MULTI-HAZARD RISK ASSESSMENT FOR GEO-RESOURCE DEVELOPMENT PROJECTS
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Introduction. The exploration and exploitation of geo-resources (a term generally referred to any kind of geological resource) may impact the surrounding environment, and for this reason such industrial activities need to be carefully planned, including the implementation of reliable environmental risk assessments (ERA). A multi-hazard risk (MHR) analysis aims at providing a theoretical framework for harmonising the methodologies employed and the results obtained from risk assessments (i.e. likelihood and consequences) considering different risk sources and taking into account possible interactions among events (e.g. Marzocchi et al., 2012; Gasparini and Garcia-Aristizabal, 2014; Liu et al., 2015; Garcia-Aristizabal et al., 2018).

The MHR problem in this kind of applications needs to be defined in the interface between a natural/built/social environment and an industrial activity perturbing it. The probabilistic model for MHR assessment, as implemented by Garcia-Aristizabal et al. (2018), relies on three fundamental concepts: (1) a logical structure that follows a bow-tie approach, (2) a Bayesian implementation for handling probabilistic information, (3) propagation of modelling uncertainties, and (4) the possibility of using data derived form integrated assessment modelling and expert judgement elicitation for analysing complex processes for which direct data is unavailable.

The analyses therefore rely on the quantification of the likelihood and related consequences of identified risk pathway scenarios structured using a bow-tie (BT) approach (e.g. Bedford and Cooke, 2001; Rausand and Høyland, 2004). The BT is widely used in reliability analysis and has been proposed for assessing risks in a number of geo-resource development applications, as for example in offshore oil and gas development (e.g. Khakzad et al., 2013, 2014; Yang et al., 2013) and for the mineral industry in general (e.g. Iannacchione, 2008).

The BT analysis, in particular, provides an adequate structure to perform detailed assessments of the probability of occurrence of events or chains of events in a given accident scenario. An example of a typical BT structure for this kind of application is presented in Fig. 1. It is targeted to assess the causes and effects of specific critical events; it is composed of a fault tree (FT, Fig. 1a), which is set by identifying the possible events causing the critical or top event (TE, Fig. 1b), and an event tree (ET, Fig. 1c), which is set by identifying possible consequences associated with the occurrence of the defined TE (e.g. Rausand and Høyland, 2004). Therefore, in the BT structure, the top event of the FT constitutes the initiating event for an ET analysis.

Methods and results. The quantitative assessment of the scenarios implemented in a BT structure is based on the probabilities assigned to the basic events of the FT and to the nodes of the ET. In this work, the BT logic structure is coupled with a wide range of probabilistic tools that are flexible enough to make it possible to consider in the analyses different typologies of phenomena. Given the different categories of risk receptors of interest, Garcia-Aristizabal et al (2018) suggest the following general criteria for structuring the MHR scenarios in a BT:

1. Impacts to primary risk receptors can be chosen as critical TEs for constructing fault trees.
2. Identification of the boundary conditions with respect to external stresses. In this way, we define the type of hazards that need to be included in the analysis.
3. For each TE identified, a deductive technique is used to identify the possible causes of such a critical event, considering the boundary conditions defined and the level of resolution of the analysis.
4. The identified TEs are also the starting points of consequence analysis, which can be
evaluated for considering both, the magnitude of the impact on the primary risk receptor, and the impacts on final risk receptors of interest.

Since major risks are rare events for which scarce or no data are usually available, Garcia-Aristizabal et al. (2018) adopt a Bayesian framework (Fig. 1d) that allows us to coherently integrate all the useful information and to update assessments as site-specific data are retrieved. In this way, the assessments can be adjusted to the dynamic environment that usually characterises operations for the development of geo-resources. The MHR assessment approach presented in Garcia-Aristizabal et al. (2018) includes five classes of probabilistic models for implementing the stochastic characteristics of FT’s basic events (namely: homogeneous Poisson process, binomial, Weibull, static- and dynamic- physical reliability models).

The performance of the proposed approach is illustrated through a simple synthetic example. The analysis is focused on the assessment of the possible pollution of an underground reservoir of drinking water during the management of flowback fluids after hydraulically fracturing a geologic formation for unconventional gas development. Two scenarios are considered in the analysis: (1) groundwater pollution caused by a spill outside of the site related to a volume of flowback fluid being transported from the well site to a disposal site; (2) groundwater pollution caused by a surface spill within the site related to the failure of a storage unit (e.g. a tank) containing the flowback fluids (for details see Garcia-Aristizabal et al., 2018).
The full BT structures defined for the scenarios analysed in this case study can be assessed combining the path probabilities and the expected consequences. The results of the MHR analysis for this case study are summarised in the risk matrix shown in Fig. 2. In this way, different risk pathway scenarios can be compared quantitatively; the bars in Fig. 2 indicate the uncertainties in the results and are defined considering the 5th and the 95th percentiles of the solutions. Considering the solutions obtained for this synthetic example, larger uncertainties are obtained in the risk estimates for the scenario involving transport accidents respect to the uncertainties in the risk estimates associated with storage failures.

3 Software tool development: MERGER. The functionalities of the methodology proposed by Garcia-Aristizabal et al (2018) for quantitative MHR assessments using a BT structure have been implemented in an open source computational tool denominated Simulator for Multi-hazard risk assessment in ExploRation/exploitation of GEoResources (MERGER). Furthermore, in the framework of the European project EPOS-IP (European Plate Observing System, Implementation Phase), a web-based tool that integrates all the functionalities of MERGER is at the moment under implementation as an online application running in the environment of the IS-EPOS platform (https://tcs.ah-epos.eu/).

The IS-EPOS Platform, which constitutes the Anthropogenic Hazards thematic core service (TCS-AH) of EPOS-IP, is a web portal created to facilitate analyses of anthropogenic seismicity, related hazards, and for assessing potential environmental impacts of geo-resources.
development. This platform provides a collection of data sets of time-correlated geophysical, technological and other relevant geo-data organised in so-called Episodes, which relate anthropogenic seismicity to its industrial cause. For details regarding the IS-EPOS platform see the quick start guide (IS-EPOS, 2018).

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References


