Hazard and Impact Knowledge for Europe

Deliverable D4.2b

Scientific specifications and requirements for the hazards and impacts data SharePoint and definitions for the Semantics Web service

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TABLE OF CONTENTS

1 INTRODUCTION

1.1 Document Background and Scope

This document presents the scientific background of the hazards and impacts Knowledge Share Point (hereafter KSP) which is specified by the underlying HIKE vocabulary keywords and concepts. The KSP vocabulary and concepts are part of the KSP web platform and have been established by the HIKE project members. The vocabulary is implemented in the Semantics Web service of the European Geo Data Infrastructure (hereafter EGDI), developed by the GeoERA GIP-project (hereafter GIP-P)

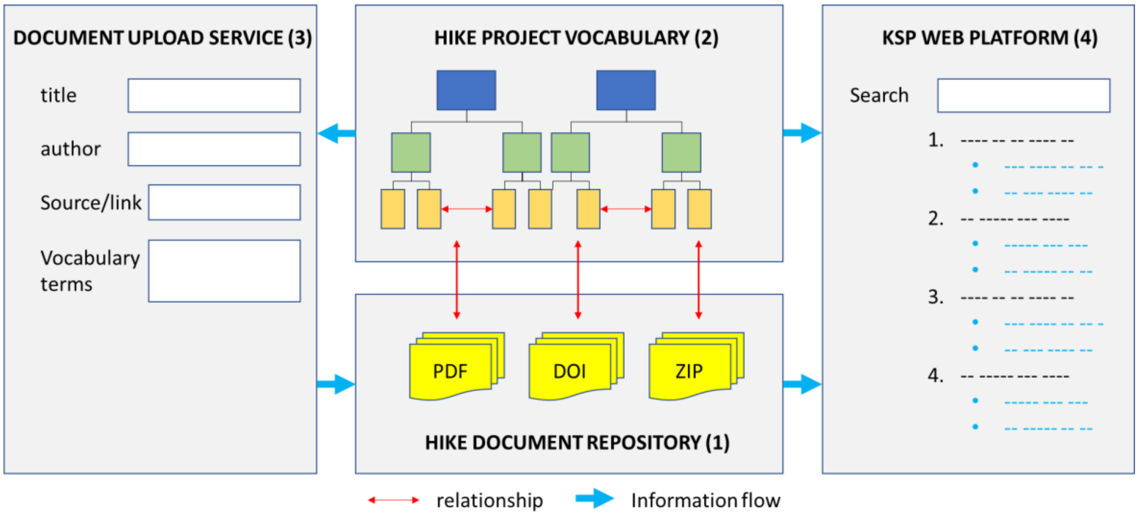

Figure 1: Schematic representation of the Knowledge Share Point design

1.2 The HIKE Knowledge Share Point design

The KSP consists of four main elements (see Figure 1):

1) A central document repository and online access point for data sources, state-of-art method reports and case studies relevant for subsurface hazard and impact assessments. The records in the repository are either actual documents and files or references to documents using a DOI (Digital Object Identifier).

2) A project vocabulary containing hierarchically structured and mutually related keywords and concepts specified by a formal description and citations and implemented in a Semantic Webservice. Each document record in the repository is linked to one or more of these keywords (or concepts) which are specified in the HIKE project vocabulary.

3) A document upload service in which registered end-users can enter new documents and data sources and assign relevant keywords (developed and maintained by GIP-P as part of EGDI)

4) A public Web Platform which allows any user to find documents in the KSP repository, either by providing any search term or by using the HIKE vocabulary keywords. The returned documents include primary records with direct keyword or search term hits as well as secondary records which are found via the semantic relations included in the vocabulary.

The KSP document upload service and the Web Platform are explained in the report D5.2b HIKE User Manual. The Document Repository is explained in the the EGDI web portal. This report provides a background to the definitions and concepts in the HIKE project vocabulary.

1.3 End-users and applications

The KSP platform provides the end-user functionalities for accessing, analyzing, retrieving and exchanging information from/into the repository. Moreover, it should allow for a diverse range of users and stakeholders interested in underground exploitation to identify targeted data, information, methods, tools and knowledge to support their needs.

The KSP platform is intended to evolve and grow with the continuous input of new information added after the project lifetime..

1.3.1 Target user groups

As mentioned in the deliverable D5.1, the target user groups are mainly divided in four types of categories (*Figure 2*). The subdivision into these categories aims at guiding the focus on the appraisal of information needed about hazard and impact of underground exploitation.

Developing Community includes stakeholder groups involved in HIKE and other geological survey organizations that provide, adapt and use information of the KSP as part of their research activities. This category is represented by the Geological Surveys, nation-wide research programs, public research institutes, etc.

Expert category includes researchers, knowledgeable person, universities, research agencies, and organizations/institutes that are not directly involved in HIKE and are looking for scientific and/or specific information. This category could also provide new information to the KSP through their scientific work and high competence in a domain/concept.

Stakeholders as regional, national and local authorities, supervisors, operators and industry looking for case studies, general information, protocols, etc.

Education, Public is the category including students, the general public or any other stakeholder searching for topics and specific information based on scientific criteria and provided by legal and thrust sources.

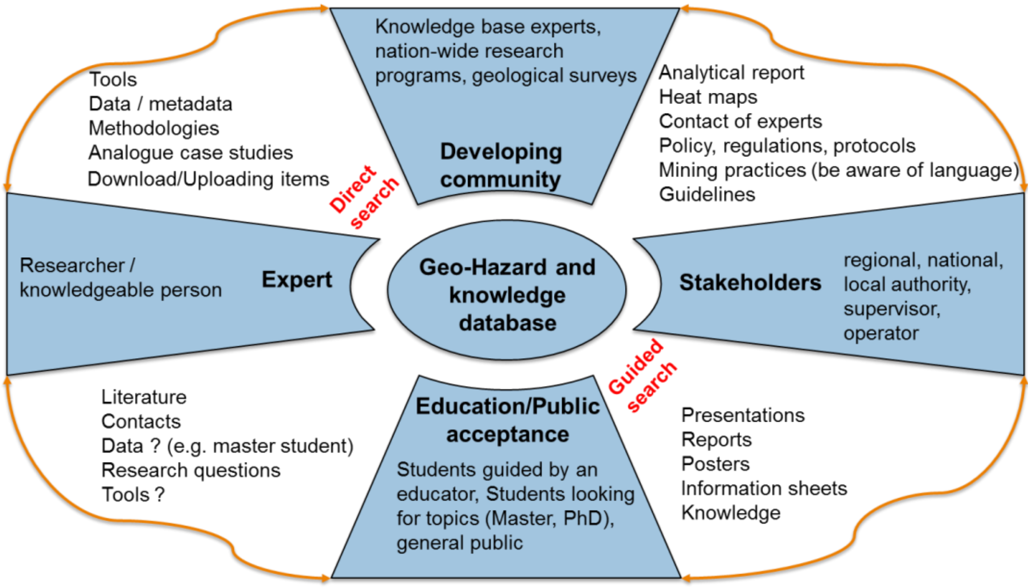

Figure 2: Main types of users and type of information related to their needs

1.4 Document Structure/Reader's guide

The semantic framework has the role of connecting the Platform with the Repository. The semantic framework will be implemented in a general Resource Description Framework (RDF) through an Ontology Web Language (OWL). To design such a system, the concepts must be defined to create hierarchy, structure and relationships between database entries. This report will introduce the overarching definitions and in the following chapters we will describe each of the main hierarchical categories.

Chapter 2 provides a general definitions and conventions
Chapter 3 details the category Hazard Mechanisms
Chapter 4 details the category Impacts types
Chapter 5 details the category Hazard Causes
Chapter 6 details the category Hazard Analysis
Chapter 7 details the category Geological Settings

1.5 Abbreviations

HIKE = Project "Hazards and Impacts Knowledge Europe"
GIP-P = Project "Geo-Information Platform"
EGS = EuroGeoSurveys organization
EGDI = European Geo Data Information Platform
HIDB = Hazard and Impacts database
SHARE = Project "Seismic Hazards Research Europe"
EPOS = Project "European Plate Observing System"
DOI = Digital Object Identifier
GSO = Geological Survey Organization
IP = Information Platform

KSP = Knowledge SharePoint
RDF = Resources Description Framework
SKOS = Simple Knowledge Organization System
OWL = Onthology Web Language

1.6 HIKE partners

#	Participant Legal Name	Institution	Country
1	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek TNO	TNO (coordinator)	Netherlands
2	Albanian Geological Survey	AGS	Albania
3	Geologische Bundesanstalt	GBA	Austria
4	Royal Belgian Institute of Natural Sciences – Geological Survey of Belgium	RBINS-GSB	Belgium
5	Geological Survey of Denmark and Greenland	GEUS	Denmark
6	Bureau de Recherches Géologiques et Minières	BRGM	France
7	Bundesanstalt für Geowissenschaften und Rohstoffe	BGR	Germany
8	Landesamt für Bergbau, Geologie und Rohstoffe Brandenburg	LBGR	Germany
9	Landesamt für Geologie und Bergwesen Sachsen-Anhalt	LAGB	Germany
10	Bayerisches Landesamt für Umwelt	LfU	Germany
11	Islenskar orkurannsoknir - Iceland GeoSurvey	ISOR	Iceland
12	Istituto Superiore per la Protezione e la Ricerca Ambientale	ISPRA	Italy
13	Servizio Geologico, Sismico e dei Suoli della Regione Emilia-Romagna	SGSS	Italy
14	Agenzia Regionale per la Protezione Ambientale del Piemonte	ARPAP	Italy
15	Lietuvos Geologijos Tarnyba prie Aplinkos Ministerijos	LGT	Lithuania
16	Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy	PIG-PIB	Poland
17	Laboratório Nacional de Energia e Geologia	LNEG	Portugal
18	Geološki zavod Slovenije	GeoZS	Slovenia
19	State Research and Development Enterprise State Information Geological Fund of Ukraine	GEOINFORM	Ukraine

2 GENERAL DEFINITIONS AND CONVENTIONS

This chapter provides a general overview and a description of the KSP semantic framework. It explains the overall structure (ontology) and the basic principles of the concept/keyword definitions and relationships.

2.1 Introduction to semantic concepts principle

The Knowledge Share Point guides the users to knowledge and information using Linked Data technology. This technology enables semantic text searching with the main goal to assist the finding of data in the HIKE KSP document repository. Keywords (or concepts) are used to tag datasets into a single hierarchy similar to a thesaurus. In this framework data queries can use this structured network of words to get search results for similar keywords within a "semantic radius". Multilingual Semantic Text Search is applied for the compilation (SKOS thesaurus) of keywords with URIs suitable for tagging metadata.

The KSP is embedded within the European Geological Data Infrastructure (EGDI) using the following tools and specifications developed by the GeoERA GIP project:

- Höfarter, C. et al., 2019: GeoERA Keyword Thesaurus, GIP-P Deliverable 4.2 (https://geoera.eu/wp-content/uploads/2019/11/D4.2-GeoERA-Keyword-Thesaurus.pdf)
- Schiegl, M. et al., 2019: GeoERA Project Vocabularies, GIP-P Deliverable 4.3 (https://geoera.eu/wp-content/uploads/2019/11/D4.3-GeoERA-Project-Vocabularies.pdf)
- The EGDI Document Repository, Report in prep. (https://www.geo-zs.si/db/egdi-search/)

This report also describes how the KSP structure and concepts relate to the Thematic Core Services for Anthropogenic Hazards, as included in the EU project EPOS (European Plate Observing System).

