperrylite, selenium and tellurium sulphides, pyrrhotite, cobaltite, as well as gold and platinum group metals.

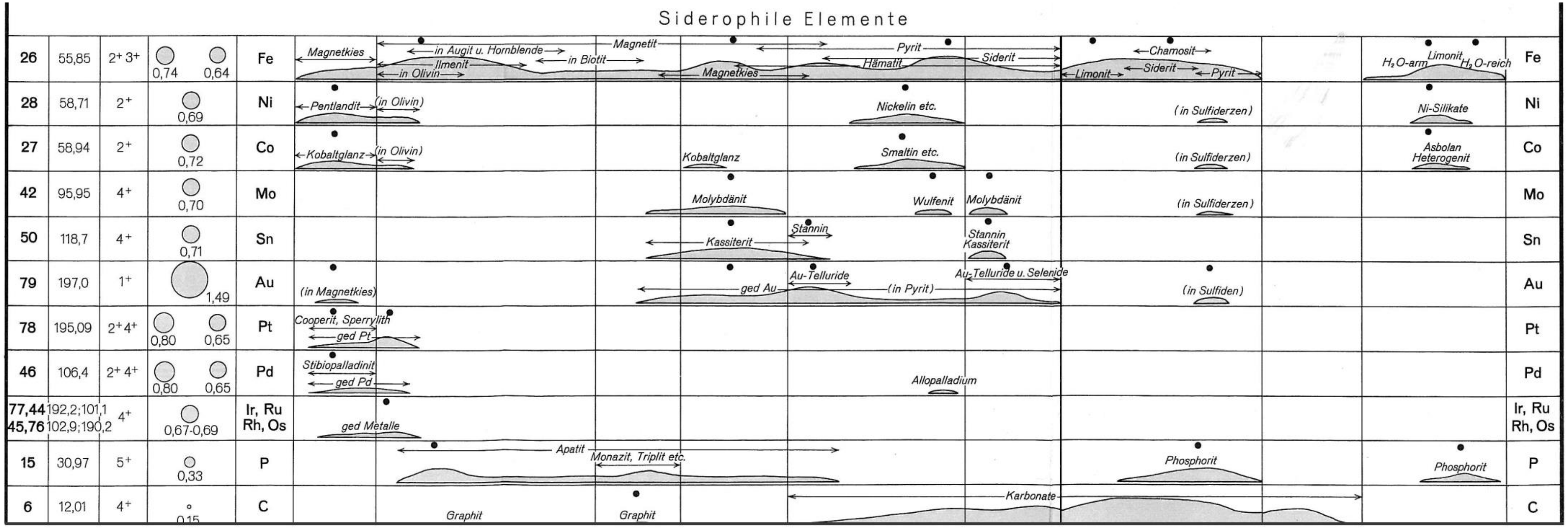
Figure 3-2: Geochemical distribution of the elements and the most important minerals (Cissarz 1965)



Übersicht über die geochemische Verteilung der Elemente und wichtigsten Mineralien auf die Lagerstättengruppen

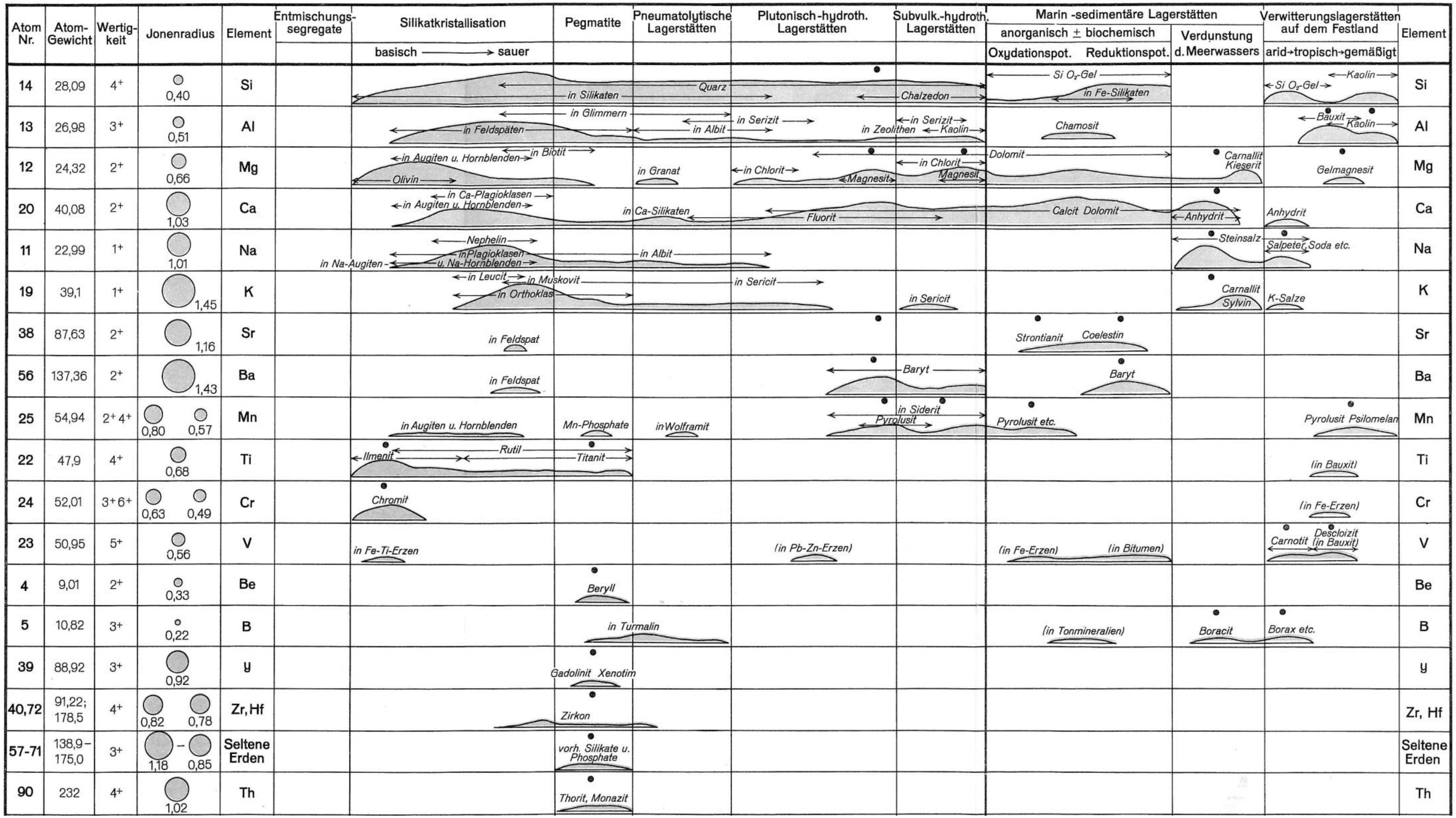
Chalkophile Elemente

Atom Nr.	Atom-Gewicht	Wertigkeit	Jonenradius	Element	Entmischungssegregate	Silikatkristallisation	Pegmatite	Pneumatolytische Lagerstätten	Plutonisch-hydroth. Lagerstätten	Subvulk.-hydroth. Lagerstätten	Marin-sedimentäre Lagerstätten			Verwitterungslagerstätten auf dem Festland	Element
											anorganisch ± biochemisch		Verdunstung d. Meerwassers		
						basisch → sauer					Oxydationspot.	Reduktionspot.		arid→tropisch→gemäßigt	
16	32,07	2⁻ 6⁺	1,85 0,29	S	←Sulfide→	Hauyn			● Sulfide ←Sulfosalze	Sulfate		● ←Sulfide→ Sulfate		Sulfide Gips	S
29	63,54	1⁺	0,96	Cu	Kupferkies				● Kupferkies ←Fahlerze, Enargit, Kupferglanz→ Bornit→	←Covellin		● Kupferkies, Kupferglanz Bornit		● Kupferglanz Covellin	Cu
30	65,38	2⁺	0,74	Zn				●	● Zinkblende	●		● Zinkblende			Zn
48	112,41	2⁺	1,01	Cd					● (in Zinkblende)					Greenockit	Cd
31	69,72	3⁺	0,62	Ga		(in Alumosilikaten)	(in Alumosilikaten)		(in Zinkblende)			(in Sulfiden)		(in Bauxit)	Ga
32	72,6	4⁺	0,50	Ge			(in Topas etc.)		● ←(in Zinkblende)→ ←Germanit→						Ge
49	114,82	3⁺	0,81	In					● in Zinkblende						In
81	204,4	1⁺	1,57	Tl			(in K-Silikaten)		● in Bleiglanz	Lorandit					Tl
82	207,21	2⁺ 4⁺	1,28 0,84	Pb					● ←Bournonit—● Boulangerit→ ←Bleiglanz→			● Bleiglanz			Pb
47	107,88	1⁺	1,31	Ag					● ←Ag-Sulfantimonide- u. arsenide→ ←Argentit→	●		● Argentit ged Ag		● Argentit ged Ag	Ag
33	74,91	3⁺	0,58	As	Sperrylith			←Arsenkies→	● ←Tetraedrit→	● Arsenide ←ged As→ ←Realgar→	(in Fe-Erzen)	(in Sulfiderzen)		(in Asbolan)	As
51	121,74	3⁺	0,76	Sb					←Tetraedrit Antimonit→	● ←Antimonit→ ●		(in Sulfiderzen)			Sb
83	209,0	3⁺	0,96	Bi				←ged Wismut→	● ←Wismutglanz→ ←Sulfosalze→	● ged Wismut		(in Sulfiderzen)			Bi
80	200,61	2⁺	1,14	Hg					←Tetraedrit→	● ←Zinnober→ ●					Hg
34	78,96	2⁻	1,91	Se	(in Sulfiden)				Pb-Ag-Au-Cu-Selenide		(in Fe-Erzen)	(in Sulfiderzen)			Se
52	127,61	2⁻	2,11	Te	(in Sulfiden)				Pb-Ag-Au-Telluride						Te

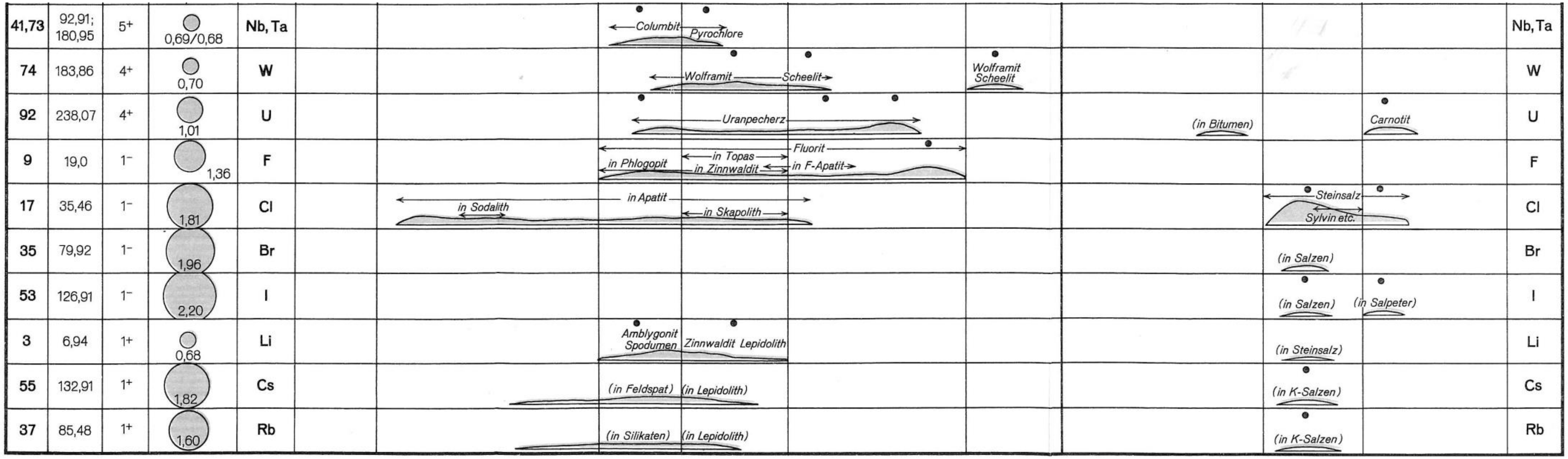

Siderophile Elemente
26 55,85 2+ 3+ 0,74 0,64 Fe
Magnetkies
in Augit u. Hornblende
Ilmenit
in Olivin
in Biotit
Magnetit
Magnetkies
Pyrit
Hämatit
Siderit
Chamosit
Limonit
Siderit
Pyrit
H₂O-arm Limonit H₂O-reich
28 58,71 2+ 0,69 Ni
Pentlandit
(in Olivin)
Nickelin etc.
(in Sulfiderzen)
Ni-Silikate
27 58,94 2+ 0,72 Co
Kobaltglanz
(in Olivin)
Kobaltglanz
Smaltin etc.
(in Sulfiderzen)
Asbolan
Heterogenit
42 95,95 4+ 0,70 Mo
Molybdänit
Wulfenit
Molybdänit
(in Sulfiderzen)
50 118,7 4+ 0,71 Sn
Kassiterit
Stannin
Stannin
Kassiterit
79 197,0 1+ 1,49 Au
(in Magnetkies)
ged Au
Au-Telluride
(in Pyrit)
Au-Telluride u. Selenide
(in Sulfiden)
78 195,09 2+ 4+ 0,80 0,65 Pt
Cooperit, Sperrylith
ged Pt
46 106,4 2+ 4+ 0,80 0,65 Pd
Stibiopalladinit
ged Pd
Allopalladium
77,44 45,76 192,2;101,1 102,9;190,2 4+ 0,67-0,69 Ir, Ru Rh, Os
ged Metalle
15 30,97 5+ 0,33 P
Apatit
Monazit, Triplit etc.
Phosphorit
Phosphorit
6 12,01 4+ 0,15 C
Graphit
Graphit
Karbonate

Übersicht über die geochemische Verteilung der Elemente und wichtigsten Mineralien auf die Lagerstättengruppen

Lithophile Elemente



Atom Nr.	Atom-Gewicht	Wertigkeit	Jonenradius	Element	Entmischungssegregate	Silikatkristallisation	Pegmatite	Pneumatolytische Lagerstätten	Plutonisch-hydroth. Lagerstätten	Subvulk.-hydroth. Lagerstätten	Marin-sedimentäre Lagerstätten: anorganisch ± biochemisch	Marin-sedimentäre Lagerstätten: Verdunstung d. Meerwassers	Verwitterungslagerstätten auf dem Festland	Element
						basisch → sauer					Oxydationspot. Reduktionspot.		arid→tropisch→gemäßigt	
14	28,09	4^+	0,40	Si			in Silikaten	Quarz	●	Chalzedon	Si O₂-Gel in Fe-Silikaten		Si O₂-Gel Kaolin	Si
13	26,98	3^+	0,51	Al		in Feldspäten	in Glimmern	in Albit	in Serizit in Zeolithen	in Serizit Kaolin	Chamosit		● Bauxit ● Kaolin	Al
12	24,32	2^+	0,66	Mg		in Augiten u. Hornblenden in Biotit Olivin		in Granat	in Chlorit ● Magnesit	● in Chlorit Magnesit	Dolomit	● Carnallit Kieserit	● Gelmagnesit	Mg
20	40,08	2^+	1,03	Ca		in Ca-Plagioklasen in Augiten u. Hornblenden		in Ca-Silikaten	Fluorit		Calcit Dolomit	● Anhydrit	Anhydrit	Ca
11	22,99	1^+	1,01	Na	in Na-Augiten	Nephelin in Plagioklasen u. Na-Hornblenden		in Albit				● Steinsalz	● Salpeter, Soda etc.	Na
19	39,1	1^+	1,45	K		in Leucit in Muskovit in Orthoklas			in Sericit	in Sericit		● Carnallit Sylvin	K-Salze	K
38	87,63	2^+	1,16	Sr		in Feldspat			●		● Strontianit ● Coelestin			Sr
56	137,36	2^+	1,43	Ba		in Feldspat			●	Baryt	● Baryt			Ba
25	54,94	2^+ 4^+	0,80 0,57	Mn		in Augiten u. Hornblenden	Mn-Phosphate	in Wolframit	● Pyrolusit	● in Siderit	● Pyrolusit etc.		● Pyrolusit Psilomelan	Mn
22	47,9	4^+	0,68	Ti		● Ilmenit Rutil	● Titanit						(in Bauxit)	Ti
24	52,01	3^+ 6^+	0,63 0,49	Cr		● Chromit							(in Fe-Erzen)	Cr
23	50,95	5^+	0,56	V		in Fe-Ti-Erzen			(in Pb-Zn-Erzen)		(in Fe-Erzen) (in Bitumen)		● Carnotit ● Descloizit (in Bauxit)	V
4	9,01	2^+	0,33	Be			● Beryll							Be
5	10,82	3^+	0,22	B			in Turmalin				(in Tonmineralien)	● Boracit	● Borax etc.	B
39	88,92	3^+	0,92	Y			● Gadolinit Xenotim							Y
40,72	91,22; 178,5	4^+	0,82 0,78	Zr, Hf			● Zirkon							Zr, Hf
57-71	138,9– 175,0	3^+	1,18 – 0,85	Seltene Erden			● vorh. Silikate u. Phosphate							Seltene Erden
90	232	4^+	1,02	Th			● Thorit, Monazit							Th



41,73	92,91; 180,95	5+	0,69/0,68	**Nb, Ta**			Columbit	Pyrochlore						**Nb, Ta**
74	183,86	4+	0,70	**W**				Wolframit	Scheelit	Wolframit Scheelit				**W**
92	238,07	4+	1,01	**U**				Uranpecherz			(in Bitumen)		Carnotit	**U**
9	19,0	1−	1,36	**F**			in Phlogopit	in Topas in Zinnwaldit	Fluorit in F-Apatit					**F**
17	35,46	1−	1,81	**Cl**		in Sodalith	in Apatit	in Skapolith				Steinsalz Sylvin etc.		**Cl**
35	79,92	1−	1,96	**Br**								(in Salzen)		**Br**
53	126,91	1−	2,20	**I**								(in Salzen)	(in Salpeter)	**I**
3	6,94	1+	0,68	**Li**			Amblygonit Spodumen	Zinnwaldit Lepidolith				(in Steinsalz)		**Li**
55	132,91	1+	1,82	**Cs**			(in Feldspat)	(in Lepidolith)				(in K-Salzen)		**Cs**
37	85,48	1+	1,60	**Rb**			(in Silikaten)	(in Lepidolith)				(in K-Salzen)		**Rb**

The following recommendations for evaluation can be derived from this if the precise mineralogical composition of the deposit is not known:

- The lithophile elements consistently demonstrate a low environmental hazard potential in terms of AMD (green). This is the case with regard to the following raw materials: bauxite/aluminium, magnesite/magnesium, silica sand/silicon, limestone/calcium, potassium carbonate/potassium, manganese, titanium, chromium, vanadium, barite, beryllium, borates/boron, zirconium, hafnium, rare earths, niobium, tantalum, tungsten[6] and lithium.
- The chalcophile elements consistently demonstrate a high hazard potential in terms of AMD (red). This is the case with regard to the following raw materials: sulphur, copper, zinc, cadmium, germanium[7], indium, tellurium, lead, silver, antimony and bismuth.
- An exception is gallium, which, depending on the source, is categorised as a siderophile, chalcophile or lithophile element, but which does not occur in economically extractable concentrations in the relevant deposits. Since gallium is generally obtained as a by-product of bauxite, the hazard potential for AMD of gallium must – similar to aluminium/bauxite (lithophile) – be classified as low (green).
- The siderophile elements iron, nickel, cobalt, molybdenum, tin, gold, the platinum group metals, rhenium and phosphorus are more ambiguous. The raw materials mostly occur in oxidic minerals, although the particular overall ‘package’ (including accompanying minerals) may often also contain sulphides. In these cases, an evaluation of ‘medium’ is recommended, although the following exceptions must be noted in the case of site-related evaluations:
    1. Placer deposits (these may be particularly relevant in the extraction of gold, platinum group metals, and tin) are generally oxidic, and demonstrate a low AMD risk (green).
    2. Molybdenum is usually a by-product of copper extraction. In these cases, a high AMD risk can be assumed (red).
    3. Similarly, gold is in part (also) extracted from copper deposits. These deposits likewise demonstrate a high AMD risk (red).
    4. Nickel and cobalt ores are, in most cases, present in the form of sulphidic iron-nickel-cobalt minerals (e.g. nickel pyrrhotite). In most cases, nickel and cobalt deposits must therefore be evaluated as having a high AMD risk (red).

