The KINDRA project: a tool for sharing Europe's groundwater research and knowledge

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Hydrogeology-related research activities cover a wide spectrum of research areas at EU and national levels. The KINDRA project (Knowledge Inventory for hydrogeology research, Grant Agreement No. 642047) seeks to create a critical mass for scientific knowledge exchange of hydrogeological research, to ensure wide applicability of research results - including support for innovation and development - and to reduce unnecessary duplication of efforts. A new terminology and classification methodology for groundwater R&D results and activities (Hydrogeological Research Classification System: HRC-SYS) has been developed based on a hierarchical structure using keywords derived from EU directives and scientific journals. This classification allows the population of a European Inventory of Groundwater Research (EIGR) of research results, activities, projects, and programmes to be used to identify critical research challenges and gaps, for better implementation of the Water Framework Directive.

Les activités de recherche en Hydrogéologie couvrent un large éventail de domaines tant au niveau européen que national. Le Projet KINDRA (Knowledge Inventory for hydrogeology research, Grant Agreement No. 642047) vise à créer une "masse critique" pour déclencher un processus d'échange des connaissances scientifiques au niveau de la recherche en Hydrogéologie, pour garantir l'application la plus large des résultats de la recherche – incluant un soutien à l'innovation et au développement, en limitant les efforts consacrés aux activités redondantes. Une nouvelle méthodologie pour les eaux souterraines, concernant la terminologie et la classification des résultats et activités de R&D (Système de Classification en recherche hydrogéologique : HRC – SYS) s'est développée, basée sur une structure hiérarchique utilisant les mots clefs dérivés des directives EU et des revues scientifiques. Cette classification permet à la population d'un Inventaire européen de recherche en eau souterraine (EIGR), d'utiliser les résultats, les activités, projets et programmes de recherche pour identifier les défis et les manques pour une mise en œuvre plus complète dans le cadre de la Directive sur l'Eau.

Las actividades de investigación relacionadas con hidrogeología cubren un amplio espectro de áreas de investigación tanto al nivel europeo como nacional. El proyecto KINDRA (Knowledge Inventory for hydrogeology research, Grant Agreement No. 642047) tiene la intención de crear una masa crítica que permita el intercambio de conocimientos científicos en el área de la investigación hidrogeológica, asegurar la aplicacion de los resultados de investigación por tanto apoyando a la innovación y el desarrollo, y reducir la duplicación innecesaria de esfuerzos. Una nueva terminología y metodología de clasificación para los resultados y actividades dentro de la I+D de las aguas subterráneas (Hydrogeological Research Classification System: HRC-SYS) ha sido desarrollada sobre la base de una estructura jerárquica utilizando palabras claves derivadas de las directivas de la UE y de revistas científicas. Esta clasificación permite rellenar un Inventario Europeo de Investigación sobre las Aguas Subterráneas (EIGR) con los resultados de investigación, actividades, proyectos y programas que se utilizarán para identificar los desafíos y lagunas en la investigación, que permitirá una mejor aplicación de la Directiva Marco del Agua.

Water is a key topic in modern society: not only is it a pivotal human, biological and environmental requirement, it also represents the engine for several research topics which are interconnected, covering the water-food-energy-climate nexus, and it has even a fundamental impact on urban systems. Groundwater is the hidden component of the water cycle, difficult to assess and evaluate, and therefore its importance is difficult to communicate. It plays a fundamental role by sustaining the health of our ecosystems, ourselves and our industrial and agricultural production. Practical and scientific knowledge related to hydrogeology research and innovation is scattered amongst various actors in Europe. With respect to the water cycle, a specific focus on hydrogeology has not been looked into until now, in spite of its utmost importance as a renewable, high-quality, naturally protected (but still vulnerable) resource. In this context, the KINDRA project (EC framework program H2020, Grant Agreement No. 642047) has the aim of creating an inventory of this knowledge base and then using the inventory to identify critical research challenges, in line with the implementation of the Water Framework Directive (WFD) and new innovation areas, within integrated water resources management based on the latest research. This approach will promote the correct management and policy development of groundwater at the EU scale, as recommended also by the Blueprint Document (EC, 2012).