2.2 General terms and definitions

This paragraph provides a short explanation of elements which define the KSP semantics framework.

2.2.1 Semantics

In general, semantics is about defining the meaning of words, phrases or any other texts. In the context of HIKE semantics are applied to keywords (or concepts) that can be linked to information and documents included in KSP document repository. Thus, it is considered as a foundation for sharing organizing, and linking data and to add value to their content. Accordingly, semantic Web technologies enable people to create data stores on the Web, establish vocabularies, and elaborate rules for handling data and representing metadata. The linking of data is empowered by technologies such as Resource Description Framework (RDF), Web Ontology Language (OWL), SPARQL and SKOS. Therefore, semantic web languages are designed to process the data and represent complex knowledge about the documents, the group of documents and possible relationships between different entities.

2.2.2 Concept (or Keyword)

In the HIKE KSP a concept defines a keyword which is linked to a formal meaning (concept description). The concept description incorporates multiple language representations for each concept (or keyword) and relations to other keywords. Typically, this concerns hierarchical relationships where a given keyword belongs to an overarching keyword. For example: the keyword “car” can be an overarching (parent) definition for the keywords “family car”, “sports car”, “transport car”, etc. The term “car” itself may be linked to an overarching keyword “means of transportation” which also encompasses terms like “train”, “ship”. Etc. Another form of relationship is based on similarity. For example, the term “car” may be considered similar “automobile”, depending on the meaning that has been assigned to “car”. Finally the KSP concepts consider “related-to” relationships. These relationships are not based on similarity but on context. For example, “car” may be related to “highway” in the sense that highways are built for cars to drive on. The concept or keyword is defined by a Uniform Resource Identifier (URI) which is a unique sequence of characters that identifies a logical or physical resource used by web technologies.

2.2.3 Ontology (or Vocabulary)

An ontology or vocabulary is the collection of keywords and concepts including their definition and formal naming, mutual relationships and the links to data and information entities. The Ontology Web Language (OWL) is used to encode semantics with the data. This technology can describe concepts, relationships between them, and categories of entities. In GeoERA the KSP concepts and keywords are represented in the HIKE project vocabulary.

2.2.4 Category or Domain

The HIKE-KSP includes domains or categories which define a group of concepts belonging together because of shared properties with a more general idea providing the logical structure for the vocabulary. Categories can be organized in a hierarchy based on their meaning and the specific theme they represent. For example: all types of vehicles but also aspects like roads, railways, etc. could be included in a main category “Transportation”.

2.2.5 **Narrower concept**

A hierarchical relationship that links two concepts. Generally, a narrower concept can be considered as a more specific element, designed under a generic idea. It is considered as a narrow scope for more detailed definitions.

2.2.6 **Broader concept**

This type of hierarchical relationship is the opposite of narrower. Defines a group of narrower concepts that are associated to common properties.

2.2.7 **Cross-concept relationships**

This property defines relationships between terms and describe the interaction between them. In order to specify the types of the relationship we can mention the following properties used: Has A, Has Types, Is A Type Of, Is Of, Parent Category, Related Terms, Synonyms, etc.

2.2.8 **Cross-categories relationships**

This measure evaluates the relation and identifies the link between concepts from different domains. This link can be specified with the following types of relationships, listed: Parent category, Is A Type Of, Assigned to Terms, Subcategories.

2.3 Main Concept Categories

The HIKE ontology covers five main categories which relate to different aspects of hazard and risk and impact assessment. The categories provide a general structure for the keywords and the information and knowledge included in the KSP document repository (see Figure 3). These categories are described and explained in the following chapters.

2.3.1 **Hazard causes**

This category presents the possible sources or conditions which can trigger a hazard event. These causes may be natural or anthropogenic (i.e. caused by human activities in the subsurface). Examples of both natural and anthropogenic causes are plate tectonic movements or injection activities , each of which could result in earthquakes.

2.3.2 **Hazard mechanisms**

This category presents the actual (geological/geophysical) process or mechanism which defines the hazard. This can for example be an earthquake or a surface deformation process. The cause or trigger for this mechanism can be of natural or anthropogenic origin.

2.3.3 **Impact types**

Impact is an alteration of a state or condition of a receiver or subject, caused or induced by a particular factor. In the context of the HIKE KSP, impacts are considered as the adverse and undesired consequences of hazardous events (seismicity, leakage, surface deformation, facility incidents) resulting in either natural subsurface processes or anthropogenic causes (extraction of energy resources, storage of CO2, energy carriers, etc). Although impacts may in general be considered as either adverse or beneficial results of particular event, the KSP specifically focuses on negative and undesired impacts of economic, social, health, cultural and environmental nature.

2.3.4 **Geological settings**

The subsurface is a dynamic environmental system influenced by the interaction of plate tectonics, water, heat and man's engineering activities. Understanding the geological context helps to comprehend the risk origin or situations involving exposure to danger, and establish a way to prevent or mitigate them. Therefore, most of the case studies will be located in a certain geological context. Hereby, the metadata will be also sorted spatially, so mentioning the site and the regional geological definitions might serve as a filter.

2.3.5 **Hazard analysis**

This special category refers to tools, methods and datasets used to identify hazards, possible effects of subsurface activities, and hazard causal factors. In practice, using the established relationships between this category and the other categories could be used to propose the best available technique or tool for assessing a certain (case-related) hazard. For example: a certain seismic risk analysis tool may be required or recommended to assess the induced seismic hazard of a geothermal project in given region and geological setting.

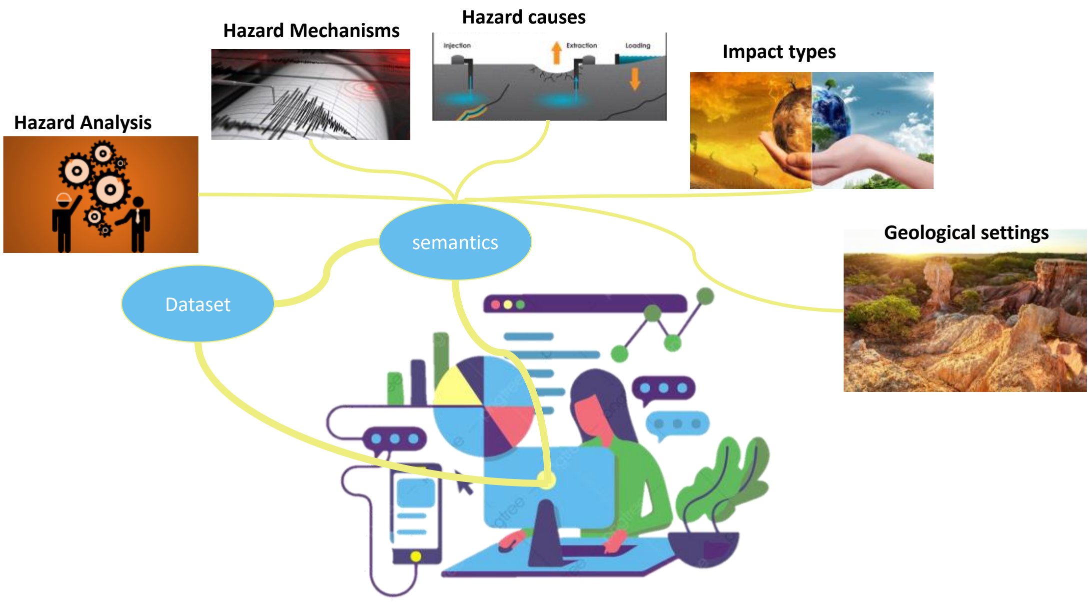

Figure 3: Representation of the KSP structure

2.4 Defining semantic relationships

2.4.1 Introduction

The main strength of the KSP lies in the application of the vocabulary and associated relationships, which enable intelligent searching rather than just developing a document repository based on arbitrary keyword searching. The KSP vocabulary relationships provide overall concepts about how various aspects of hazards causes, mechanisms, impacts, geological setting and applied tool are connected to each other. For example, a user of the platform may find certain documents about geothermal energy (by using the keyword "geothermal"). Through the embedded relationship between geothermal and seismicity, the KSP may then suggest associated documents on seismic hazard analysis tools. This paragraph explains the different types of relationships that have been implemented in the vocabulary.

2.4.2 Narrower and broader concept relationships

In general, the SKOS defines semantic relations between two concepts as: hierarchical and associative. The hierarchical link expresses that one concept is considered as more general ("broader") than the other ("narrower"). Whereas an associative link indicates that both concepts are effectively related but neither of them is more general than the other as shown in the (Figure 4). The property 'skos:related' is then representative of the associative link between two SKOS concepts, when 'skos:broader', 'skos:narrower' are considered respectively for the broader and narrower hierarchical link.

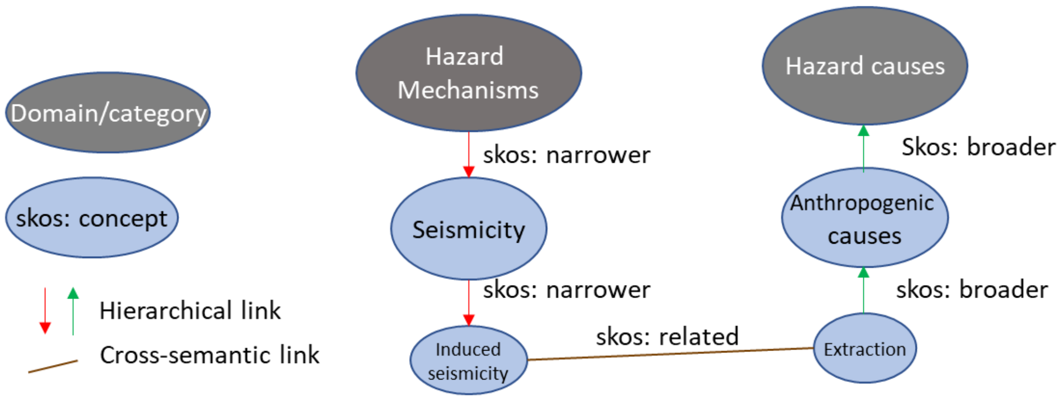

Figure 4:Basics of semantic relationships

2.4.3 Concept relationships within the same category

The KSP semantic basic relationships are defined following SKOS Mapping Vocabulary Specification. Accordingly, HIKE ontology structure was divided into main domains (Figure 5 in blue) and by identifying relevant concepts, we are actually building the hierarchy of the ontology's structure as presented below. Subsequently, each category is detailed at a first level through various concepts (Figure 5 in green) and every mentioned concept might have narrower divisions into different concepts from escalating level (given in red for level 2). Under the same category the narrower/broader property was used to assert a direct hierarchical link between two concepts.