3.1.1.2 Indicator: Paragenesis with heavy metals

Evaluation

Low (green):

The deposit has no elevated heavy metal concentrations.

Medium (yellow):

The deposit has slightly elevated heavy metal concentrations.

High (red):

The deposit has strongly elevated heavy metal concentrations.

Heavy metals are mostly a problem in ore mining and processing (extraction of primary metallic raw materials). In addition, typical parageneses with heavy metals are known also in the case of sedimen-

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[6] Although tungsten is listed in Figure 3-1 as a siderophile element, it is apparent from Figure 3-2 that exploitable deposits are generally always lithophile.

[7] Since the industrial extraction of germanium occurs as a by-product from complex copper and zinc sulphide ores, germanium is classified as chalcophile (see Figure 3-2).

tary phosphate (uranium, cadmium) (Mar, Okazaki 2012). Other abiotic raw materials (building materials, industrial minerals) are in most cases significantly less critical in terms of possible heavy metal contamination. As a result of the tendency towards autoxidation, the capacity of heavy metals to be dissolved out of mining residues is further enhanced.

Typical compositions are illustrated in what is known as the Reuter wheel of metals (see Figure 3-3). The classification goes back to work by Professor Markus Reuter at the University of Melbourne. The illustration shows the typical paragenesis of metals in ores and the nature of their occurrence in respect of sulphidic and oxidic ores. The shell-like, circular shape also illustrates which metals are typically a main component of ores and which are extracted as by-products or occur merely as unusable components.

The parageneses are closely connected to the inherent properties of the valuable elements, as discussed in Section 3.1.1.1. Specifically, they are connected to predominantly oxidic or predominantly sulphidic conditions of formation and the respective element or mineral parageneses portrayed in this wheel. With increasing distance from the centre, firstly the main metal, then by-metals, trace elements and, finally, economically irrelevant accompanying elements are listed systematically. When considering the ores as a source of heavy metals, however, it is irrelevant whether the material is of economic significance or not. In this context, substances characterised by their toxicity to animals and aerobic and anaerobic processes are described as heavy metals (Duffus 2001):

- As[8]
- Cd
- Cr
- Pb
- Hg
- Cu
- Ni
- Se
- Zn

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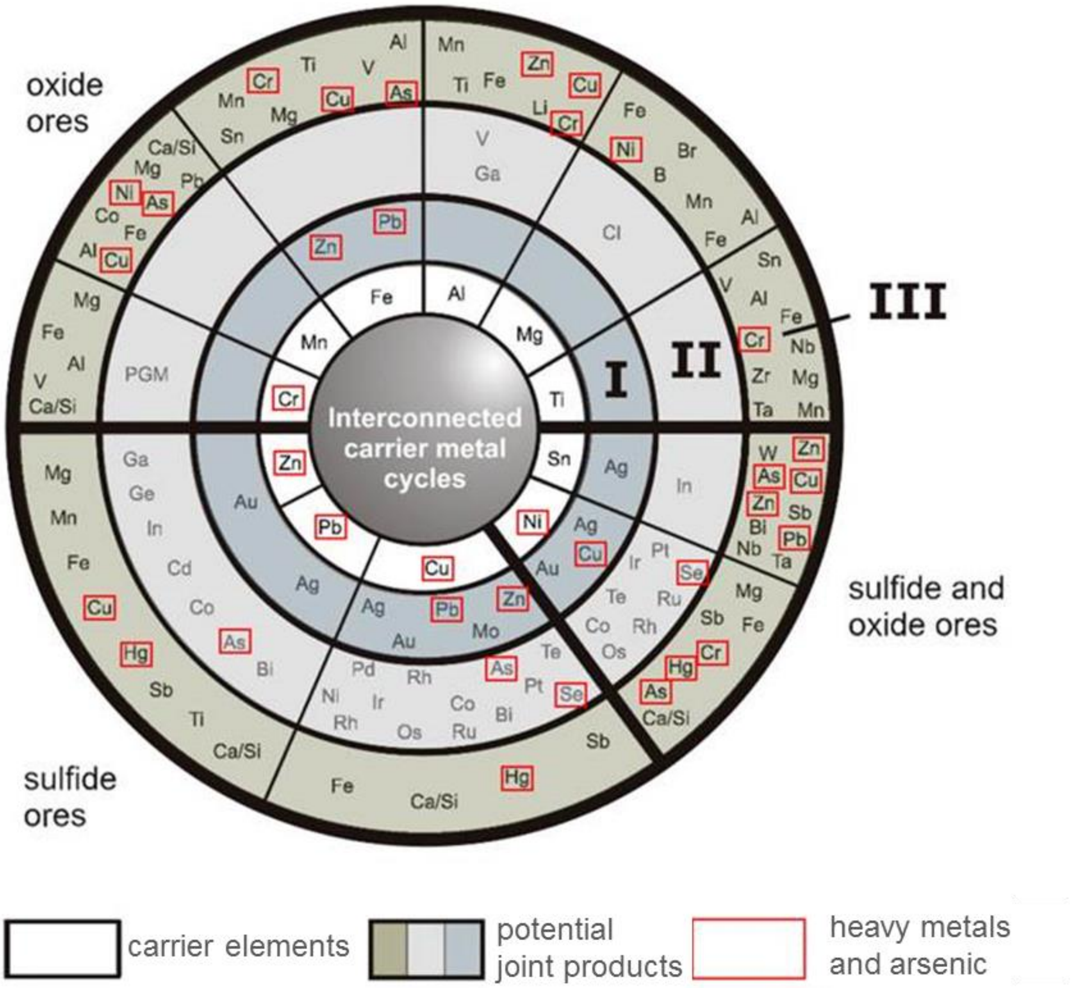
[8] Arsenic is also considered here, although, as a metalloid, it cannot be definitively assigned to the heavy metals.

Figure 3-3: The wheel of metals based on Reuter (modified according to Wellmer, Hagelüken 2015)



For the benchmarking of this indicator, too, knowledge of the mineralogical composition of the ores and companions and of the trace elements ought to be of key significance. If these parameters are not known, the following guidance is helpful.

It is recommended that mining for abiotic non-metallic raw materials be evaluated as having a low environmental hazard potential (green) from paragenetically associated heavy metals – unless there are indications of heavy metal and/or arsenic problems.

The extraction of metallic raw materials is – as evident in Figure 3-3 – for the most part plagued by a certain amount of heavy metal- and/or arsenic-related problems. Here, a blanket evaluation of a medium environmental hazard potential is recommended (yellow).

Mining for the targeted extraction of heavy metals such as lead, mercury, cadmium, chromium, copper, uranium and nickel should be evaluated as having a high environmental hazard potential (red). This also includes mining for zinc ores, since these are nearly always paragenetically associated with lead ores.

3.1.1.3 Indicator: Paragenesis with radioactive components

Raw materials and/or mining residues often exhibit uranium and/or thorium concentrations[9], which result in mining residues also having to be classified as of radiological concern. This predominantly applies to the ores and deposits of the following raw materials: uranium, thorium, rare earths, tantalum, niobium, zirconium, and sedimentary phosphate. Experience in Germany and data from China show, however, that elevated concentrations may occur with many other raw materials too, and there may additionally be deposit-specific elevated concentrations.

Evaluation

Low (green):

The deposit has low uranium and/or thorium concentrations.

Medium (yellow):

The deposit has slightly elevated uranium and/or thorium concentrations

High (red):

The deposit has elevated uranium and/or thorium concentrations.

In many cases, radioactive substances in deposits and tailings constitute key environmental, health and safety problems in raw material extraction. In general, the 'ionising radiation' exposure pathway in the context of mining is attributable solely to the concentrations of natural uranium and thorium, which generally enter the tailings during processing[10], and can accumulate during processing[11]. Other radioactive elements, such as radon gas, are part of the decay series of uranium and thorium, and can develop radiological effects via other exposure pathways (inhalation). Since, however, the occurrence of these elements always requires the existence of uranium or thorium, a reliable evaluation can be based on the concentration of uranium and thorium in the starting material.

For the radiological evaluation, in order to distinguish between low (green) and medium (yellow) hazard, activity concentrations and minimum concentrations in ores and/or tailings according to Table 3-2 can be used[12]:

- Thorium 200 Bq/kg (corresponds to a concentration of 49 ppm)
- Uranium 300 Bq/kg (corresponds to a concentration of 24 ppm).

These concentrations are derived from the gamma radiation of the decay products, which, if used as a building material, would exceed dose limits (here: 1 mSv/a). Below these concentrations, there is no requirement to isolate the ores or residues for radiological reasons[13]. Above these concentrations, the substrate must be classified as unsuitable for spending time on permanently or coming into contact with (use as a building material). People spending sustained periods on such an uncovered substrate

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[9] In the literature, these are often referred to using the acronym NORM (= Naturally Occurring Radioactive Material).

[10] Exception: During the treatment of apatite with sulphuric acid, the uranium enters the phosphoric acid and is therefore transferred into the phosphate fertiliser produced from this, whilst the radioactive decay products (particularly radium) enter the phosphogypsum. Since 510 g gypsum is generated from 310 g phosphate ore, the activity concentration of radium becomes diluted in the process by approximately a factor of 2.

[11] This concentrated radioactive material in tailings is also referred to as TENORM (Technologically Enhanced Naturally Occurring Radioactive Material).

[12] Council Directive 2013/59/EURATOM, ANNEX VIII: Definition and use of the activity concentration index for the gamma radiation emitted by building materials as referred to in Article 75

[13] The long-term, safe storage of tailings may still be required nonetheless, and may, for example, be down to the concentrations of non-radioactive components.

are exposed to a radiation risk of over 1 mSv per year[14]. This consideration of dose limits was developed as part of the ÖkoRess project and a further ongoing project by the Öko-Institut (Germany 2049 – Transition to a sustainable use of raw materials)[15] and is derived from the requirements of the EU Directive 2013/59/ EURATOM laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation[16], and from international radiation protection standards.

A second, higher dose limit (limit for high hazard level = red) is 1 Bq/g (or 1,000 Bq/kg). This comes from the fact that international radiation protection regulations no longer permit authorisation of such a material (exemption level) (IAEA 2014). From this, the dose constraints listed in Table 3-2 are produced for the purpose of specific evaluation.

Table 3-2: Dose constraints for the radiological evaluation of deposits

Evaluation	Dose constraints		Justification
Low	Dose Constraint 1a: Th content [ppm] / 49 ppm + U content [ppm] / 24 ppm < 1	If U and Th contents are known	The substrate may be used as a building material because it does not result in a risk of radiation exposure > 1 mS/a.
	Dose Constraint 1b: A_{Th} [Bq/g] / 0.2 Bq/g + A_U [Bq/g] / 0.3 Bq/g < 1	If activity concentrations (A) of U and Th are known	
Medium	Dose Constraint 2a: Th content [ppm] / 246 ppm + U content [ppm] /80 ppm < 1	If U and Th contents are known and Dose Constraint 1a is > 1	The substrate may not be used as a building material because it results in a risk of radiation exposure > 1 mS/a.
	Dose Constraint 2b: A_{Th} [Bq/g] + A_U [Bq/g] < 1 Bq/g	If activity concentrations (A) of U and Th are known and Dose Constraint 1b is > 1	
High	Dose Constraint 2a: Th content [ppm] / 246 ppm + U content [ppm] / 80 ppm ≥ 1	If U and Th contents are known	According to international IAEA Safety Standards, the substance must be monitored for radiological activity.
	Dose Constraint 2b: A_{Th} [Bq/g] + A_U [Bq/g] ≥ 1 Bq/g	If activity concentrations (A) of U and Th are known	

For selected raw materials from Chinese deposits, average values are available for the activity concentrations of thorium and uranium (see Table 3-3). They show that Chinese deposits for vanadium, rare earths, niobium/tantalum and zirconium exhibit Th and U concentrations, which is why these should be evaluated as having a high environmental hazard potential (red). The data also suggests that most other deposits also exhibit Th and U concentrations that constitute an obstacle to use of the material as a building material.

If no specific data are available on activity concentrations and/or Th and U concentrations, an evaluation can be made using the following approximations:

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[14] In cases where both thorium and uranium occur in a mixture, the values must be combined in such a way that the combined radiation dose in the case of permanent contact does not exceed 1 mSv per year (see the formulae in Table 3-2).

[15] See also Buchert et al. (2016)

[16] Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/EURATOM, 90/641/EURATOM, 96/29/EURATOM, 97/43/EURATOM and 2003/122/EURATOM.

- Mining for the extraction of uranium should be given a blanket evaluation of a high environmental hazard potential (red)[17]. The minimum concentration above which mining is worthwhile from today's technical and economical perspectives is 0.03% uranium in the ore, which corresponds to 3.72 Bq/g, and clearly exceeds both reference values.
- If no specific data is available, then rare earths, tantalum, niobium, zirconium and sedimentary phosphate (including Sahara and Florida phosphate) should be given a blanket assessment of a high environmental hazard potential (red).
- As Table 3-3 shows, with most other deposits, one must assume certain basic difficulties with regard to Th and U concentrations. Here, in case of doubt, a medium environmental hazard potential (yellow) should be assigned.
- An evaluation of a low environmental hazard potential is a possibility for the following raw materials:
    1. Deposits from oxidic sediments (e.g. placer deposits on alluvial fans)
    2. Sedimentary rocks (e.g. limestone and sandstone)
    3. Deposits on basalt
- In the process, however, the following aspects should additionally be considered, which could possibly result in them being evaluated at a higher level:
    1. Uranium is readily soluble in water on contact with atmospheric oxygen in hexavalent oxidised form, for which reason any potential uranium content in oxidic sediments (e. g. alluvial fans) is mostly washed out. Nevertheless, the geochemical solution and the transport of oxidic uranium also result in uranium often being shifted to deeper layers or in a horizontal direction, where in some cases it becomes enriched again. The geochemical enrichment from the solution particularly occurs in reducing layers (e.g. in carbon- or pyrite-containing layers). Deposit concentrations are therefore only homogenous in exceptional cases.
    2. In addition, deposits with high levels of radioactivity are known for cobalt and gold. In the case of cobalt, these are in parts of Katanga (Democratic Republic of Congo) (Tsurukawa et al. 2011), in the case of gold, in parts of South Africa (Durand 2012).

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[17] Mining for thorium does not come under consideration insofar as this is not practised in view of the low world market price and existing reserves.

Table 3-3: Average activity concentrations of U and Th in Chinese deposits, and derivation of the corresponding evaluation

Raw material	A_{Th} [Bq/g]	A_U [Bq/g]	Dose Constraint 1 (demarcation between green and yellow)	Dose Constraint 2 (demarcation between yellow and red)	Evaluation	China's share in world production (2013)
Vanadium	27.0	1.036	138.5	28.036	High	51.9%
Rare earths	5.782	3.972	42.2	9.754	High	86.4%
Niobium/tantalum	2.015	4.476	25.0	6.491	High	Nb: <2%, Ta: 5.1%
Zirconium	1.733	1.289	13.0	3.022	High	9.9%
Aluminium (bauxite)	0.240	0.482	2.8	0.722	Medium	16.3%
Lead/zinc	0.069	0.649	2.5	0.718	Medium	Pb: 52.8%, Zn: 37.3%
Coal	0.051	0.383	1.5	0.434	Medium	Not specified
Phosphate	0.026	0.396	1.5	0.422	Medium	48.0%
Tin	0.133	0.218	1.4	0.351	Medium	37.4%
Iron	0.068	0.270	1.2	0.338	Medium	46.6%
Coal (ganggestein)	0.082	0.171	1.0	0.253	Medium	Not specified
Copper	0.034	0.142	0.6	0.176	Low	8.7%
Others	0.508	0.503	4.2	1.011	High	Not specified

Sources: Hua 2011, USGS 2015

3.1.2 The 'Geology' level, 'Deposit-specific' field, 'Deposit size' indicator

The size of mineral deposits is a key influencing factor for mining-induced interventions in nature. This primarily applies to the following aspects:

- Land consumption
- Degradation of vegetation
- Scale of land movements
- Size of mine heaps and mine residues
- Impact on water balance.