The main goal of the KINDRA project (***www.kindraproject.eu***) is to create a unique knowledge inventory, i.e. a database of groundwater research results, activities, projects and programmes deemed essential

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for the identification of the state-of-the-art, future perspectives and research gaps in the groundwater field. The framework requires (i) the identification of keywords and categories for an effective and useful classification system, and (ii) the definition of a common terminology allowing the recognition of the pertinence of groundwater related topics in the field of general water research. For these reasons, a new terminology and classification methodology on groundwater R&D results and activities (Hydrogeological Research Classification System: HRC-SYS) and a European Inventory of Groundwater Research (EIGR) have been developed as the main outcomes of the KINDRA project. These have a common methodological base for classifying the results according to a harmonised terminology and give the possibility of access to the classification system by different external users. This paper presents a description of the adopted terminology and classification methodology (HRC-SYS), with related hierarchical structure on groundwater R&D results and activities, based on keywords derived from EU directives and the most relevant scientific journals dedicated to groundwater research. This classification constitutes the basis for the implementation of the European Inventory of Groundwater Research, which will contain information from each European country covered by the project partners (in particular EFG Third Parties at the national scale), including research and innovation results and knowledge improvements derived from projects directly or indirectly supported by the EC.

Keyword selection for the Hydrogeological Research Classification System (HRC-SYS)

The adoption of a classification system is necessary and clearly stated as a preliminary step in the KINDRA project, in order to gain a comprehensive understanding of the groundwater theme, by creating an overview of the scientific knowledge covering European countries. Such comprehensive coverage will result in an accurate assessment of the state of the art in hydrogeology research in various geographical and geo-environmental settings, allowing for a direct comparison and exploitation of existing synergies. The first step in identifying research gaps and formulating recommendations for the future is to build a harmonised approach for classifying and reporting European groundwater research efforts.

Keywords are necessary for performing searches using search engines and in creating and populating the inventory: they are the means for defining queries in the EIGR (European Inventory of Groundwater Research). The information and the inventory need to be searchable and comparable at any given time to past and ongoing research activities, to assess the suitability and relevance of policies and research agendas, the groundwater quantitative and chemical status and the implementation of the WFD and GWD and other key directives (the nitrate directive, REF, etc.).

The use of keywords identified in the Water Framework Directive (WFD) and Groundwater Directive (GWD), and the recent Blueprint to Protect Europe's Water Resources (BWR, European Commission, 2012) for the classification of groundwater research (covering the periods 2000-2006 and 2006-2015 for citation analyses) is a factor ensuring that this approach provides information that can be used for the assessment of the directives' importance as research drivers.

This approach also helps evaluate the relevance of groundwater research in relation to the objectives of the WFD/GWD and the societal challenges defined in the EU research programme Horizon 2020, group them by categories and evaluate science-policy feedback within water research, policy and management. Additionally, the integrated perspective of the WFD and GWD provides a good possibility for demonstrating the important links in the water-food-energy nexus among surface and subsurface waters and dependent or associated terrestrial and aquatic ecosystems. Hence, it emphasises the importance of groundwater in the hydrological cycle, not only for drinking water and other legitimate uses but also for sustaining terrestrial and aquatic ecosystems in a changing climate where freshwater availability is under pressure. In this way, about 100 relevant keywords have been identified and extracted from the Water Framework and Groundwater Directives and the Blueprint to protect Europe's Water Resources for the development of the HRC-SYS.

This approach cannot stand alone, however, as it does not cover all relevant groundwater research areas, especially the most recently developed topics. Therefore, it has to be supplemented by the identification of important keywords and topics from the most important scientific journals publishing groundwater research, which can be identified by use of sources such as the Journal Citation Reports. In scientific journals keywords are essential; this is the second most frequently searched field after the title. The main keywords are identified by analysing the data from searches of the most important international peer-reviewed journals dealing with groundwater resources. Clearly, there are many journals dealing with hydrogeology. The most convenient approach is to identify which are the groundwater journals with the highest impact or are the most influential. Based on an international ranking comparison, a list was made of the highest impact factor ("reputation") journals.

After having selected the most relevant scientific journals in the field of hydrogeology, detailed searches were carried out to identify the most frequently used and most relevant keywords in these scientific journals focusing on the volumes throughout the period 2006-2015. For the identification of keywords the list of the most commonly used keywords adopted by the *Hydrogeology Journal* (published by Springer) was considered. Comparing this proposed list with the search results obtained, it turned out that the 80 most relevant keywords from the scientific journals with high impact factor were also present in the keyword list of the *Hydrogeology Journal*. This is a very convincing match and verification of the applied approach. Therefore a keyword list was selected by KINDRA as a reference for relevant keywords from scientific journals, adding new keywords. The two lists, one derived from the EU policy documents, and the second derived from the scientific journals – including remarks from the Joint Panel of Experts of the project – have been merged into a final list that includes about 240 selected keywords, which is expected to be updated as new keywords arise in the research fields dealing with groundwater, for instance as a result of continuous technological development.