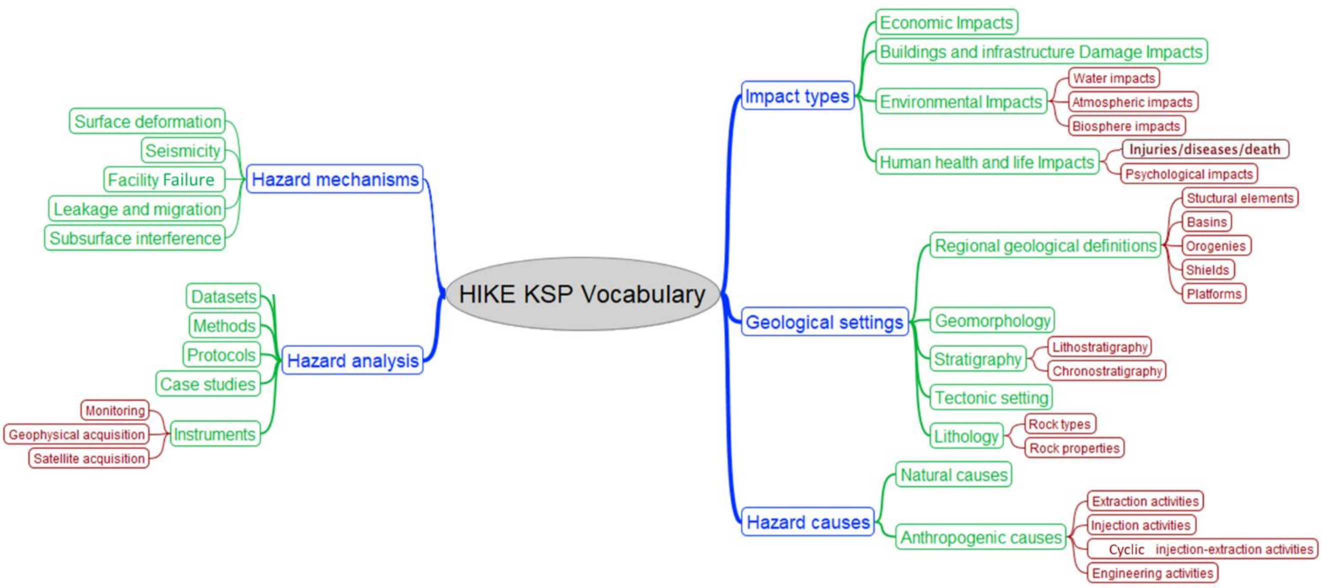

Figure 5: Schematic representation of the KSP semantics

Taking the example of 'impact type' that is one of the broader concepts defined as a category. This category is linked to four concepts from a first level (Economic Impacts, Buildings and Infrastructure and Damage Impacts, Environmental Impacts and Human health and life Impacts), each of which may be related to a number of more specific concepts at level two. All these concepts are linked by convention with 'skos:narrower'. Going from level two to level one means results in a 'skos:broader' convention.

2.4.4 Concept relationships between categories

The major and minor relationships described in the SKOS model in the previous section were limited to linguistic parents and their children (narrower and broader). However, there are many more specific relationships that can be applied. By replacing this one simple type of relationship (broader and narrower matches) with more specific categorization, a more complex structure will be developed.
For the KSP, we defined new relationship types between categories to place a context within the terms and express how these categories interact. Table 1 describes how we specified the different relationships that can be established between categories.

Table 1 : Possible relationships between concepts in different categories

	Hazard Analysis	**Hazard causes**	**Geological settings**	**Impact Types**	**Hazard Mechanisms**
Hazard Mechanisms	Analyzed by	IsHazardof	HasSetting	Leadsto	Broad/narrow
Impact Types	Analyzed by	IsImpactof	HasSetting	Broad/narrow	AreExplainedby
Geological settings	isUsedIn	AreAffectedBy	Broad/narrow	_ Directed_	_ Directed_
Hazard causes	AreIdentifiedby	Broad/narrow	AffectsOn	LeadsTo	_Directed__
Hazard Analysis	Broad/narrow	Identify	_ Directed_	_ Directed_	Analyze

2.4.5 Dealing with broader and narrower definitions in cross-category relationships

Relationships are defined between different categories. Narrower concepts were related with others from different categories (Figure 4). This step means that we will have a network between categories but also between next levels concepts definitions. The cross-category relationships are a functionality used to relate data, information and knowledge. We relate causes, mechanisms, impacts and analysis concepts to make strong and clever connections resulting in an intelligent engine which turns into an efficient tool to answer the end-user demand.

2.4.6 Data and Concept relationships

Since the semantic framework has the main role of connecting the Platform with the Repository, the concepts are defined in order to create hierarchy and put structure in the data. Therefore, the concepts and relationships will be defined through RDF (Resources Description Framework) and OWL (Ontology Web Language). OWL defines the concepts and relations between concepts. RDF defines the relationships between data records and between data and the ontology concepts (e.g. expressions of the form subject-predicate-object known as triples).

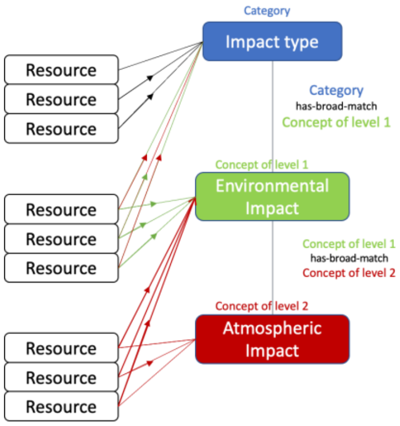

Figure 6: Data tagging and the relationship with concepts

This context is demonstrated through the example presented in Figure 5. The documents are referred here as a resource. Resource will be attributed to a chosen concept from a suggested list on the upload.

2.5 Relation to the Risk Bow-Tie Model

2.5.1 Description of the Risk Bow-Tie Model

The Bow-Tie model is a risk diagram. A method that can be used to visualize, analyze and evaluate different risk scenarios. The main goal of this model is to identify and understand hazardous events, while allowing to: 1) Define prevention measures to minimize the impact, 2) Design mitigation schemes to control impacts and 3) Minimize/counteract the consequences for the environment and human life.

2.5.2 Relating the categories to the Bow-Tie Model

Different disciplines must act together to identify the potential causes of risks, develop prevention strategies and implement a surveillance plan to monitor subsurface activities in order to mitigate risk caused by hazardous events.
The identification and mitigation of the processes that could cause potential risk, typically starts with a geological study of a particular site (mainly to illustrate geomechanical assessments of the prospected formation and the mechanical strength of the delimited units) and then investigate and understand how anthropogenic activities may trigger or induce hazardous events or accidents. Next is to try to quantify and define the risk for each case of human intervention, using different hazard research methods, including environmental and safety combinations, involving tools for the qualitative and quantitative likelihood estimation of the hazardous event and of its consequences and magnitude of impact.

Subsequently, an approach to subsurface activities hazards with the key elements needs to be outlined, together with the described initial steps to prevent hazardous events from occurring. Finally a mitigation plan is needed to reduce and control the impacts from events if occurred.
Since HIKE platform hold the attention to the hazard impact and subsurface exploration, the Bow-Tie Model was the inspiration and adopted source to structure the KSP. Following the just described Bow-tie-Model main structure, five closely related categories were identified, represented in the schema below:

- Hazard causes: to understand the processes and relate a hazard to an anthropogenic or natural cause(s) .
- Hazard mechanisms: in order to predict the hazard and try to mitigate the event, a good understanding of processes in origin of the hazard, or the hazard mechanisms, is mandatory.
- Impact types: Every hazard cause together with the hazard mechanism will have various consequences with direct and indirect impacts on both earth and life.
- Hazard research methods: To comprehend and to mitigate hazardous events, different methods and monitoring tools are developed and applied.
- Geological Settings: The key element to all these events and discussed points hinge on the geological knowledge and mastery of the underground.

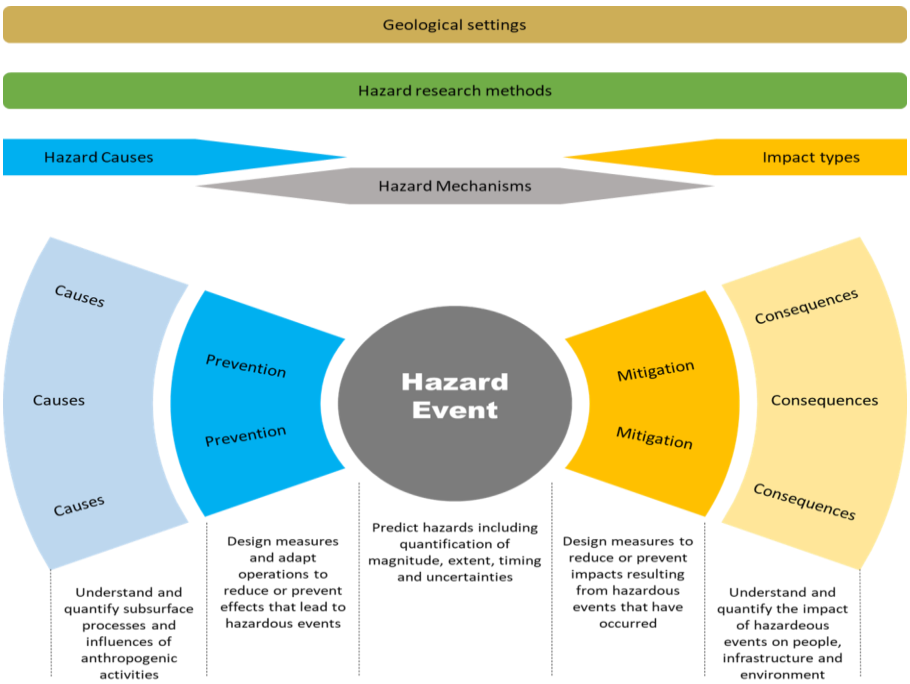

Figure 7: Representation of the KSP categories in relation with the Bow-Tie Model

2.6 Relation to EPOS-IP

2.6.1 Document repository and management system

The European Plate Observing System (EPOS) platform was designed to analyze anthropogenic and natural seismicity and other geo-hazards besides the assessment of potential environmental impact of geo-resource exploitation and other phenomena concerning solid-earth. This platform aims to integrate distributed research infrastructures to enhance the research functionalities targeted at geo-scientists, information and technology experts, decision makers and general public.
The IS-EPOS document Repository can be defined as a database of documents (papers, books, articles, theses, reports…) associated with data, technological/production processes used, applied methodologies and specific events or episodes (e.g. volcanic eruptions, large earthquakes or other hazards). These repertoires can be a perfect use for the KSP since they share the similar perspectives and thematic.

2.6.2 Vocabulary and keywords

EPOS is based on the EPOS Integrated Core Services (ICS) to integrate all collected resources. The ICS assemble information about the data, the data products and services called as the Thematic Core Services (TCS). Therefore, the TCS exists in heterogeneous formats and adopt vocabularies, protocols in order to represent these resources. This infers to the exchange and interaction between the ICS and TCS. Accordingly, this connection was insured by a data model namely EPOS-DCAT-AP. It extends and builds on an established W3C standard - the Data Catalog Vocabulary (DCAT). EPOS-DCAT-AP is found on high level Core Concepts; it includes terms and keywords such as SKOS Concepts and Concept Schemes. In this case the keywords need to be associated with Dataset and Webservice.

2.6.3 Episode definition

EPOS platform requires a set of data describing comprehensively Anthropogenic Hazard (AH) cases, those are grouped and provided to the end-user within what is called Episodes. Thus, the episode can be considered as a correlated collection of data related to a relevant process or subject. Each episode is assigned to one or more impacting factors.

The tab Episode is a way to access the AH Episode data available in the IS-EPOS web platform with options for selecting and filtering data.
Each episode is provided with some short information concerning the location and the technology associated. Those episodes can be represented in a list but are also depicted on a map show with the exact location of the selected case.