The larger deposits are, the higher the total environmental impact is likely to be. The size of these deposits depends, of course, on the raw material being extracted. They are relative to the geochemical frequency of the relevant elements in the earth's crust (Lide 2005), and are described by the Clarke value.

Evaluation

Low (green):

Small and very small deposits

Medium (yellow):

Medium-sized deposits

High (red):

Large, very large and gigantic deposits

Reference can be made to the work of Petrov when classifying deposits of different raw materials into size categories. The information provided in the Petrov Petrow table, portrayed in Table 3-4, refers to a deposit's total valuable metal content.

Table 3-4: Russian classification of the size of deposits (based on Petrov et al. 2008)

Raw materials	Unit	Small	Medium	Large	Very large	Gigantic
Ag	t	<500	500-2,000	2,000-10,000	>10,000	
Al (bauxite)	Million t ore	<10	10-100	>100		
As	1,000 t	<10	10-100	>100		
Au (primary)	t	<25	25-100	100-400	>400	
Au (placer)	t	<0.5	0.5-1	1-5	5-50	>50
Be	1,000 t BeO	<1	1-5	5-20	20-50	>50
Bi	1,000 t	<1	1-40	45-10	> 10	
Cd	t	<0.5	0.5-3	3-10	> 10	
Co	1,000 t	<2	2-15	> 15		
Cr	Million t	<0.1	0.1-1	1-10	10-100	>100
Cu	Million t	<0.5	0.5-3	3-10	>10	
Fe	Billion t	<0.1	0.1-1	1-5	5-10	>10
Hg	t	n-n*10	n*100	n*1,000	n*10,000	
Li	1,000 t Li_2O	<40-100	100-300	300-600	600-1,200	>1,200
Mn	Million t	<25	25-75	75-100	>100	
Mo	1,000 t	<25	25-150	150-500	>500	
Ni	1,000 t	<100	100-1,000	1,000-5,000	>5,000	
Pb	Million t	<0.1	0.1-1	1-2	>2	
PGM	t	<10	10-100	100-1000	>1,000	
Sb	1,000 t	<50	50-100	100-300	>300	
Se	1,000 t Se	<100	100-1,000	1,000-10,000	>10,000	
Rare earths1)	1,000 t Y	<10	10-100	100-500	>500	
Sn	1,000 t	<20	20-50	50-100	>100	
Sr	1,000 t SrO	n*10	n*100	n*1,000	n*10,000	

Raw materials	Unit	Small	Medium	Large	Very large	Gigantic
Ti (ore)	Million t TiO_2	<5	5-10	10-50	>50	
Ti (placers)	Million t TiO_2	<1	1-5	5-10	>10	
U	1,000 t	0.5-5	5-20	>20	>	
V	1,000 t V_2O_2	<100	100-1,000	>1,000		
W	1,000 t WO_3	<10	10-100	>100		
Zn	Million t	<0.5	0.5-1	1-5	>5	
Zr	Million t ZrO_2	0.01-0.1	0.1-1	1-10	>10	
Barite	Million t	<0.1	0.1-0.5	0.5-5	>5	
Bentonite	Million t	<10	10-20	>20		
Boron	Million t B_2O_3	0.1-0.3	0.3-0.5	0.5-1	1-10	> 10
Chrysolite asbestos	Million t	<1	1-5	5-50	>50	
Diamond (ore)	Million carats	<50	50-150	150-500	>500	
Diamond (placers)	Million carats	<1	1-5	5-25	>25	
Fluorite	Million t	<0.5-2	2-5	5-10	>10	
Graphite	Million t	<0.5	0.5-1	>1		
Halite	Million t	<50	50-150	150-500	>500	
Potash salt	Million t K_2O	<10	10-50	50-150	>150	
Kaolin	Million t	<5	5-20	20-50	>50	
Magnesium salt	Million t MgO	<10	10-50	50-150	>150	
Magnesite & brucite	Million t	<30	30-100	100-300	>300	
Muscovite	1,000 t	<5	5-25	25-50	>50	
Nepheline	Million t	<100	100-500	>500		
Quartz sand	Million t	<1	1-5	5-10	>50	
Moulding sand	Million t	<10	10-50	50-200	>200	
Perlite	million m^3	<5	5-50	50-200	>200	
P (apatite)	Million t P_2O_5	<10	10-50	50-100	>100	
P (phosphorite)	Million t P_2O_5	<10	10-50	50-100	>100	
S (sulphide)	Million t	<1	1-10	>10		
S (native)	Million t	<10	10-50	>50		
Talc	Million t	<0.03	0.03-0.5	0.5-5	>5-20	> 20
Vermiculite	Million t	<1	1-10	>10		
Zeolite	Million t	<first n	n*10	n*100	>	

1) Yttrium content as a representative of rare earths

In the Petrov table, data is missing for some selected raw materials such as niobium and tantalum as principal mined elements, as well as some by-products and co-products.

For the evaluation, it must be taken into consideration that the above table encompasses the resource content of the entire deposit. If this is not displayed, then in the case of ongoing mining operations it means that the parameter relevant for the evaluation is determined from the reserves that can still be extracted plus the products already mined. The latter can be determined through the extrapolation of the mined quantity over the operating period.

3.1.3 The 'Geology' level, 'Deposit-specific' field, 'Specific ore grade' indicator

The deposits currently being mined differ not only in terms of size or, as defined above, valuable metal content, but also in terms of grade (given in %, g/t or ct/t). The specific ore grade of a deposit provides information by approximation about the relative size of environmentally relevant parameters:

- Generation of solid mining waste such as overburden, tailings or waste rock;
- Product-specific energy requirement for extraction, transport, crushing, sorting and treatment of waste materials;
- Quantity of auxiliary substances and reagents in the processing of the raw materials.

Evaluation

Low (green):

High-grade ore deposit

Medium (yellow):

Average-grade ore deposit

High (red):

Low-grade ore deposit

An overall presentation of the average grades of ore deposits similar to the overview of deposit sizes given above is not yet available. Reference data can, on the one hand, be obtained using statistical methods from the evaluation of geological deposit data, as compiled and published by Singer and various other authors for the USGS and the University of Queensland (Singer et al. 2008 and 2009, Berger et al. 2009, 2011 and 2014, Cox et al. 2003, Cox/Singer 2007, Ludington/Plumlee 2009, Ludington et al. 2009, Mosier et al. 2009 and 2012).

Another key data source is operational data about ore grades from deposits currently being mined. This data, however, is frequently subject to confidentiality restrictions.

As part of the compilation of a publication on mineral grades (Priester /Ericsson n.d.), statistical data on deposits were evaluated using the Don Singer method and annual reports from ongoing operations; these relate to a total of 4,000 individual sites. The resulting grade categories of the six raw materials analysed in ÖkoRess are shown in Table 3-5).

Table 3-5: Grade categories for specific ore grades (based on Priester/Ericsson n.d.)

	Poor	Average	Rich
Gold (g/t)	<2	2-20	>20
Copper (%)	<0.3	0.3-3	>3
Zinc (%)	<1	1-10	>10
Lead (%)	<1	1-15	>15
Nickel (%)	<0.5	0.5-2	>2
Diamond (g/t)	<0.01	0.01-0.5	>0.5

As things currently stand, it is not possible to provide any similarly reliable data for other metals. Providing estimated values or benchmarks is not useful. In view of this, a sound evaluation can initially only be performed for the above six raw materials. A research group from the University of Lund is currently working to determine grade categories for, among others, copper, zinc, lead, nickel, PGMs, chromium, lithium, cobalt and iron. So far, only some of the results have been published (Sverdrup et al. 2017). In order to extend this to other metals, there is a need for research, not only to be able to perform an evaluation, but also because the differing ore grades represent the geological potential for future mining activities. This is closely related to the discussion around decreasing ore grades in the past and predictions for the future development of grades.

In the absence of information on grade categories, the evaluation can be undertaken deductively: either if the deposit has been described as comparatively high-grade or low-grade, or on the basis of the extraction method. If, with raw materials that can be mined using both surface mining techniques and underground mining, underground mining has been selected, then it can be assumed in all probability that the deposit in question is a comparatively rich one. Only high grades enable the comparatively high initial costs involved in underground mining to be recouped. This estimation is possible for raw materials such as copper and gold, as well as for niobium/tantalum, chromium, tungsten, antimony, fluorspar and barite.

3.2 The ‘Technology’ level

3.2.1 The ‘Technology’ level, ‘Mining-specific’ field, ‘Mine type indicator

The mine type gives an indication of the interventions on the earth’s surface needed to extract the raw material. By their nature, these are smallest in underground mining, a model example of this being the former Käfersteige mine near Pforzheim (fluorspar), where two openings on the surface (one for man-riding, one for ventilation) were the only signs of a mining operation. In solid rock open pit mining (quarries, open pit ore mines), the intervention is generally limited to one area, which is only marginally larger than the projection of the deposit body on to the surface. In addition, surface mining is frequently used for the deposition of mine residues, as a result of which the area for mine heaps and tailings ponds also decreases further. Mining on sedimentary deposits in unconsolidated rock (alluvial and colluvial deposits), such as on gold, diamonds, cassiterite, titanium sands, etc., as well as on lignite or bauxite) constitutes the most dramatic intervention. Consequently, this criterion is regarded as a further indicator of land consumption and interference with the ecosystem alongside deposit size.

Evaluation (intervention on the earth’s surface)

Low (green):

Underground mining / subsurface mining

Medium (yellow):

Solid rock open pit mining

High (red):

Mining on sedimentary deposits in unconsolidated rock (alluvial and colluvial deposits)

3.2.2 The ‘Technology’ level, ‘Processing-specific’ field, ‘Use of auxiliary substances’ indicator

During extraction and processing operations, use is made in some cases of toxic and otherwise environmentally hazardous auxiliary substances and operating materials that can develop negative effects for the environment when released into the surrounding area. In this respect, this indicator shows a potential burden resulting from environmentally hazardous auxiliary substances and operating materials that is intended to complement the indicator for geogenic environmental hazard potential (see Section 3.1.1) resulting from mineral paragenesis. Evaluation with this indicator also considers –

alongside normal mining operations and processing, which, especially in the case of industrial operations, is safeguarded through environmental management systems (risk analyses, definition of responsibilities, chains of communication, job descriptions and stipulation of protective measures) – the consequence of potential incidents that may be triggered by human error or technical failure, but also by natural phenomena (see also Section 3.3.1). Many of the mining-related problems discussed in the public arena and social conflicts are sparked by these hazardous incidents.

Evaluation (hazard potential concerning release of harmful substances)

Low (green):

Without auxiliary substances

Medium (yellow):

With auxiliary substances that are not classified as toxic

High (red):

With toxic reagents

Listed below are extraction and processing methods that relate to conventional mining and processing operations, and are intended to provide a guide for classifying the respective operating practice for evaluation purposes.

The extraction and processing operations ***without auxiliary substances*** include the following:

In mining:

- Mechanical loosening and loading of the rock.

In processing:

- Purely mechanical processing operations (simple gravimetric processing, selective crushing)
- Visual sorting
- Separation by hand
- Electrostatic processing
- Hot-cold loosening processes.

The extraction and processing operations ***with auxiliary substances that are not classified as toxic*** include the following:

In mining:

- Drilling and blasting.

In processing:

- Heavy media separation with FeSi
- Bioleaching, thiourea leaching
- Diamond processing on the grease table.

The extraction and processing operations ***with toxic auxiliary substances*** include the following:

In mining:

- In-situ leaching.

In processing:

- Amalgamation in gold processing (use of mercury, which, according to the Minamata Convention, ought to be completely dispensed with).
- Cyanide leaching and chlorination (both highly toxic substances, with which there have been frequent accidents).
- Solvent extraction (the solvents used in this process can generally be classified as toxic).
- Flotation (usually with highly toxic long-chain organic hydrocarbons that do not degrade easily).

3.2.3 The 'Technology' level, 'Management-specific' field, 'Mining waste management' indicator

The waste materials from mining and processing frequently give rise to long-term effects on the environment, be this through autoxidation, through leaching, through weathering processes, through passive dispersal or other natural processes. In this respect, this indicator represents a measure of the environmental hazard potential, depending on operating practice, from mining waste materials.

The document 'Bergbauliche Reststoffe' (Mining waste materials)[18], in which hazard potentials involved when dealing with mining waste materials are also described, can be used as an evaluation aid.

Evaluation (hazard potential concerning the long-term effect of mining waste materials)

Low (green):

Safe storage/deposition of tailings in the deposit (backfilling of the mine in parallel to ongoing mining, backfill of waste materials to stabilise the mining plant)

Medium (yellow):

Marketing of mine residues, e.g. as building materials; stable mining waste heaps (depending on the particle size, particle composition, steepness, height); smaller tailings ponds (< 15 m structural dam height, see below).

High (red):

Risky deposition: unstable mining waste heaps, dumps and lakes, high-volume or large-area tailing ponds, deposition in rivers or deep lakes; no strategies for making the waste materials safe after mining has been completed.

The size of tailings ponds is defined, e.g. by ICOLD, or rather in the World Register of Dams. In that register, a structural dam height of 15 m above the ground surface is deemed the minimum criterion[19].

Frequently, data concerning mining waste management is scarcely available, despite the fact that reporting obligations, e.g. in accordance with the GRI, call for information about environmental management and thereby also about the deposition of waste materials. Knowledge about the deposit (mineralisation, degree of intergrowth), the production quantities, and the processing technology used enables statements to be made about what quantities of fine- and ultrafine-particled tailings accumulate, which have to be treated or deposited in tailings ponds. Polymetallic, finely and ultrafinely intergrown ores that require processing by means of flotation or agitation leaching result in a high proportion – in terms of quantity – of fine and ultrafine residual materials, which, in combination with large extracted quantities, allow us to expect the existence of tailings ponds, provided that the operation does not (and this is only the case in exceptional circumstances and where there is an extreme water shortage) perform solid-liquid separation of tailings and deposit the solids from the slurries dry. Knowledge of the

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[18] Michael Priester and Peter Dolega: 'Bergbauliche Reststoffe'. Produced as part of the ÖkoRess project, July 2015. https://www.umweltbundesamt.de/umweltfragen-oekoress

[19] For a definition, see: http://www.icold-cigb.org/GB/World_register/general_synthesis.asp

topography and satellite images can help with classification as to whether smaller (medium environmental hazard potential, yellow) or high-volume and/or large-area tailings ponds (high environmental hazard potential, red) are concerned.

3.2.4 The 'Technology' level, 'Management-specific' field, 'Remediation measures' indicator

The indicator for remediation measures is a measure of the longevity of impacts on the environment, depending on operating practice. First and foremost, this is reflected in the planning, provision and implementation of measures for recultivation, rehabilitation or decontamination of areas adversely affected by mining and processing. This comprises partial aspects such as the dismantling of machinery and plants and also of the buildings, the backfilling or securing of shafts and tunnels, the restoration of a near-natural groundwater and surface water regime, the backfilling of extraction sites (open pit mining), the restoration of an appropriate topography and of the soil, and the reforestation or preparation of another type of subsequent use (e.g. flooding of open pit mines for recreational purposes).

Evaluation (longevity of interference with the environment)

Low (green):

Process-parallel rehabilitation or recultivation

Medium (yellow):

Financial accruals for rehabilitation

High (red):

No provisions

Similarly, it is the case for remediation measures, rehabilitation, recultivation and renaturation that these are required by national mining and environmental laws, as well as by international standards for responsible mining practice (e.g. ICMM) and as a rule the awarding of licences or legal titles without their submission, e.g. within the scope of the EIA and environmental management planning, is not possible. An account must be given of compliance with these obligations within the framework of reporting obligations, e.g. in environmental reports. The relevant information ought to be able to be found there. In general, it can be assumed that formal, industrialised mining, particularly where there is monitoring by (critical) shareholders, meets these standards, for which reason a low environmental hazard potential should rather be assigned in this case (green). In countries with a big deficiency in terms of enforcement or a lower quality of governance, and also with public-private partnerships, semi-public or public mining companies and local companies, the risk of duties of care being neglected is – based on experience – a high one, and compliance with the standards must be validated in the individual case. The situation becomes problematic in an informal or indeed illegal context; this frequently concerns artisanal and small-scale mining operations that are able to evade the obligation to implement remediation measures. Here, a high environmental hazard potential (red) should preferably be assigned.

3.3 The 'Site (surroundings)' level

When describing the sites of mines, a distinction has been drawn between 'Natural environment' and 'Social environment'. The 'Natural environment' field encompasses possible environmental hazard potentials specific to the site, whilst the 'Social environment' field focuses on conflicts of uses – related to the environment – at sites or in the areas around them.

Here it should be noted that the selected evaluation approach for the social environment is, de facto, based on country-specific indicators concerning the possibilities of social participation and corruption control. Accordingly, local and case-specific characteristics of the social environment are not taken into consideration in the evaluation. Although, on the one hand, this results in limitations with site-specific evaluations, it is possible, on the other hand – for the purposes of an initial estimation – to draw on extensively available and well-documented data. Thus while the approach does not permit an analysis of the actual social environment and the existing local conflict potentials, it still provides – via a country-specific perspective – indications of risks based on the variation shown from governance indicators. There will be more in-depth academic consideration of the social environment in the follow-up project ÖkoRess II (FKZ 3715 32 310 0).

For individual mine sites there are, in the 'Natural environment' field, a number of possible environmental hazard potentials, which are determined by the geographical location. These include climatic or seismological factors through which hazardous accidents can be triggered, additionally the danger of water availabilities being negatively affected, and the danger of ecologically sensitive areas being affected. In the evaluation matrix, goals and relevant indicators have been derived for the 'Natural environment' field for representing and measuring these site hazard potentials. These, together with the evaluation regulations developed for them, will be described in detail in the following subsections. For all indicators, it was possible, for the purposes of determining them, to identify publicly accessible spatial data sets, which means that third parties can also easily evaluate individual mine sites.