2.6.4 Domain and subdomains

The EPOS repository is grouped into different thematic categories. As mentioned before, filtering of items can be done either by year, subject, division (episodes) or author. All of these filtering processes will lead to an identical searching tools. The main category selected, like subject, is further divided into sub-categories, that are considered as more specialized filters that assemble repository items. Selecting among those filters narrow the search to a limited number of documents available. Taking the example bellow (Figure 7), the category *subject* is divided in three subdomains: Induced technology, methodology and regions (geographic location of the study).

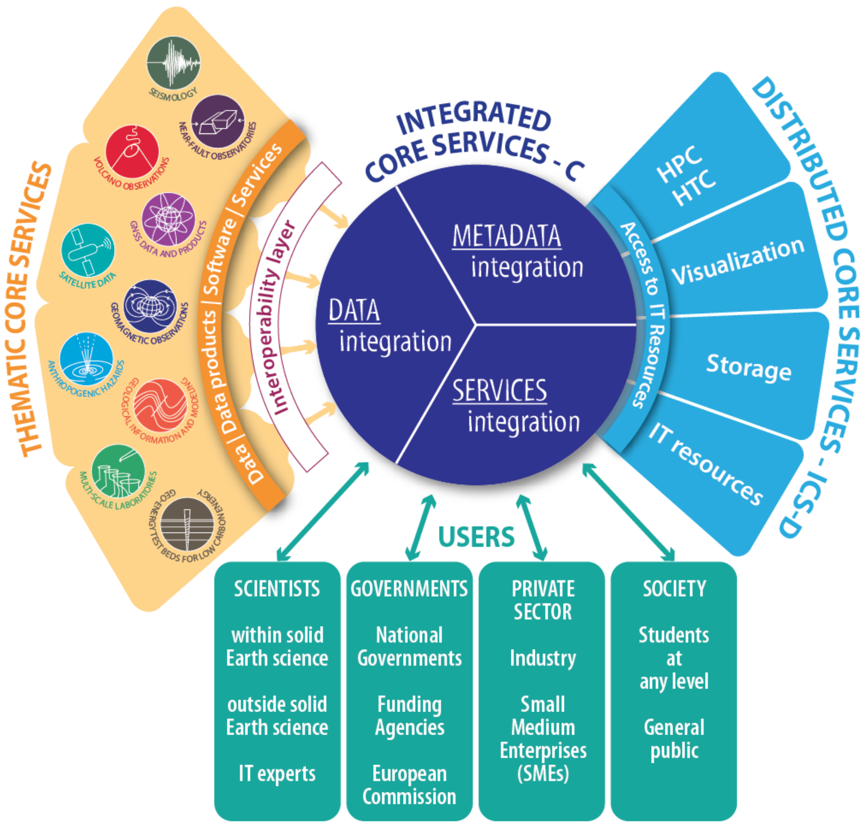

Figure 8: Representation of the EPOS' platform structure (www.epos-ip.org/)

3 HAZARD MECHANISMS

3.1 Introduction

This chapter details the category "Hazard Mechanisms" which is closely related to "causes" in the bow-tie model.

3.1.1 General category definition

The hazard mechanisms category includes the concept definitions for subsurface processes and effects that specify the actual hazard event. There are four top-level concepts which have various narrower definitions in sub-level concepts. These are "Seismicity", "Surface deformation", "Leakage and migration", and "Facility failure". All main concepts have a link with anthropogenic causes. Seismicity and surface deformation may also be linked to natural causes.

3.1.2 Relation to the Risk Bow-Tie Model

Within the Bow-Tie model, hazard mechanisms are directly related to the central hazard event (e.g. an earthquake with high peak ground acceleration). The category extends towards causal subsurface effects (e.g. induced seismicity driven by differential compaction) and consequential surface/subsurface behavior (e.g. induced seismicity resulting in accelerated ground motion).

3.1.3 Relation to EPOS Thematic Core Service Anthropogenic Hazards

The category "Hazard mechanisms" closely matches the EPOS[1] Domain and Sub-domain definitions. The concept definitions in HIKE are strictly limited to the mechanism or underlying physical effect. "Compaction induced seismicity" for example relates seismicity (the hazard mechanism) to the effect/mechanism "differential compaction".

According to the definition of the Health and Safety Authority[2] "A Hazard is a potential source of harm or adverse health effect on a person or persons". In the subsurface the source is typically an anthropogenic process (drilling, injection, extraction) or a natural process (e.g. build-up stresses leading to rock failure). Common hazards are potential earthquakes, leakages and spills and surface deformations.

The hazard is the foundation of the Bow-Tie model and sets the scope and context for further assessment. The rest of the Bow-Tie model is devoted to minimizing the chance that a hazardous event occurs or minimizing the consequences (impacts) of a hazardous event that did occur.

[1] EPOS metadata catalog: https://www.epos-ip.org/what-metadata-epos

[2] https://www.hsa.ie/eng/Topics/Hazards/

The development of Bow-Tie model generally starts with a hazard identification (or HAZID). This is a brainstorming workshop with a multi-disciplinary team to identify potential hazards. Typically it examined all possible sources of hazards within the entire life-cycle of a subsurface project.. The potential hazardous event itself is central to the evaluation. Subsequently the evaluation focuses on possible causes, consequences, preventions and mitigations. An alternative to HAZID is the TECOP method to classify risks (Technical, Economic, Commercial, Operational, or Political) and assess their probability and consequence. Bow-Tie models are ranked and selected on the basis of their potential impact.

3.2 Seismicity

Definition

This concept refers to the occurrence of earthquakes in space, time and magnitude. It is a geophysical process related to a sudden release of energy resulting from fracturing and displacement of rocks which are exposed to a local or regional stress field in the earth. Seismic activity defines the phenomenon resulted from earthquake activity or the occurrence of artificially induced/triggered earth tremors. This concept is detailed through narrower terms. This concept is aligned as well with the keywords' thesaurus, where the entity seismicity was already defined under Applied Geophysics category.

Broader concepts

Hazard Mechanism

Narrower concepts

Induced seismicity
Triggered seismicity
Natural seismicity
Generated seismicity

Semantic relationships

Environmental impacts
Economic impacts
Buildings and Infrastructure damage impacts
Physical Injuries
Death
Tectonic settings
Anthropogenic causes
Natural causes

References

https://docs.cyfronet.pl/display/ISDOC/Domain+and+subdomain+names
https://data.geoscience.earth/ncl/geoera/keyword/2398
https://www.britannica.com/science/seismicity

3.2.1 **Induced seismicity**

Definition

Induced seismicity is associated to a change in the stress level in the surrounding rocks, generated by a pore pressure variation, reactivation of existing faults, temperature change. Typically, induced seismicity is associated to with minor magnitude earthquakes and tremors that are caused by human activity

Broader concepts

Seismicity

Narrower concepts

None

Related Semantic concepts

Injection activities
Cyclic injection and extraction
Conventional gas production
Salt solution mining
Human Health and life Impacts
Buildings and Infrastructure damage impacts
Economic Impacts
Hazard Analysis

References

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Ellsworth, W. L., 2013, Injection-Induced Earthquakes: Science, v. 341, no. 6142, p. 1-6 DOI: 10.1126/science.1225942.

Braun T., S. Danesi , and A. Morelli (2020). Application of monitoring guidelines to induced seismicity in Italy. J Seismol., 24, 1015–102, hNps://doi.org/10.1007/s10950-019-09901-7

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Lamontagne M., 2013, Induced seismicity. In: P.T. Bobrowsky (Ed.) Encyclopedia of Natural Hazards, pp. 535-536

McGarr, A., D. Simpson, and L. Seeber (2002). Case histories of induced and triggered seismicity. International Handbook of Earthquake and Engineering Seismology, Part A, W.H.K. Lee et al., eds., Academic Press, 647-661

Mucciarelli M. (2013). Sismicità indotta da attività antropiche e rischio derivante. Ingegneria Sismica, Patron Editore, Bologna.

National Research Council (2013). Induced Seismicity Potential in Energy Technologies, 262 pp. The National Academies Press, Washington, D.C.

Ogwari P. O., S. P. Horton, and S. Ausbrooks (2016). Characteristics of Induced/Triggered Earthquakes during the Startup Phase of the Guy–Greenbrier Earthquake Sequence in North–Central Arkansas Seis. Res. LeN., 87 (3), 620-630; doi: 10.1785/0220150252

3.2.2 **Triggered seismicity**

Definition

Like induced seismicity, triggered earthquakes are considered to be an earth response to non-tectonic phenomena. This seismicity is considered as a result of the intervention of human in a predisposed environment. In this context, a seismic activity is highly probable to occur since the shear force is near the rupture state, which has been accelerated by human intervention.

Broader concepts

Seismicity

Narrower concepts

None

Semantic concepts

Compaction induced subsidence

Anthropogenic causes

References

(E.KLEIN, 21/06/2018) knowledge review concerning hazards and risks related to anthropogenic seismicity. Ground and underground risks division. Ineris.

Bommer, J.J., Crowley, H., Pinho, R. 2015. A risk-mitigation approach to the management of induced seismicity. J. Seismol. 19: 623–646; doi:10.1007/s10950-015-9478-z.

Gupta H.K., 2013, Triggered Earthquakes. In P.T. Bobrowsky (Ed.) Encyclopedia of Natural Hazards, pp. 1031-1036.

McGarr, A., D. Simpson, and L. Seeber (2002). Case histories of induced and triggered seismicity. International Handbook of Earthquake and Engineering Seismology, Part A, W.H.K. Lee et al., eds., Academic Press, 647-661.

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3.2.3 Natural seismicity

Definition

This natural seismic activity is recorded all around the globe and it is closely related to tectonic plates' movement, but it is observed at well in intracontinental environment. This activity is generated by tectonic forces; it is considered as a sudden release of accumulated stress in the Earth crust by movement or shaking. Earthquakes are caused by tectonic activity, volcanoes and human activity while natural seismicity refers to all of these except the ones caused by human operations.

Broader concepts

Seismicity

Narrower concepts

None

Semantic concepts

Compaction induced subsidence

References

(E.KLEIN, 21/06/2018) knowledge review concerning hazards and risks related to anthropogenic seismicity. Ground and underground risks division. Ineris

3.3 Subsurface deformation

Definition

Deformation is a generic term that translates a change in the shape, orientation or position under stress. The surface deformation delineates a distortion of geologic strata at or near the ground surface that experienced stress. This process can be resulted either by folding or faulting due to various earth forces and it affects appearance, texture and properties of the rock. Tectonic surface deformation can be either brittle or ductile. Near-surface rocks have an elastic deformation (they recover their original shape after stress is removed) and present a brittle behavior (at a certain stress, called yield point, they suffer rupture), while at depth rocks show a ductile (plastic) deformation. In the latter case, the rocks do not recover their original shape. Brittle failure is associated with earthquakes, while ductile deformation is associated with fault activity in a process called *creeping*, which can endure for long periods of times and most of the time it is aseismic (does not produce earthquakes). Earthquakes generally nucleate at large depths where the behavior is ductile, though in large earthquakes rupture propagate to (or close) to the surface, where rock behavior is brittle.

Broader concepts
Hazard mechanisms

Narrower concepts
Gradual deformation
Instantaneous deformation

Semantic relationships
Modelling
Datasets
Buildings and Infrastructure damage impacts
Human Health and life Impacts
Economic Impacts

References

Bourne, S. J., Oates, S. J., van Elk, J., & Doornhof, D. (2014). A seismological model for earthquakes induced by fluid extraction from a subsurface reservoir. Journal of Geophysical Research: Solid Earth, 119(12), 8991-9015. https://doi.org/10.1002/2014JB011663

Van Wees, J. D., Orlic, B., Van Eijs, R. M. H. E., Zijl, W., Jongerius, P., Schreppers, G. J., ... & Cornu, T. (2003). Integrated 3D geomechanical modelling for deep subsurface deformation: a case study of tectonic and human-induced deformation in the eastern Netherlands. Geological Society, London, Special Publications, 212(1), 313-328. https://doi.org/10.1144/GSL.SP.2003.212.01.21

3.4 Facility failure

Definition

In general, facility failure can occur starting with the planning phase of the facility until operating. This includes all types of facilities being constructed by human hands. Limiting our interest to related subsurface exploitation's achievements like onshore and offshore platforms, geotechnical facilities… These facilities may face failure problems that are considered as accidental, that occurs due to geological hazard, from structural distress, as an earthquake or heavy rainfall, flood, or any other natural events but it may be as well resulted from human error. Such events can demonstrate serious consequences and impacts on the project, on the structure but above all and most dangerously on workers and civil people around the area and, in worst cases, it may even lead to death. Considered as a serious matter, protocols and laws came to put order and rules to these procedures. Now, almost all the interventions are guided through manuals and protocols, followed by experts' advice. Any break of the established standards (environmental, safety …) can be inspected by the authority and judged in front of the court. Therefore, engineers must be able to identify the hazard and failure that may affect safety measure.

Broader concepts
Hazard mechanisms

Narrower concepts
Explosions
Fluid spills
Emissions

Semantic relationships
Anthropogenic causes
Natural causes
geomorphology
Tectonic settings
Regional geological definitions
Impact types
Models
Protocols

References

Parise, M., Closson, D., Gutiérrez, F., & Stevanović, Z. (2015). Anticipating and managing engineering problems in the complex karst environment. Environmental Earth Sciences, 74(12), 7823-7835. https://doi.org/10.1007/s12665-015-4647-5

Pipeline and Hazardous Materials Safety Administration in USA (2019). Federal Register / Vol. 84, No. 85 / Thursday, May 2, 2019 / Notices.

https://www.govinfo.gov/content/pkg/FR-2019-05-02/pdf/2019-08984.pdf; (accessed on September 2021).

3.5 Leakage and migration

Definition
The ability to explore the underground and to exploit the subsurface resources, has widen the human intervention and so the risk behind. One of the major faced risks and challenges is leakage and migration. While injection and extraction phases, the probability to endure a leakage or a migration is to be considered. In fact, the fluid will need a pathway to escape its initial storage system. This can occur following natural paths like natural fractures or faults as well as the fractures induced by human activities both on and underground. Moreover, this path can be afforded by casing and pipelines, any artificial human made conducts. Multiple risk factors could lead to leakage and

migration and potentially to environmental issues. Therefore, it is crucial for these risks to be examined and naturally assessed, mitigated or prevented.

Broader concepts
Hazard mechanisms

Narrower concepts
leakage and migration along constrained path
leakage and migration along unconstrained path

Semantic relationships
CO2 sequestration
Engineering activities
Methods
Tectonic settings
Environmental impacts

References

Beaubien, S. E., Lombardi, S., Ciotoli, G., Annuziatellis, A., Hatziyannis, G., Metaxas, A., & Pearce, J. M. (2005). Potential hazards of CO2 leakage in storage systems—learning from natural systems. In Greenhouse Gas Control Technologies 7 (pp. 551-560). Elsevier Science Ltd. https://doi.org/10.1016/B978-008044704-9/50056-2

Schout, G., Hartog, N., Hassanizadeh, S. M., Helmig, R., & Griffioen, J. (2020). Impact of groundwater flow on methane gas migration and retention in unconsolidated aquifers. Journal of contaminant hydrology, 230, 103619. https://doi.org/10.1016/j.jconhyd.2020.103619

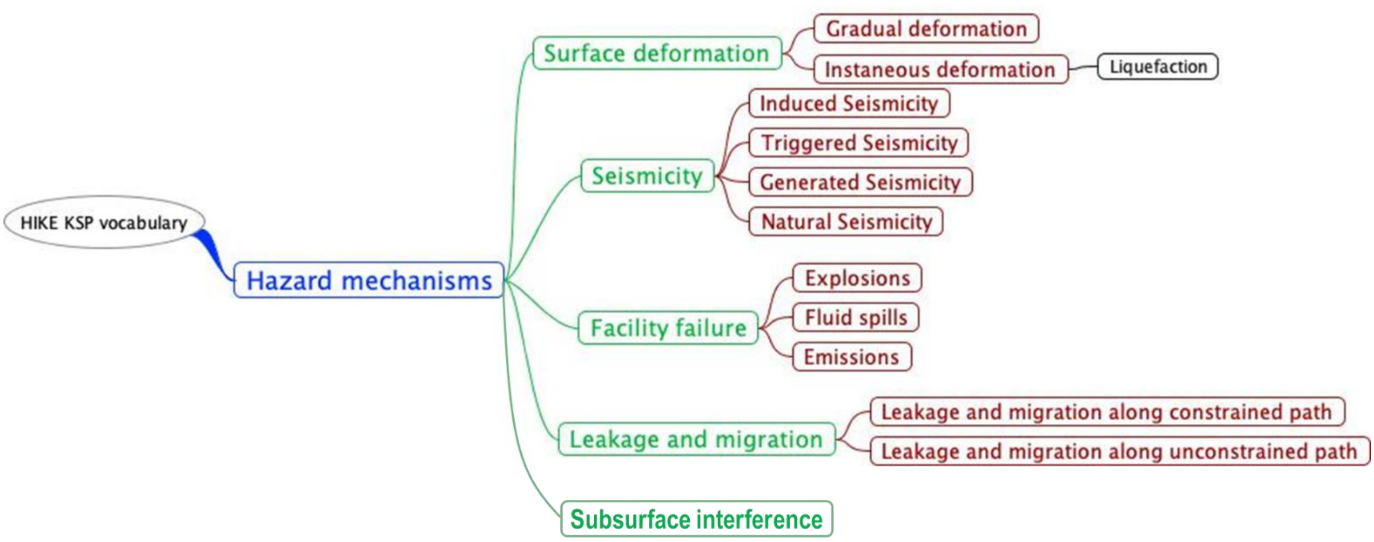

Figure 9: Second and third level concepts in the Hazard mechanisms category

4 IMPACT TYPES

4.1 Introduction

4.1.1 General category definition

Impact is an alteration of a state or conditions of a receiver or subject, caused or induced by the considered factor. In this perspective, impact may be seen as an adverse or beneficial result of a particular event. These adverse or beneficial results may include economic, social, health, cultural and environmental, including climatic, consequences.
In terms of hazard and impact assessment, impact occurs when there is a relation between hazard, exposure and vulnerability, and defines the total effects of a particular factor. When more than one factor has to be taken into consideration, the impact is expected as synergetic consequence of all (multi-hazard impact).
In terms of the time scale, impacts can be distinguished between short- and long-term impacts.
Impact types can be defined based on assets to be protected against hazards. In this case the assets that need to be protected and should be considered in the risk assessment processes include people, buildings, infrastructure, economy, environment, etc. Therefore, the proposed first level concepts include: economic impacts, buildings and infrastructure damage, environmental impacts and human health and life impacts. These first level concepts are broken down to a level of detail meaningful for making decisions and allowing to assign vulnerabilities.
Established concepts of impact types should provide a sufficient catalogue of potential impacts on receptors or assets from a range of natural and induced hazards related to geo-energy.
Direct impacts occur at the same time and place as the event, which caused them. Indirect impacts occur later or further away in distance and may be caused by the event or its further consequences. Indirect impacts often result from the direct ones. The proposed ontology includes direct and indirect impacts. Impacts are also subject to measurements and assessments. Monitoring and other tools are categorized and described in Hazard analysis section.
Concepts themselves do not propose any label or criteria for scoring impact and likelihood. The choice of criteria is largely a site specific aspect as well as a political decision. Therefore it should be part of the stakeholder discussions in a framework of risk analysis.

4.1.2 Relation to the Risk Bow-Tie Model

Impact, defined as a set of consequences, even though some might be beneficial, there are mostly losses, and therefore considered in terms of severity and impact probability for risk assessment. At a Bow-Tie model, theidentified impacts are located at right-hand side, as consequences of unwanted events.

4.1.3 Relation to EPOS Thematic Core Service Anthropogenic Hazards

As mentioned in section 2.6, EPOS thematic services deal with seismology, anthropogenic and natural hazards and different subjects that can be considered as a data resources closely related to impacts. Moreover, the thematic geological modeling and models are considered as essential materials needed to predict, assess and prevent different impacts. While EPOS treats the impact types indirectly, HIKE considers defining this subject as a thematic type.

4.2 Economic Impacts

Definition
Total economic impact consists of direct and indirect economic loss (or win). In case of loss, which is relevant to HIKE interests, it includes damage and loss assessment in financial terms – costs of a damage, costs of the reparation and restoration, costs of emergency measures, costs of long-term recovery (costs of disruption of economic activities, unemployment, indirect social costs such as those for the restoration of education and health systems).

Direct economic impact - The monetary value of total or partial destruction of physical assets existing in the affected area. Direct economic loss is nearly equivalent to physical damage.

Indirect economic impact - a decline in economic value added as a consequence of direct economic loss and/or human and environmental impacts. Indirect economic loss includes microeconomic impacts (e.g., revenue declines owing to business interruption), meso-economic impacts (e.g., revenue declines owing to impacts on natural assets, interruptions to supply chains or temporary unemployment) and macroeconomic impacts (e.g., price increases, increases in government debt, negative impact on stock market prices and decline in GDP). Indirect losses can occur inside or outside of the hazard area and often have a time lag.

Broader concepts
Impact types

Narrower concepts
Critical facilities out of use / malfunction
Disruption of transportation
Employment rate

Semantic relationships
Natural seismicity
Surface deformation
Geomorphology
Methods

References
UNISDR, 2017 - National Disaster Risk Assessment. Governance System, Methodologies, and Use of Results (In support of the Sendai framework for Disaster Risk Reduction 2015-2030),

4.3 Environmental Impacts

Definition
Environmental impact: The changes in environmental conditions lead to impacts on the social and economic functions on the environment, such as the provision of adequate conditions for health, resources availability and biodiversity. Includes the loss of and structural damage to nature conservation areas, ecosystems and protected species, as well as general environmental pollution. The costs of environmental recovery are in most cases seen as part of the economic impact.

Broader concepts
Impact types

Narrower concepts
Water impact
Atmospheric impact
Biogenic impact
Land impact

Semantic relationships
Ecological impact
Effect on the environment
Environmental change
Environmental cost
Vulnerability
Resilience
Methods
leakage and migration
Seismicity

References
Miedzinski et al., Assessing Environmental Impacts of Research and Innovation Policy. Study for the European Commission, Directorate-General for Research and Innovation, Brussels, 2013

National Disaster Risk Assessment. Governance System, Methodologies, and Use of Results (In support of the Sendai framework for Disaster Risk Reduction 2015-2030), UNISDR, 2017

Landy, M., Environmental Impact Statement Glossary. A Reference Source for EIS Writers, Reviewers, and Citizens., IFI/Plenum Publishing Corporation, New York, 1979

IPCC, in EEA Report No 1/2019 "Building a climate-resilient low-carbon energy system", 2018

4.4 Buildings and Infrastructure damage

Definition

Damage in general is defined as harm or injury to a person, property, or system resulting in impairment or loss of function, usefulness, or value.