As part of the project, the 40 case studies were evaluated with the aid of a spatial analysis using the geographic information system QGIS[20]. This is free software licensed under GNU (General Public License[21]). QGIS is being used more and more by companies and public authorities. When adapting the data sets to the measuring instruction criteria, maps were generated that were exported in raster or vector format, making them reproducible.

A prerequisite for the spatial analysis of individual mine sites is the indication of the coordinates and dimensions. With the aid of this information, the geo-referenced indicator values can be blended with the mine sites. Since the geographical dimensions of mining activities can vary very widely, they must be stated precisely. If there is no data available from the mine operators, then the dimensions can be estimated using simple visualisations from satellite data (e.g. GoogleEarth) or remote sensing software. In the best case, the surface area can be represented as a differentiated polygon. A simplified approach is the conversion of the average dimensions into a circle around the focal point of the mine site (cf. Figure 3-4). In extreme cases, with very elongated mine sites, this may result in the area being hugely overestimated overall, but the circular area is the best-suited spatial model for analyses involving a geographic information system. For better mapping of very elongated mining areas, several smaller circles can be generated.

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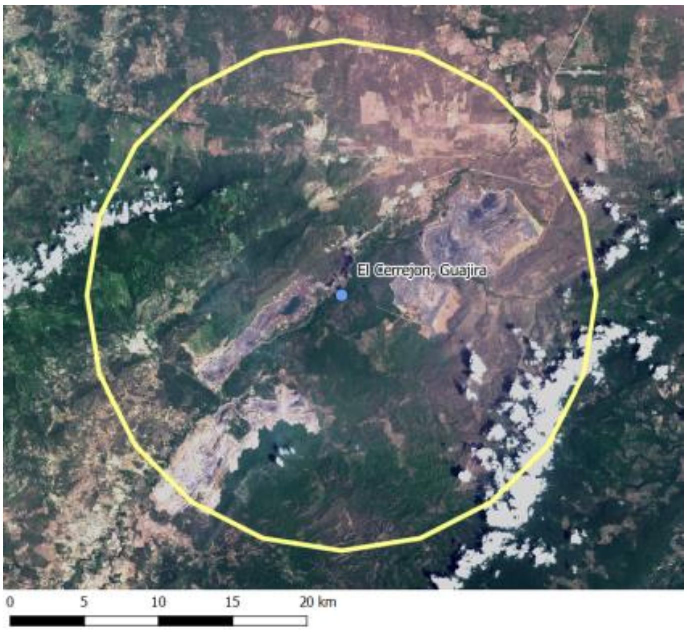
[20] http://www.qgis.org/de/site/ (last accessed on 13 July 2015)

[21] Software licence that allows users to run, study, modify and distribute the software. Such software is called 'free software'. http://www.gnu.org/licenses/gpl-3.0.html (last accessed on 13 July 2015)

Figure 3-4: Conversion of the estimated dimensions of the El Cerrejón coal mine



Basic data: Landsat 8. Image courtesy of the U.S. Geological Survey, 2015-10-03T18:19:35Z. Cartography: ifeu.

In Figure 3-4, the yellow circle shows the dimensions (diameter) of 35 km, which were taken into consideration for the spatial analysis of the site.

3.3.1 The 'Site (surroundings)' level, 'Natural environment' field, 'Natural accident hazards' indicator

Mining activities, as a result of mining and processing operations, increase the danger of damage to the environment within a region. This hazard can be amplified as a result of the particular geographical conditions at the site. This includes conditions that impair the mining facilities and infrastructure and hence result in substances harmful to the environment being released and the surrounding area becoming contaminated. Extreme natural events cannot be adequately predicted for all regions, but it is possible, from the known natural conditions, to derive the hazard potential for particularly exposed regions. This includes, for example, knowledge about regions at risk of flooding (floods), steep slopes in high mountain regions (landslide, rockslide), storm events (wind damage, storm surges) or earthquake zones (mass movements).

To evaluate the 'Avoiding natural accident hazards' goal, four indicators (cf. Table 3-6) and a special rule for the Arctic region are used, which are viewed as critical when it comes to mapping natural accident hazards. The hazard potentials for earthquakes, landslide, tropical storms and floods were developed, among other things, for analyses in the Global Assessment Report on Disaster Risk Reduction (GAR). Since 2009, the report has been published every two years by the UNISDR[22], and analyses data and information relating to natural disasters. The UNISDR makes the spatial data bases and background papers used available via an internet platform[23]. The selected sub-indicators for the 'Natural accident hazards' indicator are based on data sets from the GAR. This does not cover extreme natural events for the Artic region such as floods or polar storms. Since, however, an increased accident hazard exists as a result of these, a special rule has been derived here. The selected sub-indicators are described in more detail in the sections below.

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[22] United Nations International Strategy for Disaster Reduction (UNISDR).

[23] GAR 2013: http://preview.grid.unep.ch (last accessed on 13 July 2015)
GAR 2015: http://www.preventionweb.net/english/hyogo/gar/2015/en/home/ (last accessed on 13 July 2015)

Table 3-6: Selected indicators for the 'Avoiding natural accident hazard' goal

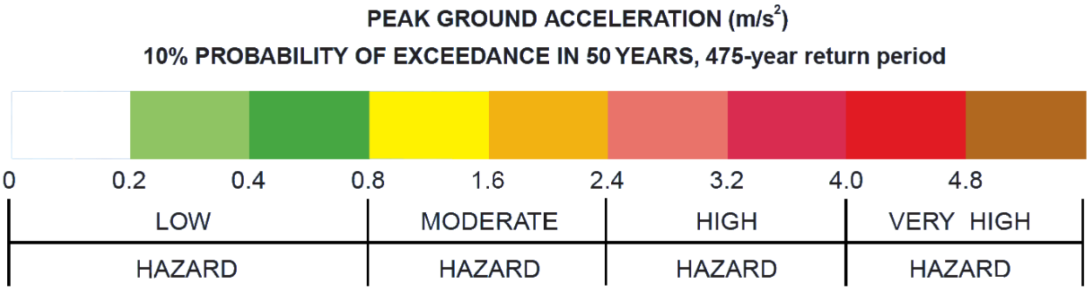
Indicator	Potential environmental events	Resulting accident hazards
Earthquake hazard	Rockfall, rockslide, tsunami	Dam collapses Destruction of line systems Accelerated leaching of harmful substances
Landslide hazard	Rockfall, rockslide	
Tropical storm hazard	Storm surge, storm damage	
Flood hazard	Floods	
Special rule: hazards for the Arctic and Antarctic	Polar storms, flooding from snowmelt, permafrost dynamics	

3.3.1.1 Earthquake hazard

Earthquakes are among the most devastating natural phenomena on earth, since huge forces – which are due to tensions within the earth's crust – are released within a few minutes. These forces act on the environmental matrices of the earth's surface, where they can cause shifts and transformations. Humans' habitats can be directly destroyed by the forces from the earthquake or be indirectly affected by subsequent events such as landslides, dam collapses or tsunamis. The effects may occur in selective areas or, depending on the intensity and extent of the earthquake, involve larger geographical units.

A relatively large amount is known about the earth's earthquake zones, and the recording of earthquakes has a comparatively long history. The Global Seismic Hazard Assessment Program (GSHAP) was created in 1992. As part of this project, data have been collected worldwide and earthquake hazard maps developed (Shedlock et al. 2000). Categorisation of the earthquake risk is performed with the aid of a probability calculation. The unit used is the horizontal peak ground acceleration (PGA), which, specific to a region, can with a probability of 10% be exceeded in the next 50 years. The PGA of a region is an important parameter for planning, and has been used as a data basis for the hazard maps of the UNISDR Global Risk Assessment Report. Table 3-7 shows the measuring instruction for classifying the results. The grouping here is based on the allocation from the Global Seismic Hazard Map according to GSHAP[24] (Figure 3-5).

Figure 3-5: Hazard potential scale according to GSHAP



Source: Legend of the GLOBAL SEISMIC HAZARD MAP (Shedlock et al. 2000)[25].

In order to determine the earthquake hazard for mine sites, the spatial data from the GSHAP were downloaded and adapted in line with the ÖkoRess evaluation. The result is shown in Figure 3-6. According to this, 9% of the land surface is assessed as having a medium (yellow) hazard potential and a further 3.6% as having a high (red) hazard potential.

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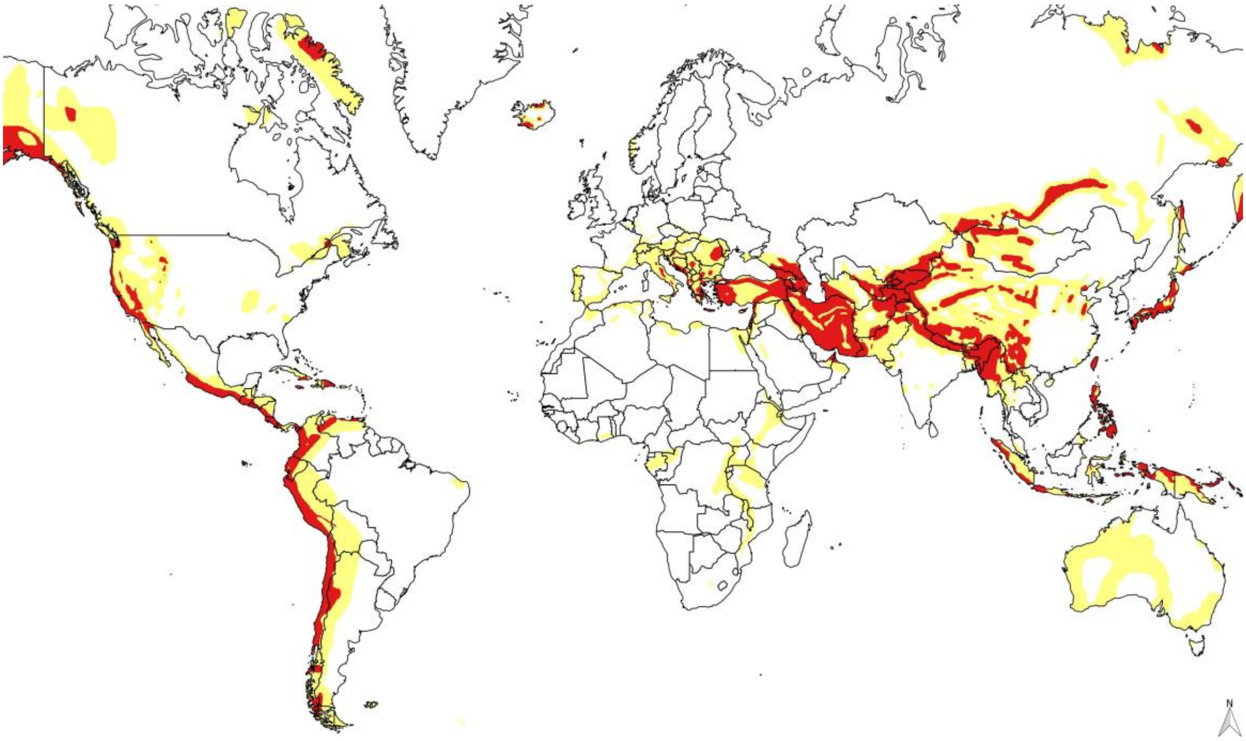
[24] http://www.seismo.ethz.ch/static/GSHAP/ (last accessed on 10 July 2015)

[25] "All GSHAP products and maps are available freely and are not covered by copyright, provided that the source is cited" http://www.seismo.ethz.ch/static/GSHAP/ (last accessed on 10 July 2015)

Table 3-7: Evaluation for the 'Earthquake hazard' sub-indicator

Evaluation of earthquake hazard according to peak ground acceleration (PGA)	
0 to < 0.8 m/s^2 PGA (10% probability of exceedance in 50 years)	Low (green)
0.8 to 2.4 m/s^2 PGA (10% probability of exceedance in 50 years)	Medium (yellow)
> 2.4 m/s^2 PGA (10% probability of exceedance in 50 years)	High (red)

Figure 3-6: Distribution of earthquake hazard based on the ÖkoRess evaluation (yellow = medium; red = high)



Basic data (Shedlock, K. M. et al. 2000); cartography ifeu.

3.3.1.2 Landslide hazard

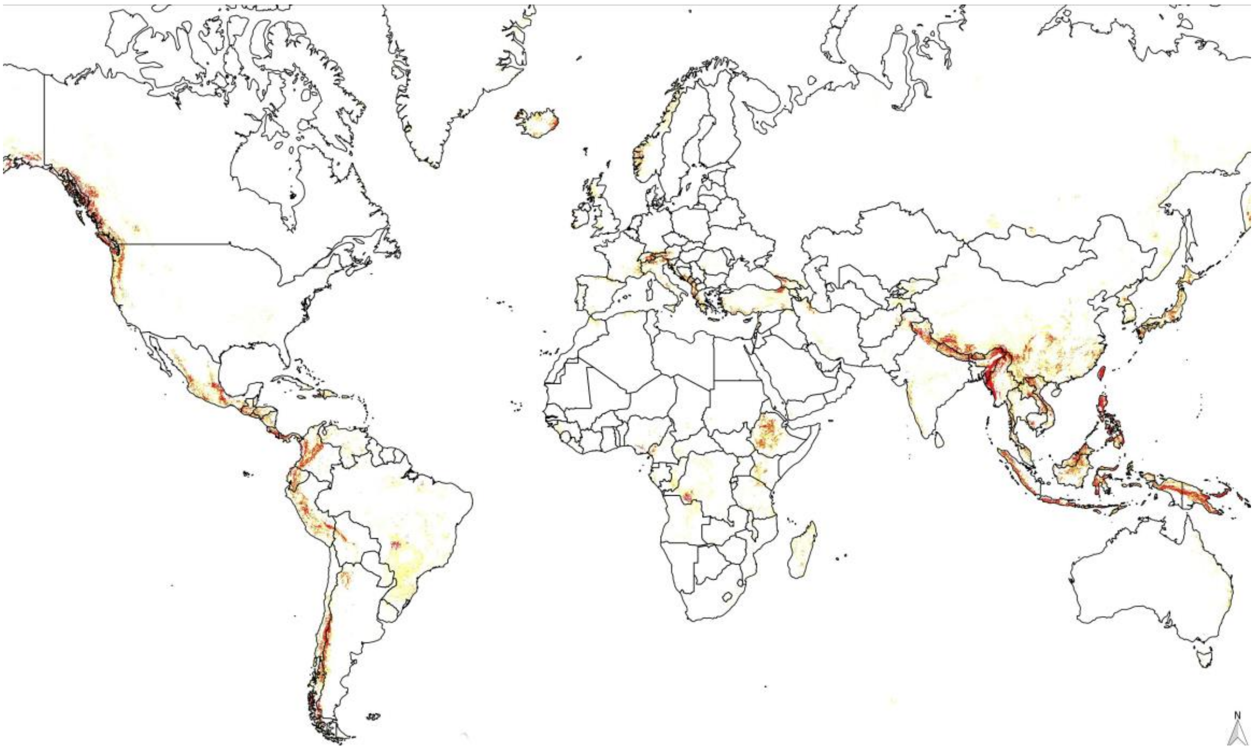
A landslide is a mass movement triggered by the force of gravity, and a dynamic process on the earth's surface that shapes and constantly changes the landscape. On a small scale, landslides essentially occur in all locations where there is a slope. The steeper this slope, the more accelerated this mass movement over the course of time. The real danger to humans is more from mass movements over a wide area, such as large landslides, rockslides or rock avalanches. These mass movements are triggered by an interplay of moisture and gravitational tractive forces (Zepp 2011). Steep slopes are particularly vulnerable, since the tractive forces are greatest here. Thus the hazard potential of landslides is not limited to high mountain regions, but the likelihood of there being steep slopes here is greater. For the evaluation of specific sites at the micro-level, it is possible, using the method of remote sensing with the aid of satellite data, to analyse and evaluate the relief energy. Looking at this globally, spatial data on landslide hazard zones, published in the 'Global Assessment Report on Disaster Risk Reduction 2013' by UNISDR (UNISDR 2013), are used. Key input parameters for the calculation of the indicator are the gradient, geological factors, soil moisture, vegetation cover and precipitation in an area[26]. This gives rise to a hazard map for gravitational mass movements triggered by precipitation. Gravitational mass movements can additionally be triggered by earthquakes, but these hazard zones have already been covered sufficiently by the 'Earthquake hazard' indicator in this project. The indicator was no longer taken into account in the new GAR 2015, which is why the data from the GAR 2013 were used. To represent the hazard potential, an index with four categories (low, medium, high, very high) was formed by the data authors. The implementation of this index in the measuring instruction is shown in Table 3-8.

Table 3-8: Evaluation for the 'Landslide hazard' sub-indicator

Evaluation of 'Landslide hazard triggered by precipitation'	
Low	Low (green)
Medium	Medium (yellow)
High, Very high	High (red)

Figure 3-7 provides an overview of the global distribution of landslide hazards with allocation according to Table 3-8. According to this, 5.2% of the land surface is assessed as having a medium (yellow) hazard potential and 2.4% as having a high (red) hazard potential.

Figure 3-7: Distribution of landslide hazards based on the ÖkoRess evaluation (yellow = medium; red = high)



Basic data UNISDR 2013; cartography ifeu.

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[26] Data were calculated by the International Centre for Geohazards (NGI) as part of the 'Global Assessment Report on Risk Reduction 2013', and made available via an internet platform. http://preview.grid.unep.ch (Last accessed on 24 June 2015)

3.3.1.3 Tropical storm hazard

Every year, tropical storms cost hundreds of people their lives and cause major economic losses. Tropical storms trigger a series of events that endanger humans and their infrastructure. For example, high wind speeds, severe precipitation and storm surges are generated. The formation of tropical storms is concentrated in the zone between 5 and 30 degrees latitude (north and south) (Schönwiese 2013). In this region, approximately 80 storms form every year. Not every storm is equally intense, which means there are relatively calm years, but also disastrous events such as Hurricane Katrina, which killed 1,800 people in the USA in 2005.