It is obvious that nowadays constructions are crucial to the society As we use buildings and infrastructure at a daily basis. Actually, lifelines the equivalent to infrastructures are defined as "systems or networks, which provide for the circulation of people, goods, services and information upon which health, safety, comfort and economic activity depend" (RH, 1991). These constructions constitute and carry the society as well as economy, therefore it is essential to monitor and prevent any potential hazard that can pose an actual risk. The consequences can vary from light impacts to even a disaster with fatalities. Commonly, these constructions are affected either by natural events like slope failures (landslides), liquefaction, and tsunami, or resulted as well from a human error in the conception or a human intervention to provoke seismicity. The idea is to identify these impacts and the cause of buildings and infrastructure damage, then use models and datasets to provide recommendations, assessment plans to prevent this accident from occurring.

Broader concepts

Impact types

Narrower concepts

Buildings collapse
Infrastructure failure
Landscape alteration

Semantic relationships

insignificant
minor/substantial
moderate/serious
significant/very serious
catastrophic/disastrous

Mass Movements
Seismicity
Salt solution mining
Datasets
Tunnel building

References

Kongar I., Giovinazzi S. (2014) Damage to Infrastructure: Modeling. In: Beer M., Kougioumtzoglou I., Patelli E., Au IK. (eds) Encyclopedia of Earthquake Engineering. Springer, Berlin, Heidelberg.

Physical Geology by Steven Earle

http://www.businessdictionary.com/definition/ecological-risk-assessment.html

Parker, S. P. & Corbitt, R. A., McGraw-Hill Encyclopedia of Environmental Science & Engineering - Third Edition, McGraw-Hill, Inc., USA, 1993…

RH, P. (1991). Lifelines: an emergency management priority for the United States in the 1990s. . Disasters 15(2), 172–176.

4.5 Human Health and life Impacts

Definition

Human life and health are the most valuable variables that need to be considered in each action made.

The human impact can refer to the quality of life which is understood as daily living enhanced by wholesome food and clean air and water, enjoyment of unfettered open spaces and bodies of water, conservation of wildlife and natural resources, security from crime, and protection from radiation and toxic substances. It may also be used as a measure of the energy and power a person is endowed with that enable him or her to enjoy life and prevail over life's challenges irrespective of the handicaps he or she may have.

Human impact can be defined as a number of people affected – including deaths, severely injured or illness, psychological problems, displaced due to loss of home or livelihoods.

Broader concepts

Impact types
Quality of life

Narrower concepts

Physical Injuries
Diseases

Death
Psychological impacts
Stress
Forced displacement

Semantic relationships
Exposure
Receptor
Impact factors

References

https://www.unisdr.org/files/52828_nationaldisasterriskassessmentpart1.pdf

http://www.businessdictionary.com/definition/ecological-risk-assessment.html

Gunawan, O., Mooney, J., Aldridge, T. Natural Hazards Partnership. Hazard Impact Framework. First Edition. 2017

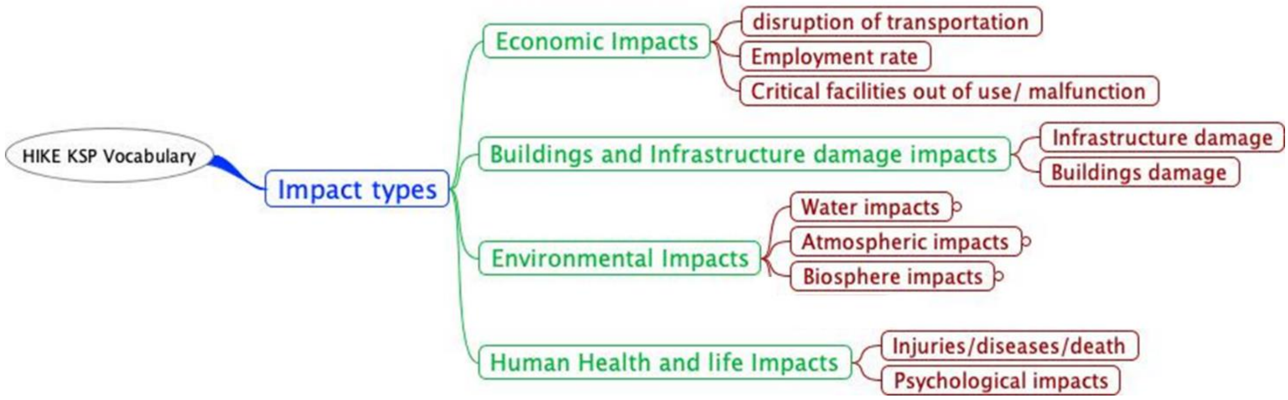

Figure 10: Second and third level concepts in the Impact types category

5 HAZARD CAUSES

5.1 Introduction

5.1.1 General category definition

This category presents the knowledge on a wide range of both natural and anthropogenic hazard origin. It is important to stress here that the anthropogenic processes can in many cases be responsible for triggering and/or influencing natural hazard mechanisms.
Therefore, when referring to hazard's causes, these are often classified in two types: natural and anthropogenic.

5.1.2 Relation to the Risk Bow-Tie Model

Hazard causes, similarly to hazards mechanisms need to be taken into account mainly on the left hand side of the Bow-Tie Bow-Tie Model which apply for the risk prediction and risk prevention. The more is known about creation of hazardous geological processes the better measures may be implemented to counteract possible enhancement of unwanted natural processes, which sometimes may even lead to abandonment of planned activities as only possible way of prevention against occurrence of an obvious hazardous event. Understanding what causes unwanted natural processes (and how they propagate) is also necessary on the mitigation side of the Bow-Tie Model, as it allows to model different ranges of hazardous event in advance and prepare adequate ways of impact (or adverse consequences) mitigation.

5.1.3 Relation to EPOS Thematic Core Service Anthropogenic Hazards

In EPOS, the hazard definitions include a mixture of causes (e.g. Mining induced seismicity) or are associated to geological settings (e.g. reservoir induced seismicity). Furthermore, the idea of EPOS is to aggregate all non-seismic related hazards under one category called "Anthropogenic hazards". HIKE aims to define a further subdivision for these hazards.

5.2 Natural causes

Definition
A Natural hazard is a concept specified under the category 'Hazard causes" and it is designed as the definition of physical event that can be a source of harm or a potential to cause loss. Generally, these natural processes are a part of our environment and may pose miscellaneous threats human life sphere. If there is no community or human that would be endangered , this phenomenon is no longer considered as a hazard. In our classification we divide Natural hazard cause term as derived from solid earth, hydrogeological or atmospheric phenomena. Thus, this architecture eliminates any disaster resulting from pollution, contaminations or any cause associated with manmade actions.
These three 1st level concepts will be further detailed through narrower 2nd level ones.

Broader concepts
Hazard causes

Narrower concepts
Solid earth
Hydrogeological causes
Atmospheric causes

Semantic relationships
Natural Hazards
Anthropogenic Hazards
Hazard Mechanism
Hazard Analysis
Geomorphology?
Surface deformation?
Seismicity?
Impact types
Instruments?
Modelling
Software

References

Bokwa A. (2013) Natural Hazard. In: Bobrowsky P.T. (eds) Encyclopedia of Natural Hazards. Encyclopedia of Earth Sciences Series. Springer, Dordrecht

Burton, I., Robert W. Kates and Gilbert F. White. The Environment as Hazard (New York: Oxford University Press, 1978).

5.3 Anthropogenic causes

Definition
Anthropogenic hazards are hazards issued from human action or inaction and they may manifest through natural hazards. Another way of conceptualizing a man-made hazard is as a natural hazard frequency, magnitude or intensity aggravated by human activities. Nevertheless, human intervention may also cause natural hazards where none existed before, by reducing a natural ecosystem's tolerance. Thus, hazards, which are part of nature, often turn into disasters due to human actions or inactions (UNESCO,2007).
To summarize, this term is assigned to a hazard resulted from a human intent, negligence, human error and involving a failure of man-made system (Lakshmi, M. & Kumar, 2015).
Anthropogenic hazards are broadly classified into four major groups covering the multiple ways by which humans can cause dangerous events both to their own wellfare and property and to the natural environment. This classification is based on initial

changes caused by an activity – changes in pressure, stress field, integrity or (fluid) composition in the subsurface, posed by introducing or removing a mass (fluid, solid, supercritical, gaseous, etc.) or energy (heat) or by drilling and engineering subsurface formations. Hence, this categorization was developed according to the physical mechanisms involved/used in the process leading to the hazard: extraction, injection or an alternation of those (e.g. energy storage, geothermal doublets). In addition, we included engineering causes which is the technological hazards due to engineering failure (surface infrastructure installment, well completion, etc.)

Broader concepts
Hazard causes

Narrower concepts
Extraction activities
Injection activities
Alternating injection-extraction activities
Engineering activities

Semantic relationships
Hazard Mechanism
Hazard Analysis
Impact types

References
Gill, Joel C., et Bruce D. Malamud. « Anthropogenic Processes, Natural Hazards, and Interactions in a Multi-Hazard Framework ». Earth-Science Reviews 166 (mars 2017): 246-69. /Gill et Malamud, « Anthropogenic Processes, Natural Hazards, and Interactions in a Multi-Hazard Framework ».

Anthropogenic Hazard and Disaster Relief Operations: A Case Study of GAIL Pipeline Blaze in East Godavari of A.P. Procedia - Social and Behavioral Sciences. 189. 198-207/ Lakshmi, M. & Kumar, V.. (2015)

5.3.1 Extraction activities

Definition
These activities are related to the removal of wanted or unwanted subsurface solids and/or fluids for a specific objective, for example the uptake of groundwater, extraction of fossil/mineral deposits (solids and fluids) or artificially injected substances, etc.. These activities provoke either a change in a stress field around rock formations and cavities, a decrease of the underground pressure or both. These changes may induce and trigger various hazard mechanisms, mainly seismicity and surface deformation (e.g. subsidence). For example, with hydrocarbon extraction, differential compaction may result in differential stresses along faults which can cause induced earthquakes. Salt

solution mining can provoke collapse of subsurface structures resulting in gradual or abrupt surface subsidence/deformation. Underground mining of solid deposits like coal or ores creates void space which may provoke underground stress release mechanisms which would lead to mine damage both under and on the surface.
The general concept "Extraction activities" is further detailed into particular types of mining activities.

Broader concepts
Anthropogenic hazards

Narrower concepts
Conventional gas production
Unconventional gas production
Conventional oil production
Unconventional oil production
Geothermal production
Surface mining
Subsurface mining
Salt solution mining
Water production

Semantic relationships
Geological settings
Impact types
Seismicity
Surface deformation
leakage and migration
Tectonic settings

References
Gill, Joel C., et Bruce D. Malamud. « Anthropogenic Processes, Natural Hazards, and Interactions in a Multi-Hazard Framework ». Earth-Science Reviews 166 (mars 2017): 246-69. /Gill et Malamud, « Anthropogenic Processes, Natural Hazards, and Interactions in a Multi-Hazard Framework »

5.3.2 Injection activities

Definition
Different existing case studies have shown that high-volume fluids injection into the subsurface indeed triggered hazard mechanisms. Subsurface injection is generally a process used in different industrial contexts. Common examples are the permanent injections and sequestration of liquids from oil/gas production and industrial processes or captured CO_2 into a porous trapped geological formations. The injection process can be used for conventional and unconventional oil & gas extraction to improve and drive

production (enhanced oil and gas production through injection of CO_2 and other gases). Specific activities are mentioned in the narrower concepts.
Investigating the effect of fluid injection may involve multiple science domains beyond only geomechanics, like hydrogeology and geochemistry, as the interaction of injected fluid with the reservoir such as mineral dissolution or phase precipitation increases the risk behind this operation and could amplify significant problems, so proper recognition of all physical and chemical reactions for effective risk mitigation is essential.

Broader concepts
Anthropogenic hazards

Narrower concepts
CO2 sequestration
Water injection
Fracking
EOR

Semantic relationships
Energy storage
Oil & gas production
Geothermal production
Induced seismicity
Leakage and migration
Modelling
Monitoring

References
United State Environmental Protection Agency – Underground Injection Control (UIC). https://www.epa.gov/uic/general-information-about-injection-wells. Accessed on October 2021.

Verdon et al., « Subsurface Fluid Injection and Induced Seismicity in Southeast Saskatchewan ».

5.3.3 Cyclic injection and extraction activities

Definition
The removal of subsurface fluids is commonly associated with their natural replacement by other fluids, according to pressure equalization rule. In case of systems with low permeability, the decreased underground pressure can be quickly renewed by artificial injection of missed mass in industrial process with use of injection wells. This term covers all activities that require simultaneous or alternating use of extraction and injection wells, like in complex operations within Enhanced oil and/or gas recovery, or energy production with use of underground temporary storage of fuels and/or gases.

The effectiveness of such activities as well as their safety and security relies on determining the best process scenario, which requires the best possible recognition of natural conditions as well as process needs and outcomes. The concept is further divided in the various activities that used for the subsurface exploitation and can activate or be a hazard cause. The defined narrower concepts can be connected to resulted hazard mechanism that can occur and the tools to assess this hazard.

Broader concepts
Anthropogenic hazards

Narrower concepts
Geothermal doublet production
Hydrogen storage
Natural gas storage
Nitrogen storage
Compressed air energy storage
Underground thermal storage

Semantic relationships
Water Impacts
Economic Impacts
Methods
Modelling
Monitoring

References
Parisio, F., Vilarrasa, V., Wang, W. et al. The risks of long-term re-injection in supercritical geothermal systems. Nat Commun 10, 4391 (2019). https://doi.org/10.1038/s41467-019-12146-0.

Miyazaki, B. (2009). Well integrity: An overlooked source of risk and liability for underground natural gas storage. Lessons learned from incidents in the USA. Geological Society, London, Special Publications, 313(1), 163-172. http://dx.doi.org/10.1144/SP313.11

5.3.4 Engineering activities

Definition
Advanced civil engineering certainly offers great opportunities in changing surrounding environment into more usable space better fit to fulfill the needs of modern societies but it also comes with accidents and failures that would never happen in natural conditions or if so, not now but only possibly in the future. We can consider engineering activities as the main reason of a technological hazard. This includes hazardous material incidents, industrial plants failures, boreholes failures, spills and leakages

This concept comes to identify the human direct responsibility for hazards that civil engineering introduce – both due to particular technology which brings more profit than possible pay-back and due to human failure or ignorance.. The following 3rd level concepts will show particular activities related to geo-energy applications. Due to its character, the concepts are closely linked with Hazard analysis category and impacts types.

Broader concepts
Anthropogenic hazards

Narrower concepts
Tunnel building
Drilling
Nuclear waste storage
Bridge
Roads
Dam

Semantic relationships
Monitoring

References

Gong, W., Juang, C. H., & Wasowski, J. (2021). Geohazards and human settlements: Lessons learned from multiple relocation events in Badong, China–Engineering geologist's perspective. Engineering Geology, 285, 106051. https://doi.org/10.1016/j.enggeo.2021.106051

Elbaz, K., Shen, J. S., Arulrajah, A., & Horpibulsuk, S. (2016). Geohazards induced by anthropic activities of geoconstruction: a review of recent failure cases. Arabian Journal of Geosciences, 9(18), 1-11. https://doi.org/10.1007/s12517-016-2740-z

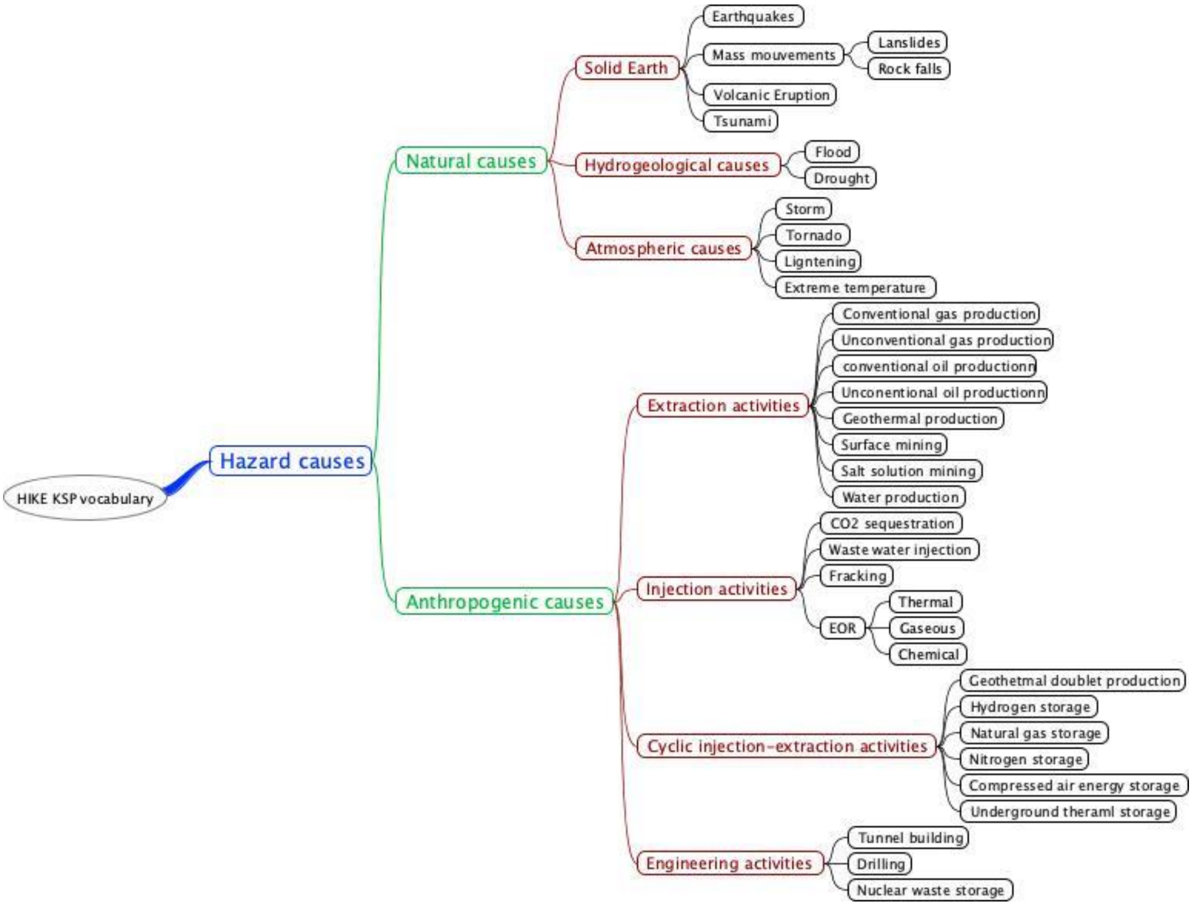

Figure 11: Second and third level concepts in the Hazard causes category

6 HAZARD ANALYSIS

6.1 Introduction

Knowledge of hazards that are connected with regional and local natural conditions as well as with an activity or activities that are already performed or planned in an area is crucial for any project design and cost analysis. Moreover, a local society has full right to know all advantages and disadvantages of everything that takes place in their living space and needs to know facts to actively participate in decision making process. When we add that only with proper hazard recognition one can proceed with risk analysis and design appropriate risk minimization and mitigation measures, it becomes obvious that reliable and affirmed hazard analysis instruments, methods, tools and protocols are necessary for each subsurface project planning.

6.1.1 General category definition

In this context and in order to bring suitable answer to the end-user's questions, Hazard Analysis domain definition was essential. It presents available methods, tools and datasets, as well as technically and legally approved protocols to help the user to determine the appropriate way to determine perceived hazards resulting from a particular activity in particular conditions. Showing also a set of case study analysis delivers a broader picture of practical use of presented methodology and allows for better understanding of hazard mechanisms, their relationship with human activities and risk resulting from their interaction.

Relationships between this domain and various concepts has been established to indicate the conditions of use, the data necessary for running a tool, method or protocol. Based on this idea, our classification consists of five concepts of a first level. Each of this level will be eventually detailed into further narrower concepts.

6.1.2 Relation to the Risk Bow-Tie Model

There has been a growing awareness in this recent year that the understanding of the human intervention effect through different case studies is very helpful to comprise a hazard mechanism and to design its proper management. Hazard analysis are then performed to identify the hazard, its causes, mechanisms and possible effects on different fields. With decent hazard recognition in its all aspects, we can determine the risk posed on the planned activities as well as enable preparation of adequate prevention measures and mitigation protocols.

6.1.3 Relation to EPOS Thematic Core Service Anthropogenic Hazards

EPOS includes various tools and applications for hazard assessment (see section 2.5). HIKE contributes to this with a presentation of case studies and methods in order to illustrate practical examples:

- D3.2_HIKE_Improved_Seismic_Events_Localization
- D3.3_HIKE_Subsidence_Assessment_Techniques

- D3.4_HIKE_Improved_Reservoir_Seals_Assessment
- D3.5_HIKE_Subsurface_Injection_Safety_Seismicity

6.2 Datasets

Definition

To conduct any research one needs to have proper information to establish his analysis on and/or to verify the final models. Data needed for particular analysis usually (except for credibility) must have proper format, be collected in a proper way and in many cases, in and within a proper time, have acceptable degree of uncertainty, etc. The concept describes how important data preparation and verification is, what kind of data might be needed for particular analysis, how to obtain measurement results (with relation to Instruments, another level 2 concept) and which kind of Earth observation results may be already collected and structured in public databases, including hazardous events inventory. Different analysis conducted in HIKE's case studies will show a diversity of data required for different aspects of hazard analysis (measurements, processed data, model parameters, etc.). The advantages of public available GIS databases, which add the spatial coordinates directly to basic or processed results of field research can be hardly overestimated and allow for comparative studies with more mature and recognized hazardous cases.

Broader concepts

Hazard analysis

Narrower concepts

Interpreted datasets
Measured parameters
Modeled parameters

Semantic relationships

Instruments
Case studies
Seismicity
Regional geological definitions
Anthropogenic causes
Natural causes

References

Not applicable

6.3 Methods

Definition

Tools, models and methods will provide guidance for the user to assess and understand hazards as well as to help mitigating risks. HIKE presents different case studies in which various methods are explained and used (See 6.2). Such methods and tools can include 3D/4D models, analytical/empirical/stochastic models applied to their workflow, scripts in various coding languages (such as java, excel, python, MATLAB…) and could be delivered through GitHub for open-source tools, a link to a website or zipped documents.

To summarize, the concept will guide an user through different ways of hazard assessment based on different examples and reports and will present a wide spectrum of methods (in relation with datasets and software) used for hazard analysis depending on the request.