The data from tropical storms are recorded over long time series in meteorological databases. From this, hazard maps were prepared by the UNISDR in the 'Global Assessment Report on Disaster Risk Reduction' (UNISDR 2015a). Using a statistical analysis of the storm distribution over the available time series, hazard maps were created that represent the anticipated peak wind speeds for different recurring time periods.

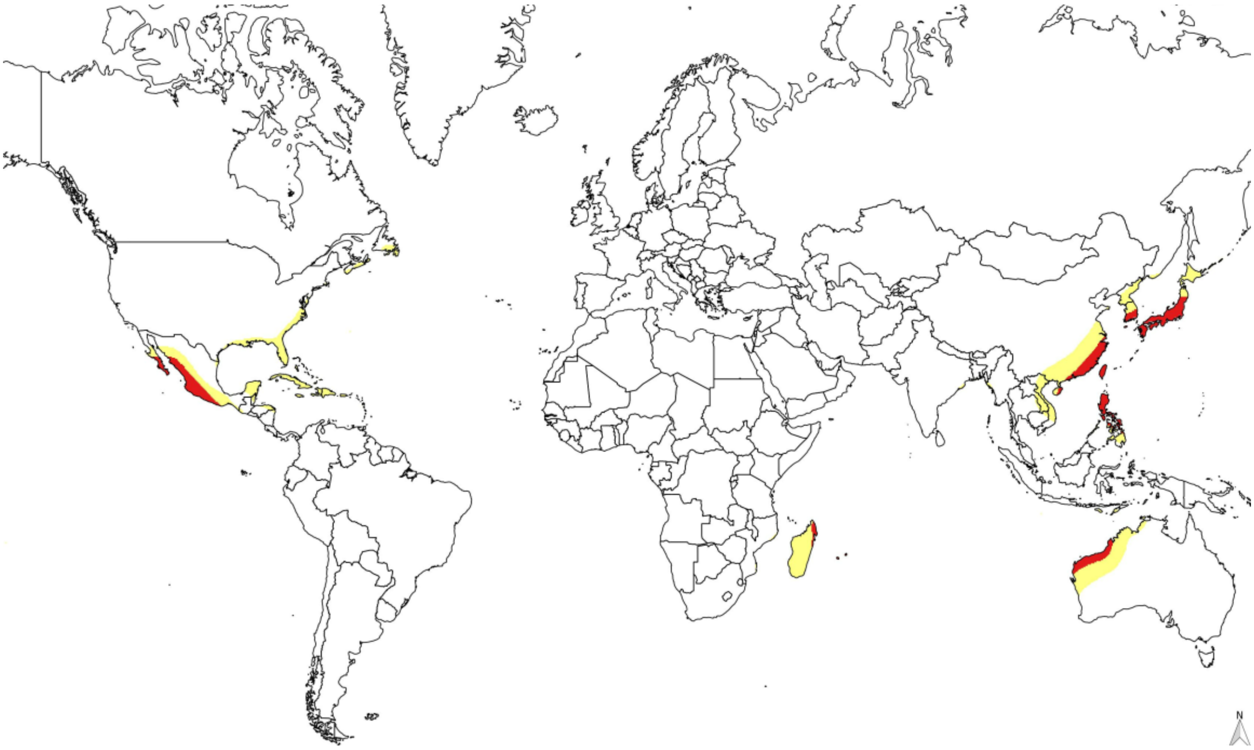
For this project, the 'Tropical Storm Hazard' data set in the time period of 100 years was selected (UNISDR 2015a). It expresses, in a similar way to the term 'flood of the century', the anticipated peak wind speeds for tropical storms in an observation period of 100 years. To map the hazard potential, an index with five intensity groups was formed in the representation provided in the GAR 2015. The implementation of these groups in the measuring instruction is shown in Table 3-9.

Table 3-9: Evaluation for the 'Tropical storm hazard' sub-indicator

Evaluation of 'Hazard from tropical storms with peak wind speeds of the century'	
119–153 km/h	Low (green)
154–177 km/h and 178–208 km/h	Medium (yellow)
209–251 km/h and > 252 km/h	High (red)

Figure 3-8 provides an overview of the global distribution of the tropical storm hazard with allocation according to Table 3-9. According to this, 3% of the land surface is assessed as having a medium (yellow) hazard potential and 1% as having a high (red) hazard potential.

Figure 3-8: Distribution of the tropical storm hazard based on the ÖkoRess evaluation (yellow = medium; red = high)



Basic data UNISDR 2015b; cartography ifeu.

3.3.1.4 Flood hazard

Floods are the most frequent disaster events affecting humans. These may have different causes and intensities. Periodically occurring floods are natural processes which humans have adapted to. Humanitarian disasters and destruction occur in cases where the intensity of the flooding deviates hugely from the norm, or where floods are triggered by particular events such as severe precipitation or sudden snowmelt. These extreme events result in humanitarian and economic losses, since society and infrastructure are not adapted to cope with the impact. Flooding therefore also constitutes a hazard for mine sites, because facilities can be flooded and harmful substances washed out.

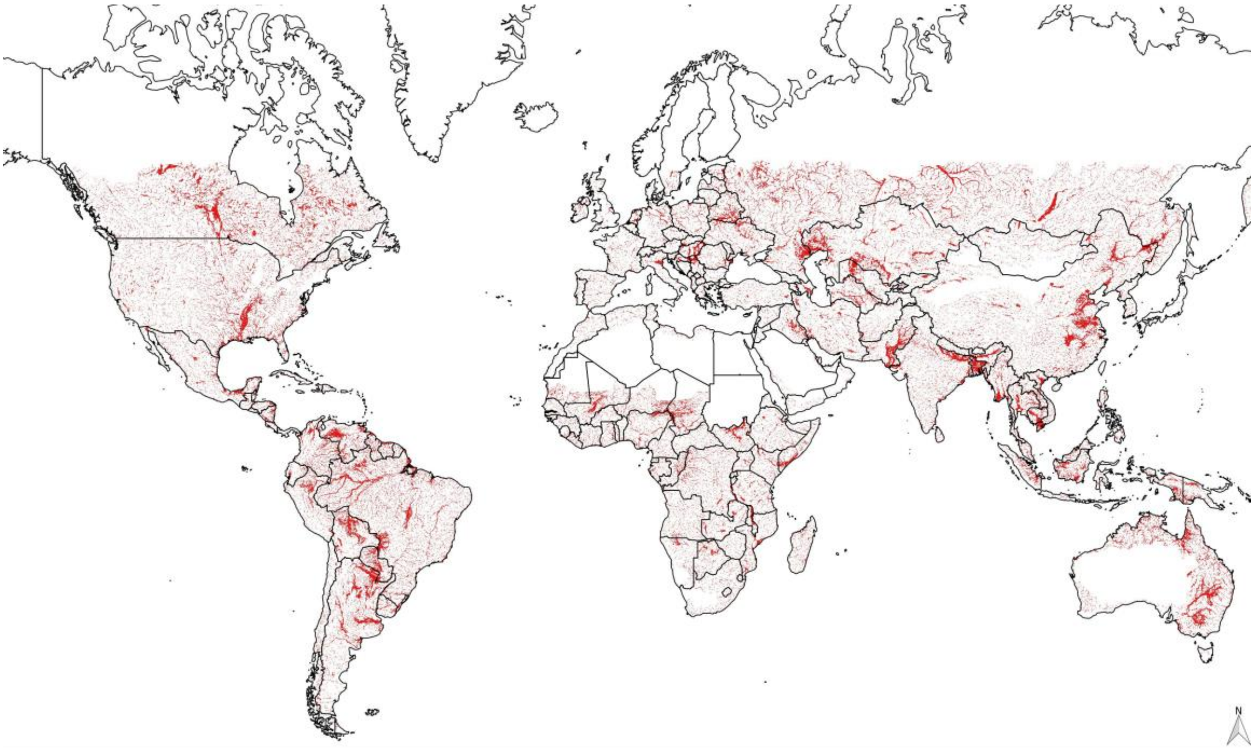
The GAR 2015 looks at the hazard from floods triggered by river flooding. Compared with the GAR 2013, the data set for the GAR 2015 was revised and further developed by the CIMA Foundation and UNEP-GRID. From this, hazard maps for floods with six different observation periods (T= 25, 50, 100, 200, 500, 1,000 years) were produced. The spatial resolution is 1 km x 1 km. For the analysis of site hazard potentials for mines, the observation period of 100 years was selected. The unit of the hazard map is the anticipated maximum flood level within 100 years (in centimetres). In the representation in the GAR 2015, no further grouping into hazard categories was carried out, consequently a high hazard potential (red) is assigned as soon as measurable flooding of at least 5 cm occurs. Table 3-10 shows the implementation of the limits in the measuring instruction.

Table 3-10: Evaluation for the ‘Flood hazard’ sub-indicator

Evaluation of the flood hazard based on the ‘maximum flood level in 100 years’	
Not specified and < 5 cm	Low (green)
≥ 5 cm	High (red)

Figure 3-9 provides an overview of the global distribution of the areas with flood hazard with allocation according to Table 3-10. According to this, approximately 10% of the land surface is assessed as having a high hazard potential (red). Owing to the limited geographical extent of input parameters[27] for the model, only floods between 60 degrees north latitude and 56 degrees south latitude can be displayed.

Figure 3-9: Distribution of flood hazard based on the ÖkoRess evaluation (red = high)



Basic data UNISDR 2015b, basic data CIMA Foundation and UNEP-GRID; cartography ifeu.

3.3.1.5 Special rule: hazards for the Arctic and Antarctic

For the Arctic and Antarctic regions there is an increased hazard potential owing to the extreme weather conditions. Polar storms, floods due to snowmelt, and the dynamics of permafrost over the course of the year entail, among other things, increased hazards in relation to the site safety of technical mining installations such as, above all, tailing ponds and waste heaps. These weather conditions are not sufficiently represented in the four previously described sub-indicators, and no relevant global data set is available for the named extreme events.

Since the Arctic and Antarctic are highly sensitive ecosystems and there is only limited regenerative capacity of the ecosystem owing to the low mineralisation rates and restricted biological decomposition, a separate evaluation rule was defined for these regions.

The Antarctic is protected for a limited time period via the Antarctic Treaty and its follow-on agreements[28]. In particular, with the resolution by Consultative Meeting XVI on protected areas of the Antarctic, the Antarctic Treaty was supplemented by the Protocol from 1991, which gives the reasons for

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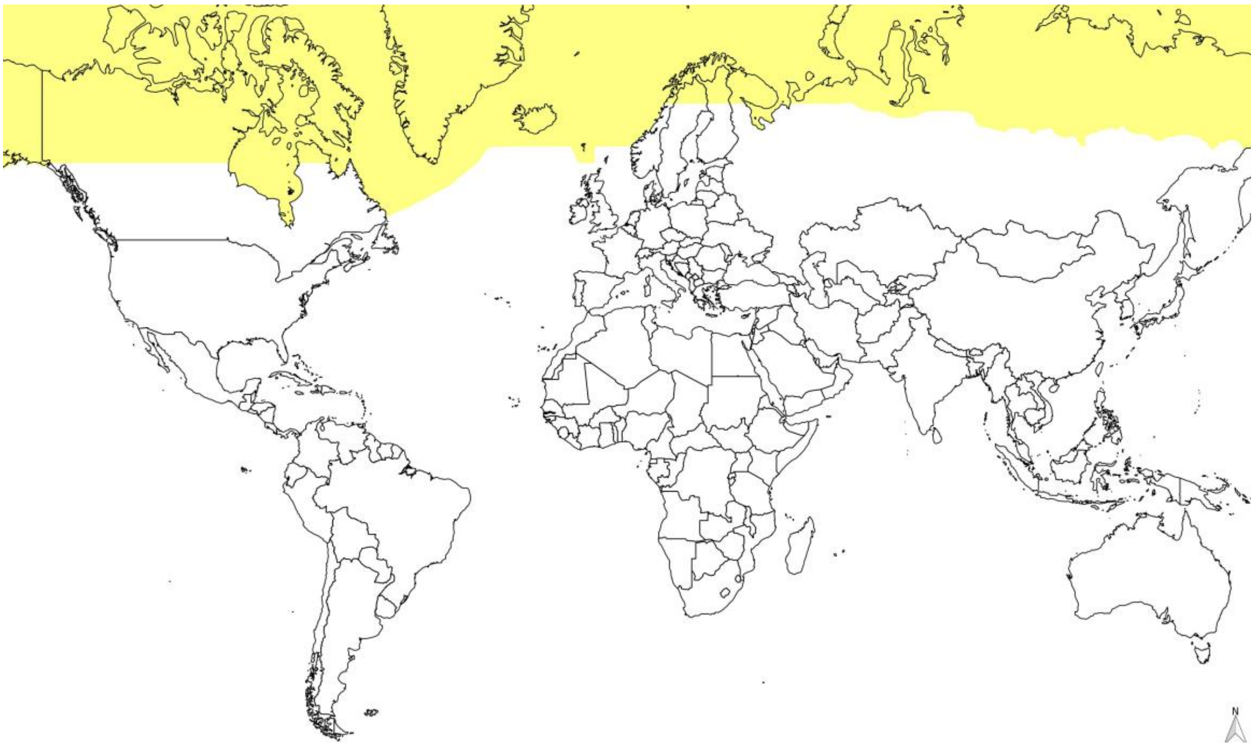
[27] The Shuttle Radar Topography Mission (SRTM) recorded elevation data relating to the earth's surface between 60 degrees north latitude and 56 degrees south latitude. These data belong, among others, to the input parameters of the flood data set of the CIMA Foundation and UNEP-GRID.

[28] The Antarctic Treaty was signed on 1 December 1959 by 12 contracting member states and entered into force on 23 June 1961. It relates to the area south of 60 degrees south latitude. Since then, the Treaty has been signed by 41 additional

a comprehensive environmental protection system for the Antarctic, with a code of conduct for environmentally compatible behaviour and a ban on mining activities. The provisions can only be rescinded after 50 years at a Review Conference. Consequently, the Antarctic is not considered any further in the measurement instruction.

There is no equivalent, comprehensive protection for the Arctic. For this reason, a conservative approach was taken and a general medium hazard potential (yellow) assigned to this region. The delimitation of the Arctic follows, in this evaluation, the Arctic Monitoring and Assessment Programme (AMAP), a Working Group of the Arctic Council[29]. AMAP is involved in international programmes for reducing emissions and the impact of climate change. To this end, AMAP publishes, at regular intervals, a report on the state of the Arctic. As a basis for the work, the Arctic region[30] is, in accordance with AMAP, defined according to a series of different criteria (Murray et al. 1998). This space comprises 13.4 million km^2, or 9% of the total land surface (cf. Figure 3-10).

Figure 3-10: The Arctic Region according to AMAP with ÖkoRess evaluation (yellow = medium)



Basic data AMAP 1998; cartography ifeu.

3.3.1.6 Merging of the sub-indicators – evaluation of the 'natural accident hazards'

The 'Avoiding natural accident hazards' goal cannot be adequately assessed with a single indicator. The previously described sub-indicators with the special rule for the Arctic are exclusive. They are, however, merged for the evaluation scheme into an assessment value, in order to represent the 'Avoiding natural accident hazards' goal with an indicator result.

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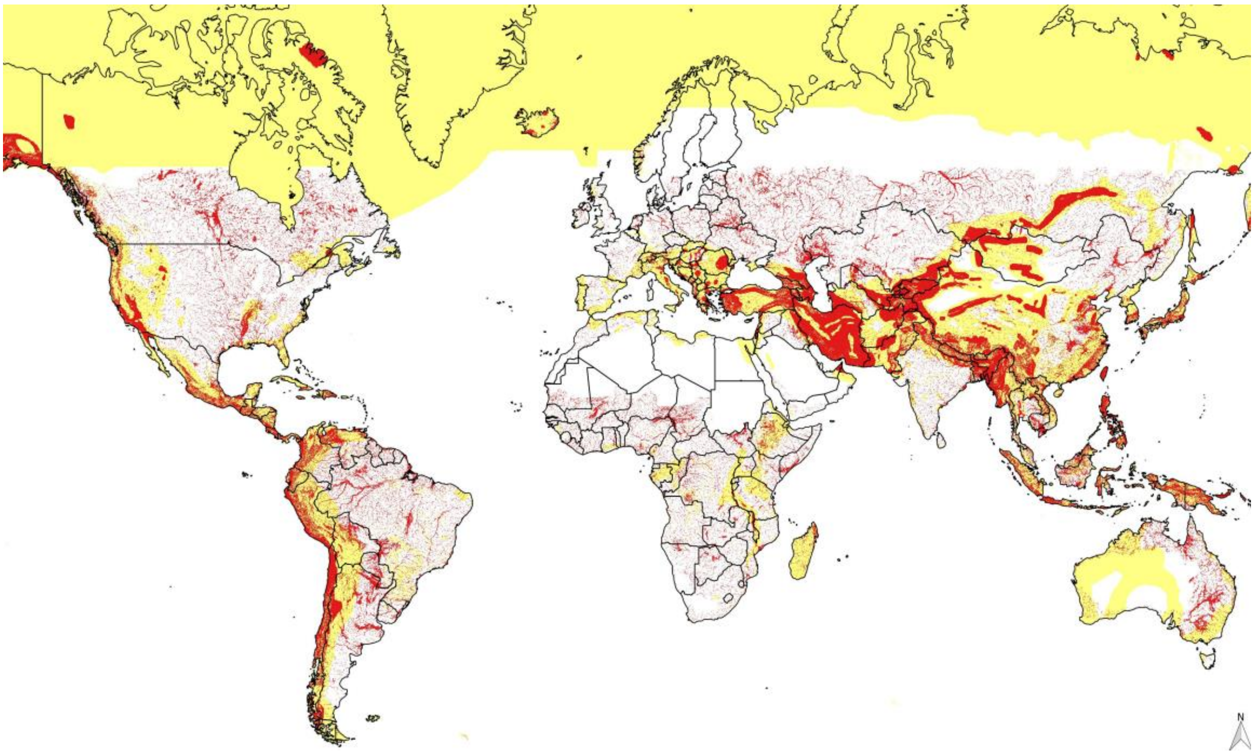
states, of which in addition to the 12 original signatories, 17 became consultative states (states entitled to vote). The Environmental Protection Protocol added in 1991 entered into force on 14 January 1998. It has been ratified by all current 29 consultative states. Of the 24 non-consultative states, eight have signed the Environment Protocol (http://www.ats.aq/e/ats_meetings_atcm.htm; http://www.ats.aq/devAS/ats_parties.aspx?lang=e).