Broader concepts
Hazard Analysis

Narrower concepts
Modelling
Analytical approaches
experimental approaches

Semantic relationships
Induced Seismicity
Natural Seismicity
Buildings collapse
Tectonic Settings
Leakage and migration

References
Not applicable

6.4 Protocols

Definition
Protocols and guidelines for hazard assessment, mitigation of risks are specified by various laws and directives. Their aim is to proceed subsurface activities with safety assurance and to avoid any unnecessary risks, impacts or costs to society and environment.

Broader concepts
Hazard Analysis

Narrower concepts
Not applicable

Semantic relationships
European legal system
MS legislation
Environmental Impacts
Anthropogenic causes
Human Health and life Impacts
Seismicity

References

Health Hazard Response Protocol, 2019. Ministry of Health and Long-Term Care. Ontario – CA (https://www.health.gov.on.ca/en/pro/programs/publichealth/oph_standards/docs/protocols_guidelines/Health_Hazard_Response_Protocol_2019_en.pdf)

6.5 Case studies

Definition

This concept relates to documented hazard and impact studies such as cases investigated in the WP3 of HIKE. Case studies can be used as analogues for other regions and can contribute to sharing of knowledge and experiences.

Broader concepts
Hazard Analysis

Narrower concepts
None

Semantic relationships
Not applicable

References
Not applicable

6.6 Instruments

Definition

As said before, hazard analysis and risk management starts with data, reliable and accurate for particular purposes. This data must be obtained with use of more or less complicated and sophisticated equipment dedicated for particular measurements and observations. These concept presents the most common techniques for acquisition of data of various kind and delivers instructions for use of them for particular tasks. It covers instrumentation both for geo-data collection and man-made processes monitoring.

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Broader concepts
Hazard Analysis

Narrower concepts
Monitoring
Geophysical acquisition
Satellite acquisition

Semantic relationships
Buildings collapse?
Infrastructure failure?
Seismicity
Anthropogenic causes
Measured parameters

References
Not applicable

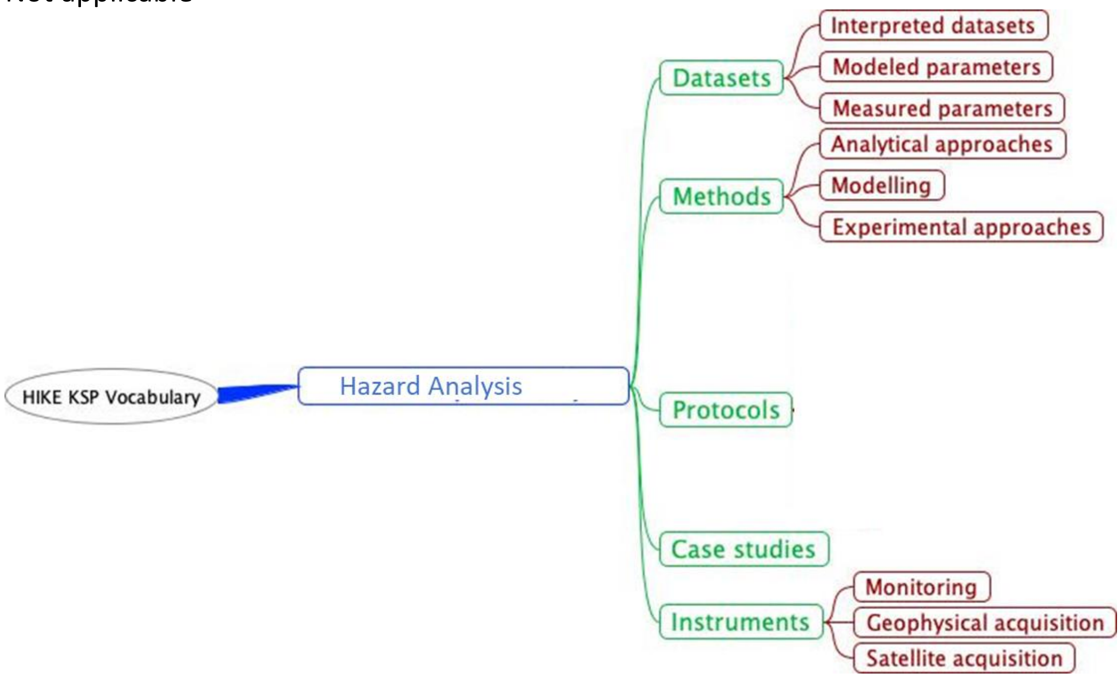

Figure 12: Second and third level concepts in the Hazard analysis category

7 GEOLOGICAL SETTINGS

7.1 Introduction

7.1.1 General category definition

The earth's crust, on which surface we carry out our daily activities, is shaped by internal forces and surface processes. Gravity and several heat sources drive internal earth mass currents that drive tectonic plates movements, which in turn generate volcanic eruptions, earthquakes and tsunamis and shape the earths relief in conjunction with ocean-atmosphere interaction. Geology is the science that studies earth processes that have a profound impact on human life.

7.1.2 Relation to the Risk Bow-Tie Model

Both natural and anthropogenic hazard mechanisms are related to a geological process in a geological context. Actually, the definition of geological hazard expresses any natural or induced geological process that can impose a danger, loss or damage, environmental, economic or social. The Bow-Tie Model is a risk assessment scheme, that is an iterative process which is always assigned to a specific conditions and starts with the site characterization. Geodynamics, geomorphology associated with geophysics and hydrogeology need to be recognized and described in a way sufficient for reliable hazard analysis as well as possible prevention and/or mitigation measures planning and implementation. The geological settings concept describes fundamental geological conditions which regulate possible hazards kinds and extend of hazardous events in interaction with different human subsurface projects.

7.1.3 Relation to EPOS Thematic Core Service Anthropogenic Hazards

EPOS includes the analysis and the characterization of complex surface structures. HIKE differentiates between geological datasets, geological modelling and geological settings.

Broader concepts
Not applicable

Narrower concepts
Geomorphology
Tectonic settings
Regional geological definitions
Stratigraphy
Lithology

7.2 Geomorphology

Definition
Geomorphology is the study of landforms, their processes, form and sediments at the surface of the Earth . Study includes looking at landscapes to work out how the earth

surface processes, such as air, water and ice, can mold the landscape. Landforms are produced by erosion or deposition, as rock and sediment is worn away by these earth-surface processes and transported and deposited to different localities. The different climatic environments produce different suites of landforms. The landforms of deserts, such as sand dunes and ergs, are a world apart from the glacial and periglacial features found in polar and sub-polar regions.
Most geomorphic processes operate at a slow rate, but sometimes a large event, such as a landslide or flood, occurs causing rapid change to the environment, and sometimes threatening humans. So, geological hazards such as volcanic eruptions, earthquakes, tsunamis and landslides, fall within the interests of geomorphology.

Broader concepts
Geological settings

Narrower concepts
None

Semantic relationships
Geological hazards
Surface deformation
Buildings and Infrastructure damage impacts
Modelling
Datasets
Natural causes

References
https://www.geomorphology.org.uk/what-geomorphology-0

Komac B., Zorn M., 2013, Geohazards. In: P.T. Bobrowsky (Ed.) Encyclopedia of Natural Hazards, p. 387

Guthrie R., 2013, Geological/geophysical disasters. In: P.T. Bobrowsky (Ed.) Encyclopedia of Natural Hazards, pp.387-400.

7.3 Tectonic setting

Definition
This concept covers plate tectonics as large scale movements of the Earth's crust, which result in a number of distinct geologic features all over the world. It also deals with the conditions of regional or local stress fields, originated from plate tectonics but which are affected also by local factors

Broader concepts

Geological settings

Narrower concepts
None

Semantic relationships
Buildings and Infrastructure damage impacts
Modelling
Monitoring
Geophysical acquisition
Natural causes
Anthropogenic causes
Economic impacts

References
https://openei.org/wiki/Tectonic_Settings
https://www.sciencedirect.com/topics/earth-and-planetary-sciences/tectonic-setting

7.4 Regional geological definitions

Definition
The idea of this concept is to discuss in details different regional geological contexts. The great focus here will be on identified regions where specialists will provide insights into the geological context, basin analysis, sedimentary processes and describe the structural regime in order to analyze the zone's geology and tectonics.

Broader concepts
Geological settings

Narrower concepts
Structural Elements
Basins
Orogeny
Shields
Platforms

Semantic relationships
Not applicable

References
USGeological Survey (2007). Introduction to Regional Geology, Tectonics, and Metallogenesis of Northeast Asia. https://pubs.usgs.gov/of/2007/1183/a/

7.5 Stratigraphy

Definition

The following concept represent a scientific discipline concerned with the description of rock successions and their interpretation in terms of a general time scale. It provides a basis for historical geology, and its principles and methods have found application in such fields as petroleum geology and archaeology..

The principle of stratigraphy is to divide the rock in sequences of strata forming units, called depositional sequences, with determination of the time relationships that are involved, and to correlate units of the sequence—or the entire sequence—with rock strata elsewhere. Based on that, the International Union of Geological Sciences (IUGS; founded 1961) established a commission on stratigraphy to standardize a stratigraphic scale. This has provided a basis for harmonization of geological nomenclature and it is being applied for petroleum geology for locating petroleum reservoirs (e.g. North, 1985).

Broader concepts

Geological settings

Narrower concepts

Lithostratigraphy

Chronostratigraphy

Semantic relationships

Not applicable

References

https://www.britannica.com/science/stratigraphy-geology North, F.K. 1985, Petroleum Geology, Unwin Hyman, USA.

7.6 Lithology

Definition

If we mentioned before subdividing the sequences into lithostratigraphic units, certainly this was based on a criterion: lithology. Lithology is a state, a description of the physical characteristics of the outcrop of a unit (color, texture, grain size and composition etc.).

This term has the purpose of identifying and mapping zones and perform respective correlations. These parameters help determine the rock type and give additional information on a particular depositional environment.

Broader concepts

Geological settings

Narrower concepts

Rock types
Rock properties

Semantic relationships
Not applicable

References
https://en.wikipedia.org/wiki/Lithology
https://petrowiki.spe.org/Lithology_and_rock_type_determination
…

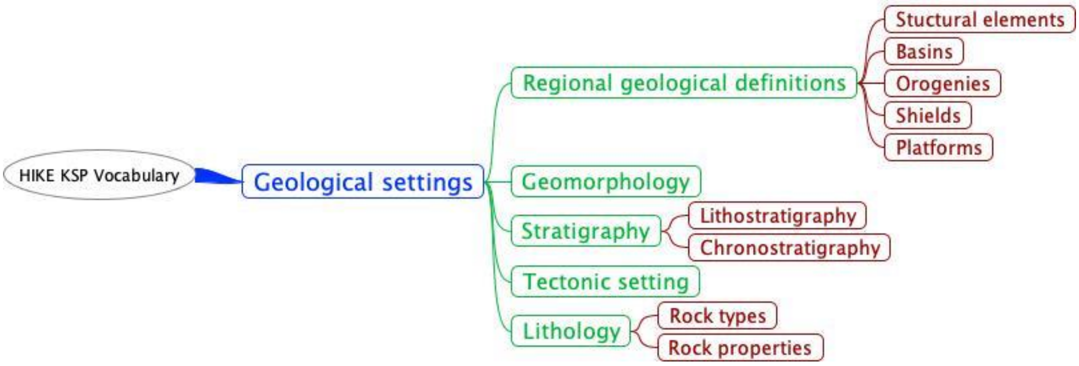

Figure 13: Second and third level concepts in the Geological settings category