[29] An intergovernmental forum designed to strengthen cooperation between the Arctic states and their inhabitants. The focus is on the specific needs of inhabitants and on environmental protection of the Arctic.

[30] The spatial data can be downloaded here: http://www.amap.no/about/geographical-coverage (last accessed on 4 August 2016).

Since each of the sub-indicators is significant taken for itself, the summary evaluation is performed according to the maximum principle: the site receives the highest assigned hazard potential from the sub-indicators. This means that if one of the four sub-indicators indicates 'red' for a deposit, a high environmental hazard potential is assigned; if one of the sub-indicators shows 'yellow', a medium environmental hazard potential is assigned. Only if none of the indicators show 'red' or 'yellow' is a low environmental hazard potential assigned. Figure 3-11 represents the merging of the sub-indicators according to the maximum principle in a map.

Figure 3-11: Merging of the 'Natural accident hazards' sub-indicators with the ÖkoRess evaluation (yellow = medium; red = high)



Basic data Shedlock, K. M. et al. 2000; UNISDR 2013, 2015b; CIMA Foundation and UNEP-GRID; AMAP 1998; cartography ifeu.

3.3.2 The 'Site (surroundings)' level, 'Natural environment' field, 'Water Stress Index (WSI) and desert areas' indicator

The extraction of raw materials is associated with a high water requirement, depending on the size of the mining operation, the intensity, technology and geology. Depending on the hydrological situation, this may result in competition over use, e.g. with agriculture. The danger of competition over water use particularly exists at sites where there is either already low water availability or there are already high levels of water withdrawal.

The two aspects are represented effectively using the Water Stress Index (WSI), which is used here as an indicator. The Water Stress Index WSI according to Pfister et al. (2009) is based on the ratio of annual freshwater withdrawal to hydrological availability[31]:

WTA = water use / water availability

Here, hydrological availability is an annual average based on data from the so-called 'climate normal period 1961-1990'. In order, by way of contrast to this, to take into account seasonal fluctuations in

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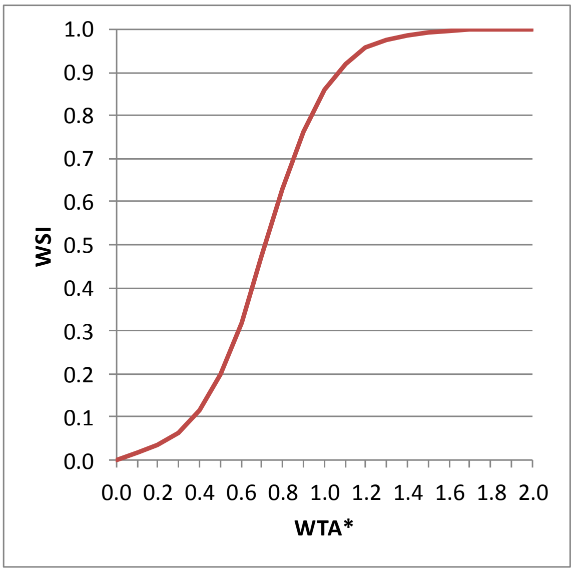
[31] Pfister et al. (2009): 'hydrological availability' (WTA, **W**ithdrawal **T**o **A**vailability)

water availability caused by varying precipitation quantities or evaporation, one variation factor (VF) (per watershed) was introduced and a modified WTA* calculated. The WTA* is not linear. In order to obtain continuous values between 0.01 and 1 for an evaluation, the WTA* was converted using a logistic function into the WSI. Below a WSI of 0.01, only minimal water stress exists, since any water use has at least marginal local impacts (Pfister et al. 2009). Figure 3-12 shows the relationship between WTA* and WSI, and the calculation formula for WSI.

Figure 3-12: Relationship between WSI and WTA*, and the calculation formula for WSI



$$WSI = \frac{1}{1 + e^{-6.4 \times WTA*}\left(\frac{1}{0.01} - 1\right)}$$

Data basis following Pfister et al. (2009)

The WSI curve has been created in such a way that the point of inflection at WSI=0.5 corresponds to the WTA of 0.4, which represents the threshold value between moderate and severe water stress (with VFmedian = 1.8; WTA* = 0.72). There is no distinction between minimal and moderate water stress in Pfister et al. (2009). The average value between 'minimal' (WSI < 0.01) and 'severe' (WSI > 0.5) lies at a WSI of 0.09 (WTA 0.2; WTA* 0.36). In Germany, WSI values generally lie below 0.13[32]. According to the Federal Environment Agency, national data show that there is no water stress in Germany (UBA 2015). On the basis of this, the boundary between 'low' and 'moderate' water stress is set at 0.15.

The WSI, however, only inadequately represents some desert regions of the world (e.g. very low water stress in the deserts of Western Australia). This is due to the definition of the indicator, which, alongside the water availability, also takes into account the water withdrawal. In very sparsely populated regions, this therefore also gives rise to a very low level of water withdrawal and in some desert regions a low WSI value. For the 'Avoiding competition over water usage' goal, therefore, restriction to the WSI falls short. Consequently, alongside the WSI, the 'desert region' site factor is additionally taken into consideration. Figure 3-13 shows the terrestrial desert regions using the classification of the WWF[33]. Deserts and xeric shrublands, shown in red, were assigned a high hazard potential (red) in the ÖkoRess evaluation.

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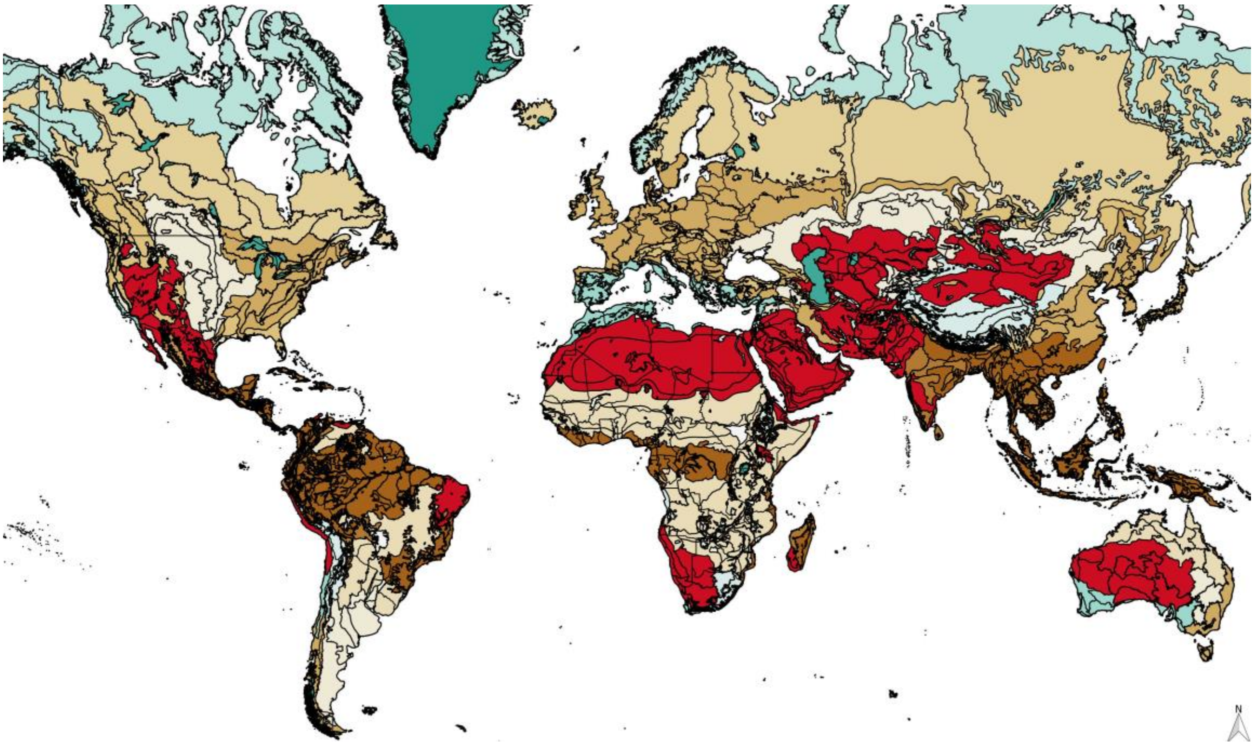
[32] Exception: border region between North Rhine-Westphalia and Belgium/Holland (WSI 0.2981)

[33] Data basis can be downloaded from the WWF website: http://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world (last accessed on 4 August 2016).

Figure 3-13: Terrestrial ecoregions of the world based on the WWF (desert regions are shown in red)



Basic data: Olson et al. 2001; cartography: ifeu

The resulting evaluation for the 'Water Stress Index and desert areas' indicator is shown in Table 3-11.

Table 3-11: Evaluation for the 'Water Stress Index and desert areas' indicator

Evaluation for the Water Stress Index (WSI) and desert areas			
WSI	0 up to < 0.15	Low water stress	Low (green)
WSI	0.15 to 0.5	Moderate water stress	Medium (yellow)
WSI	> 0.5	Severe water stress	High (red)
Desert areas		Desert region based on the WWF classification	

In order to determine the WSI for mine sites, the Google Earth™ layer published by Pfister et al. (2009) was used; this displays the WSI worldwide at watershed-level[34]. Figure 3-14 shows the global distribution of the WSI with the evaluation in accordance with Table 3-11.

Knowing the geographical location of the mining region to be evaluated, the WSI values can be read off directly. In cases where a mining region lies in several watersheds with different WSI values, then a conservative approach is to be taken and the highest value always assumed.

The WSI takes into account quantitative aspects of water use. Over and above this, qualitative aspects are also significant regarding adverse effects on water use (change in the water quality). So far, however, it is not yet possible to systematically assess this aspect at the global level. In the evaluation system derived here, the hazard potential for water contamination, as well as for the contamination of other environmental matrices, is indirectly represented via the indicators for the 'Avoiding pollution risks' goal (see Section 3.1.1)

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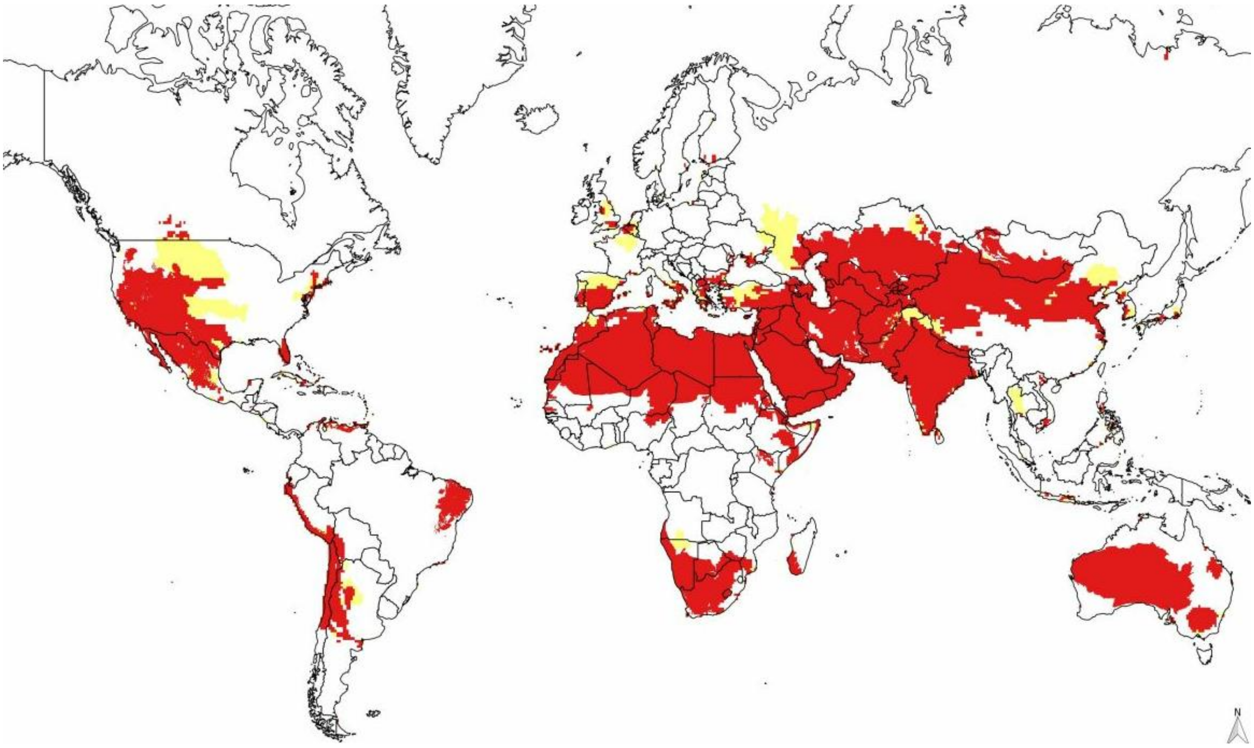
[34] http://www.ifu.ethz.ch/ESD/downloads/EI99plus/Impact_factors_Water_LCA_pfister_et_al.kmz (last accessed on 13 July 2015)

Figure 3-14: Distribution of the hazard of competition over water use based on the ÖkoRess evaluation (yellow = medium; red = high)



Basic data Pfister et al. (2009); WWF; cartography ifeu.

3.3.3 The 'Site (surroundings)' level, 'Natural environment' field, 'Protected areas and AZE sites' indicator

The extraction of abiotic raw materials in the context of mining constitutes the step in the global production chain that interferes most directly with nature. In addition, environmental burdens may have an impact far beyond the actual extraction site (e.g. road construction, water pollution). Ideally, an indicator for evaluating the protection or preservation of valuable ecosystems or ecosystem services ought to indicate all environmentally sensitive areas that require protection. To date, however, this is not possible, as globally no conclusive systematic surveys or mapping for this exist.

By way of a minimum approach, first of all existing protected areas already officially designated as such shall be taken as a basis as an indicator for the 'Protecting valuable ecosystems' goal. The officially designated protected areas include, for example, the UNESCO Natural World Heritage Sites designated on the basis of the Convention Concerning the Protection of the World Cultural and Natural Heritage[35] and the 'protected areas' from the Global Protected Areas Programme of IUCN (International Union for Conservation of Nature)[36]. Also included are protected areas that were designated as part of the Ramsar Convention[37] or to fulfil the objectives of the Convention on Biological Diversity[38].

For classification into the evaluation scheme, the protected areas must be differentiated according to their 'value'. This is based on the draft standard of the Initiative for Responsible Mining Assurance (IRMA). IRMA sets 'highly protected areas' as 'no-go zones', whilst 'protected areas' should be treated

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[35] http://whc.unesco.org/en/list/

[36] http://www.iucn.org/about/work/programmes/gpap_home/gpap_quality/gpap_pacategories/

[37] http://www.bfn.de/0310_ramsar.html

[38] Convention on Biological Diversity, CBD

as special cases (exploration and mining can take place if the activities comply with the protection objectives of the protected area; compensation may possibly be necessary).

'Highly protected areas' are:

- World Heritage Sites
- Nominated World Heritage Sites
- IUCN category I-IV protected areas
- Category I-V marine protected areas[39]
- Core areas of UNESCO biosphere reserves[40].

'Protected areas' are:

- IUCN Category V-VI protected areas
- Ramsar sites that are not already IUCN category I-IV protected areas
- Natura 2000 sites
- UNESCO Biosphere Reserves beyond the core areas
- Indigenous and Community Conserved Areas (ICCAs) in which free, prior and informed consent (FPIC) has been demonstrated, in compliance with the requirements of Chapter 2.10
- Important Bird Areas (IBAs)
- Official buffer zones of sites designated as Highly Protected Areas and other areas outside the boundaries of Highly Protected Areas in which mining activities may affect the values for which the Highly Protected Area was designated for protection
- Sites that are currently included on a State Party's official Tentative List for World Heritage Site inscription[41]
- Other officially designated protected areas.

Beyond the officially designated protective areas, there are internationally recognised designations of particularly environmentally sensitive areas, such as AZE sites, which are designated by the Alliance for Zero Extinction (AZE). These are areas in which at least one species threatened with extinction has been established (endangered or critically endangered on the IUCN Red List of Threatened Species). Information on AZE sites can be found in a report from 2005[42]. The status was updated in 2010; worldwide, 920 species have been identified in 588 areas[43].

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[39] http://cmsdata.iucn.org/downloads/uicn_categoriesamp_eng.pdf

[40] http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/world-network-wnbr/wnbr/

[41] http://whc.unesco.org/en/tentativelists

[42] http://www.abcbirds.org/newsandreports/special_reports/AZE_report.pdf

[43] http://www.zeroextinction.org/sitesspecies.htm

Table 3-12: Evaluation for the 'Protected areas and AZE sites' indicator

Evaluation of environmental hazard potential for designated protected areas and AZE sites		
Not a protected area	No designation / no AZE site	Low (green)
Protected area	All other official protected areas and AZE sites	Medium (yellow)
Highly protected area	UNESCO World Heritage Sites, nominated World Heritage Sites, IUCN category I-IV protected areas, core areas of UNESCO biosphere reserves	High (red)

As far as possible, areas designated as valuable ecosystems should be included in the evaluation. The measuring instruction shown in Table 3-12 for classification of the analysis results comprises all officially designated protected areas and AZE sites accordingly, as far as they are relevant for this project[44].

Officially designated protected areas are documented in a global database on protected areas, the World Database on Protected Areas (WDPA), a joint initiative of IUCN and UNEP-WCMC. Details are available online at ProtectedPlanet.net.

http://www.protectedplanet.net/

Using the map, further information can be retrieved, such as the IUCN category, which enables classification into 'highly protected area' or 'protected area'.

AZE sites can be determined from a pdf map or a live map:

http://www.zeroextinction.org/sitesspecies.htm

It was possible to download the data sets associated with the two maps[45], and these can be used for analyses[46]. Figure 3-15 provides an overview of the global distribution of protected areas with the evaluation in accordance with Table 3-12.

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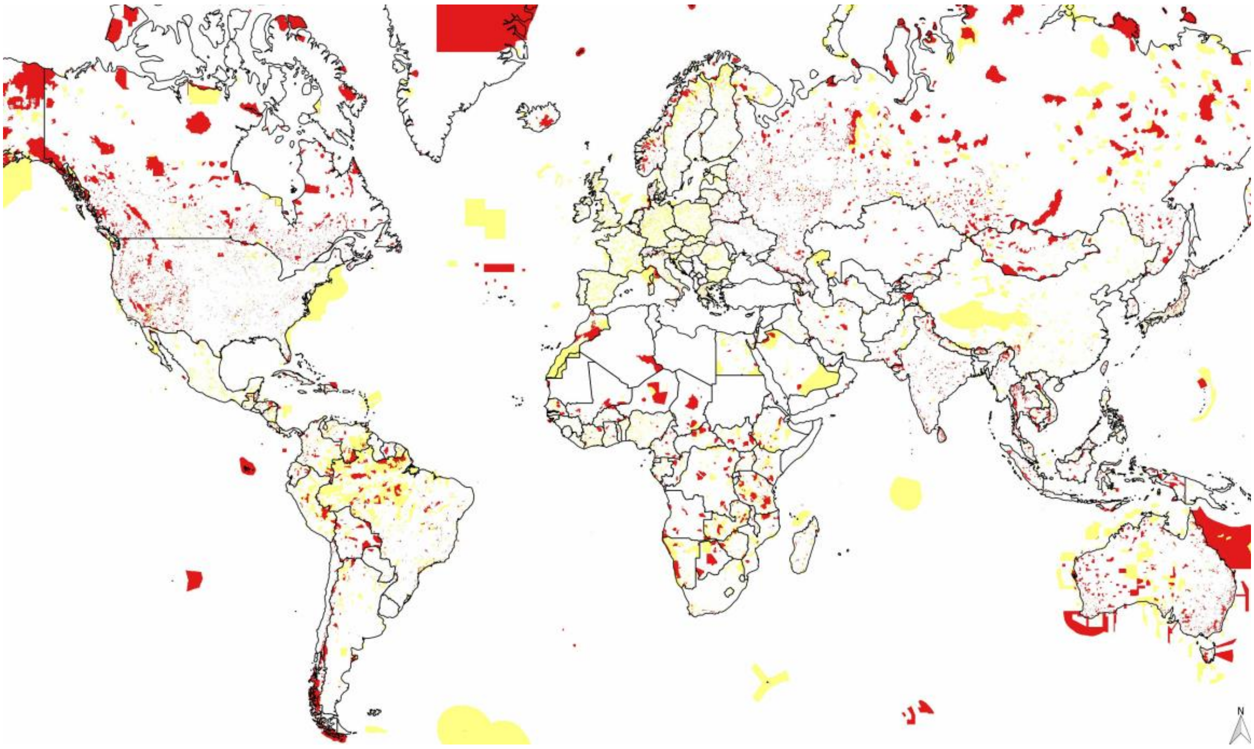
[44] The IUCN category I-V marine protected areas are not evaluated, since in this project only land-based mining sites are considered.

[45] The processed data were downloaded on 15 April 2015.

[46] It should be noted at this point that the data set from protectedplanet.net is constantly being updated and in some cases still contains data gaps. Furthermore, in the data set only the designated World Heritage Sites and the total area (core area and buffer zone) of the UNESCO biosphere reserves are shown. Nominated World Heritage Sites and the core areas of the UNESCO biosphere reserves cannot, to date, be displayed separately via the data set. When considering individual mine projects, however, this should be taken into consideration.

Figure 3-15: Distribution of designated protected areas and AZE sites based on the ÖkoRess evaluation (environmental hazard potential yellow = medium; red = high)



Basic data IUCN / UNEP-WCMC 2015 and Alliance for Zero Extinction 2010; cartography ifeu.

3.3.4 The 'Site (surroundings)' level, 'Social environment' field, 'Conflict potential with local population' indicator

Background

In conflict research, it is undisputed that there can be a connection between mineral deposits and conflicts[47]. In general, it must be noted that the existence of a conflict is not evaluated as negative *per se* in social science research. Generally, conflicts can be regarded as an expression of diverging interests, i.e. situations which are unavoidable in modern societies. The evaluation of conflicts is, ultimately, linked to the question of how these are resolved. In general, the cases range from ones in which conflicts are negotiated peacefully and to the satisfaction of all participants to situations in which the groups involved try to assert their interests using violence. Intermediate forms are situations in which conflicts of interests cannot be satisfactorily negotiated over a longer period, meaning that outbreaks of violence in the future appear a possibility.

Based on this continuum of conflict situations, Heidelberg Institute for International Conflict Research has developed a five-part classification scheme that groups existing conflicts on the basis of their intensity (HIIK 2014).

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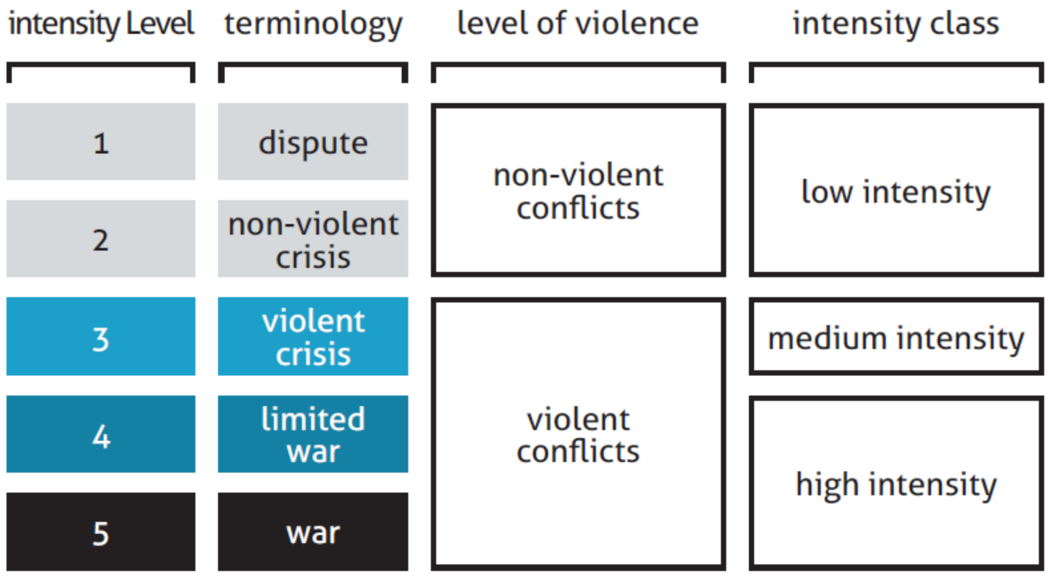
[47] At the same time, it is disputed whether the presence of mineral resources actually increases the likelihood of armed conflicts or not (see, among others, McNeish 2010). This debate is not directly relevant for the further evaluation method.

Figure 3-16: The classification of conflicts based on their intensity



Source: HIIK 2014

Using this system, Heidelberg Institute for International Conflict Research records conflicts annually, and assigns one or more conflict items to them. Here ‘resources’, meaning mineral deposits, are one of a total of ten possible conflict items, so that, with the aid of this conflict barometer, at least a retrospective estimation of the conflict impact of a mining project is possible.

Since, however, this approach can only be used with existing projects, the authors recommend an alternative approach for the evaluation, which is essentially based on their own estimation of the political and social prerequisites for peaceful and comprehensive conflict resolution. In the process, the authors assume that environmentally induced conflicts of use can generally be peacefully negotiated if the following prerequisites are met:

- If population groups affected by environmental impacts can express their concerns publicly and without the fear of being disadvantaged further, and these can also be listened to within the context of political discourse.
- The implementation of political decisions is not systematically subverted by corruption.

For an approximate estimation of these factors, it is possible, at least at the national level, to use the World Governance Indicators (WGI) of the World Bank:

The World Bank publishes country-specific data for six different aspects of governance[48]. The data, in turn, are based on a number of other governance-based country rankings. Overall, the World Bank Governance Indicators are held in high regard. The following indicators are available:

- Voice and Accountability
- Political Stability and Absence of Violence/Terrorism
- Government Effectiveness
- Regulatory Quality
- Rule of Law
- Control of Corruption.

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[48] http://info.worldbank.org/governance/wgi/index.aspx#reports

In the original data set, the indicator values are given in a range from -2.5 (worst value) to 2.5 (best value). Building on this, the countries are – in all six categories – recorded in a ranking list. Depending on the position in this ranking list, in turn a percentage is given (100% for the best position, 0% for the worst position).

For an estimate of environmentally induced conflict risks, it is recommended that the respective country values for 'Voice and Accountability' as well as 'Control of Corruption' be used. By this means, an indication can be provided of how high risks are in terms of the insufficient involvement of local population groups and how high the risks originating from the subversion of standards through corruption are estimated to be.

Specifically, the following evaluation key is proposed:

Evaluation (Conflict potential with local population)

Low (green):

Both indicator values ≥ 65%

Medium (yellow):

- At least one indicator value in the range 45% to 65%
- No indicator value < 45%

High (red):

At least one indicator value < 45%

4 Evaluation of the data quality

When using the evaluation scheme shown, gaps and/or evaluations based on not fully representative data must be assumed, depending on the individual case. In order to make the data quality transparent, it is recommended that an indication of the underlying data quality is provided along with the evaluation of individual indicators. At the same time, alongside the data quality, it should also be taken into consideration whether the evaluation is based on data that it was possible to research on site, or is based on the use of the numerous recommendations attached to the measuring instruction. If, for individual indicators, no evaluation is possible, then the reasons for this should be gone into briefly. Specifically, the following quality categories are recommended:

A = high, can be derived directly from available data

B1 = medium, can be estimated on the basis of available information

B2 = medium, classified according to measuring instructions

C = low, no concrete information, no general specifications in the measuring instructions, (expert) estimate

Y = assessment not possible due to a lack of data at the site, as there are no indications for an assessment and no general assessment rules are given in the method

Z = assessment not possible due to lack of methodological basis or comparative data In addition, informal additional comments can be given regarding the availability of data in individual cases.

5 Findings from the application of the method

In parallel to the development of the site-related evaluation method, the facts necessary for evaluating mine sites were researched and described for 40 case studies and also gradually adapted with consideration for each other (cf. here also Sections 7 and 9 in the ÖkoRess I Concept Volume). To this end, the respective work statuses of the evaluation method were frequently used on the case studies available at the time, the results compared and the findings obtained from them used to further develop and finalise the method.

The evaluation method was continuously developed during the course of the project using the experiences from evaluation of the case studies. In particular, in the 'Geology' and 'Technology' levels, comprehensive measuring instructions and evaluation tools were compiled, and in some cases only derived and developed within the scope of the project, e.g. regarding the deposit size, which enable an evaluation even where the data situation is poor. With the 'Specific ore grade' indicator, so far there is only an evaluation tool available for the raw materials gold, copper, zinc, lead, nickel and diamond. As a general principle, the informative value of the evaluation increases with the quality of the available data at the specific site.

For the 'Natural environment' and 'Social environment' indicators, internet-based maps were used and analysis tools developed which, if the precise location and dimensions of the sites are available, permit clear allocation.

It was noticed that specialist knowledge in the fields of geology and mining is very helpful in the description and evaluation of mine sites, but is not an absolute prerequisite.

If at all possible, the description and evaluation of the sites should be done by one party, and the description should be based as precisely as possible on the evaluation scheme. Through transparent documentation of the procedure, in particular in relation to the description of the data quality, combined description and evaluation reports constitute the best basis for an evaluation by third parties[49].

6 Conclusion and recommendations for action

The site-related method for the evaluation of environmental hazard potentials in the extraction of abiotic primary raw materials provides a newly developed tool for estimating and evaluating the environmental hazard potentials for individual mining projects.

The method is based on numerous existing scientific analyses and results, but still constitutes an innovation in respect of its methodological approach. It has been developed in iterative processes as an evaluation approach for environmental hazard potentials of mining sites, and adapted and validated using practical examples. Despite a deliberate restriction to only a few indicators, the systems reflect the range of the geological, technical and site conditions, and demonstrate the diversity of the possible environmental effects that come from mining. The significance of the environmental impact is also illustrated by many of the 40 case studies processed; in particular, these have led to the insight that the effects caused by mining are very heterogeneous, in terms of both their nature and their scale, and depend on the raw materials mined in each case, on site-related factors, and the environmental protection measures implemented. It is striking here that, although in many places environmental protection measures are taken, these are usually insufficient to reduce all environmental effects to a possible minimum or to comprehensively factor in the environmental costs. At the same time, in many regions of the world, mining is still occurring that does not heed any kind of environmental protection measures. Particularly important here is the quality of environmental governance.

6.1 Classification of the evaluation results and limits to what they can tell us

The **site-related evaluation** presented in this report describes an environmental hazard potential with 13 indicator evaluations, each in three categories (low, medium and high environmental hazard potential), for a case-by-case approach.

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[49] The Concept Volume for the ÖkoRess I project describes the selection of the sites for the 40 case studies and the procedure for the description and evaluation, and the evaluation results, including evaluation of the data quality.

The evaluation system is designed in such a way that the analysis of the indicators can be performed without on-site surveys and by professionals without specific background experience relating to mining. For the geological and technical indicators, in the best-case scenario, the data relevant to evaluation are available for the site in question. If this is not the case, then the evaluation tools permit an evaluation on the basis of raw material-specific contexts. The site indicators can be determined using the geographical coordinates. The indicator for environmental governance is produced from the country indices for the site. This, by its nature, results in major simplifications and therefore to the limited informational value of the results. The following limitations must be taken into account:

- The results are only meaningful as environmental hazard potentials for a site. The results always constitute initial estimations, which on no account can or should replace an Environmental Impact Assessment (EIA).
- Information on specific levels of damage in the event of accidents or the release of harmful substances occurring during normal operation cannot be represented using the methods.
- The results from the site-related evaluation do not provide any indication of a company's environmental management and therefore do not constitute an evaluation of the mine operator. They only provide information about site-, deposit-, technology- and governance-specific hazard potentials.
- For concrete estimations such as investment decisions, the planning of measures, etc. the results must always be complemented by on-site surveys, e.g. an EIA. The evaluation can, however, provide qualified estimations as to which sub-aspects should be examined in particular detail.
- Having evaluation results from several sites tends to lead to the comparison of (mine) sites with each other. This is neither the intention nor does it always produce meaningful results, since the evaluation is performed qualitatively without reference to a basis of comparison. Instead, each evaluation result should be considered individually and, as such, provides information about hazards intrinsic to the site or waste material and possible hotspots in terms of duties of care, licensing requirements, environmental impact assessments, etc.
- Despite the lack of a basis of comparison and qualitative evaluation, the evaluation results from possible sites can be used as a first step towards or as part of a site comparison, which does, however, need to be supplemented by specific on-site analyses.
- The authors recommend dispensing with an aggregation of the results of the individual indicators and instead using the results matrix as an end result, which still enables identification of all the facts from the individual evaluations. Consequently, the connections between individual indicators that exist in practice (interdependencies), which can intensify or inhibit the potentials to different degrees, have not been addressed.

6.2 Recommendations for application and action

With the site-related evaluation system, an evaluation system now exists for mining and processing sites that takes into account the deposit-specific, technical and geographical parameters, and parameters relevant to environmental governance, and permits a multifactorial, reproducible, reliable and transparent evaluation of environmental hazard potentials. The range of applications is diverse:

- Site-related decisions – whether for the (co-)financing of mining projects, the acquisition of ores and concentrates from remote mining projects, or the independent assessments of as yet unrecorded impacts and risks – require a sound scientific basis, which, however, can only be established in many cases with substantial financial and logistic efforts. For many stakeholders in industry, finance and civil society, drafting such comprehensive assessments only then comes into question when projects take form or initial reports on environmental problems become known. This gap can be filled in by the method presented here for the estimation of environmental hazard potentials of individual mining projects, supplemented by the method for the estimation of mining residues. Indeed, these methods cannot and should not replace any comprehensive environmental impact assessment, but can facilitate robust initial assessments for companies, financial institutions and civil society groups and can be used as an initial 'hazard radar' for environmental issues.

- A further field of application for such a hazard radar rests with decision-makers and geological services in developing countries. While as a general rule the relevant committees and authorities have very limited personnel and financial resources, the task of inspecting contract awards and mining operations in terms of their environmental impacts and providing, if applicable, relevant restrictions and conditions/obligations is nevertheless incumbent upon them. Indeed, even here the site-related evaluation method presented cannot replace any well-developed environmental impact assessments, but it provides nevertheless a good approach in order to give robust initial assessments and to plan further investigations with comparatively low expense. In addition, this initial assessment can provide support with reviewing environmental impact studies, e.g. in licensing procedures.
- Using the results from the evaluations of several sites in a developing country, it would be possible, within the scope of policy consultation, to derive recommendations and suggestions for supportive capacity building regarding the handling of environmental conflict potentials, and for focal areas with regard to licensing and monitoring in the respective countries.
- In addition, information can be derived from the results as to where reporting obligations for mining companies should be intensified.
- Finally, the evaluation system and its results may be helpful for individual sites when it comes to further developing standards and guidelines or agreeing these in a binding manner; this applies whether it is through governments, financial institutions and mining initiatives or along supply chains in commercial and business relationships (BMUB/UBA 2017). The individual environmental hazard potentials have a bearing on existing directives and guidelines, for example in relation to
    - Acid Mine Drainage:
      GARD (Global Acid Rock Drainage Guide), which was developed under the auspices of the International Network for Acid Prevention (INAP) with funding from the Global Alliance through Golder Associates, and constitutes a framework for acidic mine drainage water, its formation and prevention[50]. See also the UmSoRess Steckbriefe from the UFOPLAN project[51].
    - Auxiliary substances / reagents:
      The Cyanide Code (ICMI – International Cyanide Management Code For the Manufacture, Transport, and Use of Cyanide In the Production of Gold) was developed as a multi-stakeholder initiative under the guidance of the United Nations Environmental Program (UNEP) – and the International Council on Metals and the Environment

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[50] http://www.gardguide.com/index.php?title=Main_Page

[51] https://www.umweltbundesamt.de/umweltfragen-umsoress and https://www.umweltbundesamt.de/dokument/umsoress-steckbrief-global-acid-rock-drainage-gard (in German)

(ICME), and represents a standard for the safe management of cyanide in gold mining[52]. See also the UmSoRess Steckbrief on cyanide[53].

- Hazardous incidents:
  The following initiatives, among others, have produced standards on safe mining practice:
  ICMM (International Council on Mining & Metals) within the framework of the 10 principles for sustainable development in the mining and metals industry[54] and as a position statement on tailings dams[55]. See also the UmSoRess Steckbrief on ICMM[56].

  ICOLD (International Commission on Large Dams) has published best practice standards on the safe design of mining dams[57] and on dams and the environment[58].
- TSM (Towards Sustainable Mining), an initiative by the Mining Association of Canada, sets internationally recognised standards for sustainable mining practice[59]. Additional standards have been developed on topics such as mining waste management, crisis situations and communication, mine closure and water management, and are updated for topical reasons (e.g. after the collapse of a dam in 2014[60]). See also the UmSoRess Steckbrief on TSM[61].
- Mining waste management:
  The Best Available Techniques (BAT) Reference Document (BREF) for the Management of Waste from Extractive Industries was issued by the EU to support the implementation of the EU Mining Waste Directive[62] and has recently been revised and is complemented by a guidance document on best practices in the Extractive Waste Management Plans[63]
- Protected areas: ICMM Good Practice Guidance for Mining and Biodiversity and Position Statement on Mining and Protected Areas[64]
- Governance: EITI, possibly also the National Resource Charter or Africa Mining Vision[65].

Many of the cases of application referred to above call for international agreements that go beyond a purely German initiative. This publication to support a discussion at the European level about appropriate, higher-level initiatives.

6.3 Need for further research

The authors certainly see the need for further research, in particular in order to improve the available data for applying the method, and in individual cases also to supplement the evaluation tools. For the

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[52] https://www.cyanidecode.org/sites/default/files/pdf/18_CyanideCode12-2016.pdf

[53] https://www.umweltbundesamt.de/dokument/umsoress-steckbrief-international-cyanide (in German)

[54] https://www.icmm.com/en-gb/about-us/member-commitments/icmm-10-principles

[55] https://www.icmm.com/tailings-report and https://www.icmm.com/en-gb/environment/tailings

[56] https://www.umweltbundesamt.de/dokument/umsoress-steckbrief-international-council-on-mining (in German)

[57] http://www.icold-cigb.net/GB/dams/dams_safety.asp

[58] http://www.icold-cigb.net/GB/dams/dams_and_environment.asp

[59] http://mining.ca/towards-sustainable-mining

[60] Case Study Canada as part of Öko-Ress II (not yet published)

[61] https://www.umweltbundesamt.de/dokument/umsoress-steckbrief-towards-sustainable-mining-tsm (in German)

[62] https://www.umweltbundesamt.de/dokument/umsoress-steckbrief-eu-bergbauabfallrichtlinieand (in German)

[63] https://publications.europa.eu/en/publication-detail/-/publication/f18472f8-36aa-11e9-8d04-01aa75ed71a1/language-en/format-PDF/source-87989698

[64] https://www.umweltbundesamt.de/dokument/umsoress-steckbrief-icmm-good-practice-guidance-for (in German)

[65] https://www.umweltbundesamt.de/dokument/umsoress-steckbrief-the-natural-resource-charter (in German)

‘Specific ore grade’ indicator, for example, evaluation tools should be created for as many other raw materials as possible. So far, evaluation tools are only available for gold, copper, zinc, lead, nickel and diamonds.

However, at the stage presented, the method is by all means sound. Ideally, further development should take place within the context of frequent and extensive use of the method. Then, for example, the values collected could be merged in a database, enabling the evaluation tools to be reviewed and developed further. In addition, by analysing the usage experience with the existing evaluation system, it is possible to identify which indicators are hard to back up with data. From these findings, the following aspects can be derived:

- How the evaluation tools need to be refined
- In which instances the evaluation tools lead to false positive or false negative results, and
- which exceptional circumstances should be taken into account.

7 Reference list

Akcil, Koldas (2006): Akcil, A.; Koldas, S.: Acid Mine Drainage (AMD): causes, treatment and case studies. In: Journal of Cleaner Production 14 (2006) 1139-1145.

Alliance for Zero Extinction (2010): 2010 AZE Update. Washington D.C. www.zeroextinction.org (accessed on 1 July 2015).

AMAP (1998): Geographical Coverage. Arctic Monitoring and Assessment Programme (AMAP). http://www.amap.no/about/geographical-coverage (accessed on 21 January 2016).

Basedeau (2009): Basedeau, M.: Ressourcenkonflikte. In: Wissenschaft & Frieden, 2009-2: Ressourcen: Ausbeutung, Krieg, Elend. Internet: http://wissenschaft-und-frieden.de/index.php?mid=0&pid=11&jvar=126 (accessed on 18 November 2015).

BMUB (Ed.) (2012): Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit: Deutsches Ressourceneffizienzprogramm (ProgRess). Programm zur nachhaltigen Nutzung und zum Schutz der natürlichen Ressourcen. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit. Berlin. Available online at http://www.bmub.bund.de/fileadmin/Daten_BMU/Pools/Broschueren/progress_broschuere_de_bf.pdf, last checked on 19 January 2016.

BMUB/UBA (Ed.) (2017): Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit I Umweltbundesamt: Schritt für Schritt zum nachhaltigen Lieferkettenmanagement - Praxisleitfaden für Unternehmen; Berlin, Dessau, January 2017.

Berger et al. (2009): Berger, V. I., Singer, D. A., Orris, G. J.: Carbonatites of the world, explored deposits of Nb and REE: Database and grade and tonnage models. U.S. Geological Survey Open-file Report 2009–1139, 17 p. and database, available online at http://pubs.usgs.gov/of/2009/1139/.

Berger et al. (2011): Berger, V. I., Singer, D. A., Bliss, J. D., and Moring, B. C.: Ni-Co laterite deposits of the world; database and grade and tonnage models. U.S. Geological Survey Open-File Report 2011-1058, available online at <http://pubs.usgs.gov/of/2011/1058/>http://pubs.usgs.gov/of/2011/1058/.

Berger et al. (2014): Berger, V. I., Mosier, D. L., Bliss, J. D., and Moring, B. C.: Sediment-hosted gold deposits of the world—database and grade and tonnage models: U.S. Geological Survey Open-file Report 2014-1074, 46 p. http://pubs.usgs.gov/of/2014/1074/].

Buchert et al. (2016): Buchert, M.; Bulach, W.; Degreif, S.; Hermann, A.; Hünecke, K.; Mottschall, M.; Schleicher, T.; Schmidt, G.; Stahl, G.; Ustohalova, V.: Policy Paper 2: Deutschland 2049 - Auf dem Weg zu einer nachhaltigen Rohstoffwirtschaft, Darmstadt, June 2016, available at https://www.oeko.de/oekodoc/2600/2016-607-de.pdf, last accessed on 30 November 2016.

Bundesinstitut für Risikobewertung (Ed.) (2016): Toxikologische Bewertung von chemischen Stoffen. Available online at http://mobil.bfr.bund.de/en/toxikologische_beurteilung_von_chemischen_stoffen-70287.html, last checked on 19 February 2016.

Cissarz, A. (1965): Einführung in die allgemeine und systematische Lagerstättenlehre. Stuttgart: Schweizerbart’sche Verlagsbuchhandlung.

Cox et al. (2003, revised 2007): Cox, D. P., Lindsey, D. A., Singer, D. A., Diggles, M. F.: Sediment-hosted copper deposits of the world—Deposit models and database. U.S. Geological Survey Open-File Report 2003-107, 1.3, http://pubs.usgs.gov/of/2003/of03-107/

Cox, Singer (2007): Cox, D. P., Singer, D. A.: Descriptive and grade-tonnage models and database for iron oxide Cu-Au deposits. U.S. Geological Survey Open-File Report 2007–1155 [http://pubs.usgs.gov/of/2007/1155/]

Duffus, J. H. (2001): 'Heavy Metals' – A Meaningless Term. In: Chemistry International Vol. 23, No. 6.

Durand, J. F. (2012): The impact of gold mining on the Witwatersrand on the the rivers and karst systems of Gauteng and North West Province, South Africa. In: Journal of African Earth Science, 68, pp. 24-43, 2012.

European Commission (Ed.) (2014): Report on critical raw materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials.

European Commission (Ed.) (2010): Critical raw materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials. Brussels.

Graedel et al. (2012): Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christofferson, L. et al.: Methodology of Metal Criticality Determination. In: *Environmental Science & Technology* 46 (2), pp. 1063–1070, 2012.

Graedel et al. (2015): Graedel, T. E.; Harper, E. M.; Nassar, N. T.; Nuss, Philip; Reck, Barbara K.: Criticality of metals and metalloids. In: *Proc Natl Acad Sci USA* 112 (14), pp. 4257–4262. DOI: 10.1073/pnas.1500415112. 2015

Ludington, Plumlee (2009): Ludington, S., Plumlee, G. S.: Climax-type porphyry molybdenum deposits. U.S. Geological Survey Open-file Report 2009–1215, 16. http://pubs.usgs.gov/of/2009/1215/

Ludington et al. (2009): Ludington, S., Hammarstrom, J., and Piatak, N.: Low-fluorine stockwork molybdenite deposits. U.S. Geological Survey Open-file Report 2009–1211, 9 http://pubs.usgs.gov/of/2009/1211/

HIIK (2014): Heidelberger Institut für Internationale Konfliktforschung: Conflict Barometer 2013. Heidelberg, 2014.

Hua, L. (2011): The Situation of NORM in Non-Uranium Mining in China. China National Nuclear Safety Administration. Internet: http://www.icrp.org/docs/Liu%20Hua%20NORM%20in%20Non-Uranium%20Mining%20in%20China.pdf (accessed on 22 January 2016).

Humphreys (2005): Humphreys, M.: Natural Resources, Conflict, and Conflict Resolution. Uncovering the Mechanisms. In: Journal of Conflict Resolution, Vol. 49/4, 2005, pp. 508-537.

IAEA (2014): Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. General Safety Requirements Part 3. Vienna, 2014.

IUCN/UNEP-WCMC (2015): The World Database on Protected Areas (WDPA) [Online]. UNEP-WCMC. Cambridge, UK. www.protectedplanet.net (accessed on 1 July 2015).

Kuenzer et al. (2006): Kuenzer, C.; Zhang, J.; Tetzlaff, A.; van Dijk, P.; Voigt, S.; Mehl, H.; Wagner, W.: Uncontrolled coal fires and their environmental impacts: Investigating two arid mining regions in north-central China. In: *Applied Geography* 27 (1), pp. 42–62. 2006

Lide, David R. (2005): CRC Handbook of Chemistry and Physics, 85th edition, CRC Press, Section 14, Geophysics, Astronomy, and Acoustics; Abundance of Elements in the Earth's Crust and in the Sea. Boca Raton, Florida.

Manhart, Schleicher (2013): Manhart, A., Schleicher, T.: Conflict minerals – An evaluation of the Dodd-Frank Act and other resource related measures. Öko-Institut e.V., Freiburg, 2013.

Mar, Okazaki (2012): Mar, S. S.; Okazaki, M.: Investigation of Cd contents in several phosphate rocks used for the production of fertilizer. In: Microchemical Journal 104 (2012) 17-21.

McNeish (2010): McNeish, J.-A.: Rethinking Resource Conflict. World Development Report 2011, Background Paper. New York, 2010.

Mosier et al. (2012): Mosier, D. L., Singer, D. A., Moring, B. C., Galloway, J. P.: Podiform chromite deposits; database and grade and tonnage models. U.S. Geological Survey Scientific Investigations Report 2012-5157, 45. and database. (Available at http://pubs.usgs.gov/sir/2012/5157/.)

Mosier et al. (2009): Mosier, D. L., Berger, V. I., Singer, D. A.: Volcanogenic massive sulfide deposits of the world—Database and grade and tonnage models. U.S. Geological Survey Open-file Report 2009–1034, http://pubs.usgs.gov/of/2009/1034/

Murray et al. (1998): Murray, J. L.; Hacquebord, L.; Gregor, D. J.; Loeng, H.: Physical / Geographical Characteristics of the Arctic. In: AMAP Assessment Report: Arctic Pollution Issues. pp. 9–24. 1998

National Research Council of the National Academies (Hg.) (2008): Minerals, Critical Minerals, and the U.S. Economy. Washington D.C.

Nuss, Eckelman (2014): Nuss, P.; Eckelman, M. J.: Life Cycle Assessment of Metals: A Scientific Synthesis. In: *PLoS ONE* 9 (7), p. e101298. DOI: 10.1371/journal.pone.0101298.

Olsen et al. (2001): Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V., Underwood, E. C., D’amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., others: Terrestrial Ecoregions of the World: A New Map of Life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. In: BioScience. Vol. 51, No. 11, pp. 933–938. 2001

Pfister et al. (2009): Pfister, S., Koehler, A., Hellweg, S: Assessing the Environmental Impacts of Freshwater Consumption in LCA. In: Environmental Science & Technology. Vol. 43, No. 11, pp. 4098–104.

Priester/Ericsson (n.d.): Mineral Grades, as yet unpublished

Priester et al. (2013): Priester, M., Wetzenstein, W., Lewis, S., Hentschel, T., Kirch, E., Dorn, R.: Costs of social protests in mining areas. Projekt-Consult, Bad Vilbel, 2013.

Priester, Dolega (2015): Priester, M.; Dolega, P.: Bergbauliche Reststoffe - Teilbericht ÖkoRess. Berlin. Available online at http://www.umweltbundesamt.de/sites/default/files/medien/378/dokumente/bergbauliche_reststoffe_final_151106.pdf, last checked on 19 January 2016.

Prior et al. (2012): Prior, T.; Giurco, D.; Mudd, G.; Mason, L.; Behrisch, J.: Resource depletion, peak mineral and the implications for sustainable resource management. In: *Global Environmental Change* 22 (3), pp. 577–587. 2012.

Ross (2003): Ross, M.: The Natural Resource Curse: How Wealth Can Make You Poor. In: Bannan, Collier 2003: Natural Resources and Violent Conflict. Options and Actions. World Bank, New York, 2003.

Salomons, W. (1995): Environmental impact of metals derived from mining activities: Processes, prediction, prevention. In: *Journal of Geochemical Exploration* 52 (1-2), pp. 5–23.

Singer et al. (2008): Singer, D. A., Berger, V. I., Moring, B. C.: Porphyry copper deposits of the world: Database, map, and grade and tonnage models, 2008. U.S. Geological Survey Open-file Report 2008–1155, http://pubs.usgs.gov/of/2008/1155/

Singer et al. (2009): Singer, D. A., Berger, V. I., Moring, B. C.: Sediment-hosted zinc-lead deposits of the world: Database and grade and tonnage models. U.S. Geological Survey Open-file Report 2009–1252, http://pubs.usgs.gov/of/2009/1252/

Schönwiese, C.-D. (2013): Klimatologie. Ulmer. Stuttgart.

Shedlock et al. (2000): Shedlock, K. M., Giardini, D., Grünthal, G., Zhang, P.: The GSHAP Global Seismic Hazard Map. In: Seismological Research Letters. Vol. 71, No. 6, pp. 679–689. 2000.

Sverdrup et al. (2017): Sverdrup, H. U., Ragnarsdottir, K. V., Koca, D.: Integrated Modelling of the Global Cobalt Extraction, Supply, Price and Depletion of Extractable Resources Using the WORLD6 Model, BioPhysical Economics and Resource Quality, 2, 1, p. 1.

Tsurukawa et al. (2011): Tsurukawa, N.; Prakash, S.; Manhart, A.: Social impacts of artisanal cobalt mining in Katanga, Democratic Republic of Congo. Öko-Institut e.V., 2011.

UBA (2015): Umweltbundesamt: personal communication during a project meeting at the Federal Environment Agency in Berlin on 8 October 2015.

Udayabhanu, Prasad (2010): Udayabhanu, S. G.; Prasad, B.: Studies on Environmental Impact of Acid Mine Drainage Generation and its Treatment: An Appraisal. In: Indian Journal of Environmental Protection 30 (2010) 953-967.

UNISDR (2013): From Shared Risk to Shared Value –The Business Case for Disaster Risk Reduction. In: Global Assessment Report on Disaster Risk Reduction. Global Assessment Report on Disaster Risk Reduction. United Nations Office for Disaster Risk Reduction (UNISDR). Geneva.

UNISDR (2015a): Making Development Sustainable: The Future of Disaster Risk Management. Global Assessment Report on Disaster Risk Reduction. United Nations Office for Disaster Risk Reduction (UNISDR). Geneva.

UNISDR (2015b): Annex 1: GAR Global Risk Assessment: Data, Methodology, Sources and Usage. Global Assessment Report on Disaster Risk Reduction. United Nations Office for Disaster Risk Reduction (UNISDR). Geneva.

USGS (2015): Mineral commodity summaries 2015. U.S. Geological Survey, Reston.

Wellmer, Hagelüken (2015): Wellmer, F. W., Hagelüken, C.: The Feedback Control Cycle of Mineral Supply, Increase of Raw Material Efficiency, and Sustainable Development. In: Minerals 2015, 5(4). 815-836.

White, W.M. (2013): Geochemistry. Chichester. Wiley-Blackwell.

Zepp, H. (2011): Geomorphologie. Schöningh. Paderborn.