The hierarchy of the Hydrogeological Research Classification System (HRC-SYS)

For classifying groundwater research and knowledge, the KINDRA project group has defined the categorisation of all groundwater research according to three main categories: 1) Horizon 2020 societal challenges, 2) Operational Actions and 3) Research Topics (***Figure 1***). Each of these three main categories includes five overarching groups allowing for an easy overview of the main research areas, as described below.

Horizon 2020 defines seven main categories of Societal Challenges (SCs) for which

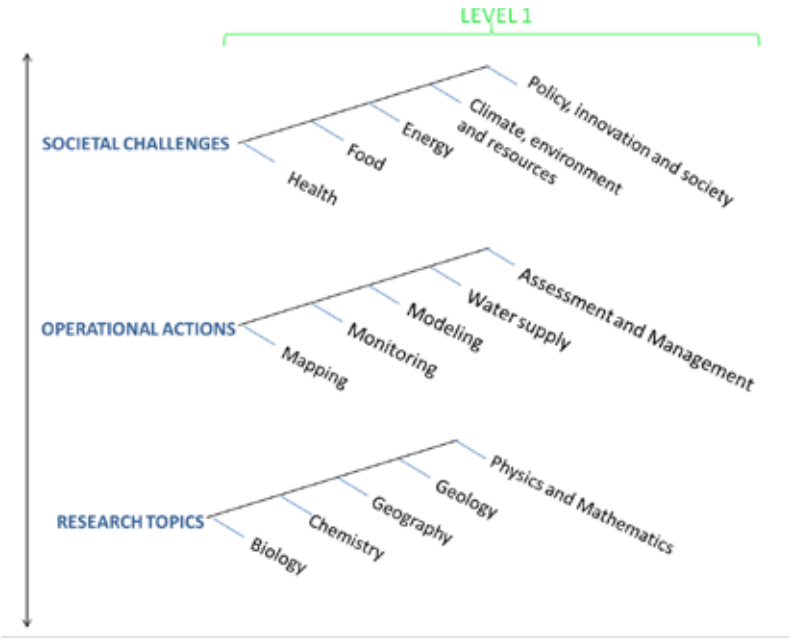

Figure 1: Tree hierarchy diagram.

research programmes for 2014-2020 will be defined and developed according to identified research needs. Groundwater research may be conducted under all of these SCs except for SC4 (Smart, green and integrated transport), which is not relevant. Furthermore, we consider SC6 (Europe in a changing world - inclusive, innovative and reflective societies) and SC7 (Secure societies - protecting freedom and security of Europe and its citizens) similar in scope, as both consider issues related to the development of secure and prosperous societies and EU policies to ensure such a development. Therefore SCs 6 and 7 are grouped into one SC with the title "Policy, Innovation and Society". The resulting final five societal challenges selected as overarching themes for categorisation of groundwater research are therefore: 1. Health; 2. Food; 3. Energy; 4. Climate, environment and resources; 5. Policy, innovation and society.

The five main Operational Actions adopted as overarching actions or activities – intended to include all identified activities in the identified keywords – are based partly on literature searches in the Web of Science, Scopus (SciVal) and Google Scholar, and their results on the number of papers published in each category, and partly based on expert judgment, used to determine how the different Operational Actions are related. The five overarching activities covering all operational actions, taking into account the results of an end-user survey performed during the project, have been identified as: 1. Mapping, 2. Monitoring, 3. Modelling, 4. Water Supply, 5. Assessment & Management.

The research topics constitute by far the largest group of keywords, and it was impossible to identify five of the selected research topics as overarching research topics that include all of the more than 150 identified research topics. Based on the understanding that hydrogeology or groundwater research is a natural science discipline and generally relates to one or more of the other main natural science disciplines, the following five overarching groundwater research topics have been selected: 1. Biology, 2. Chemistry, 3. Geography, 4. Geology, 5. Physics & Mathematics.

The identification of the three main categories (Societal Challenges, Operational Actions and Research Topics) and the subdivision of each of these into five overarching groups give us the tree hierarchy classification shown in ***Figure 1***. The adopted merged list of keywords consisting of about 240 terms has also been organised in a tree hierarchy, where the overarching groups represent Level 1, followed by Levels 2 and 3. Subsequently, items from the complete merged list of keywords have been distributed under pertinent categories.

The classification system previews the interaction among the three main categories through a 3D approach, where along each axis the five overarching groups are indicated. Societal Challenges (SC) as put forward by the EC policy priorities of the Europe 2020 strategy are represented by the vertical (z) axis in ***Figure 2***, while Operational Actions (OA), which are instrumental

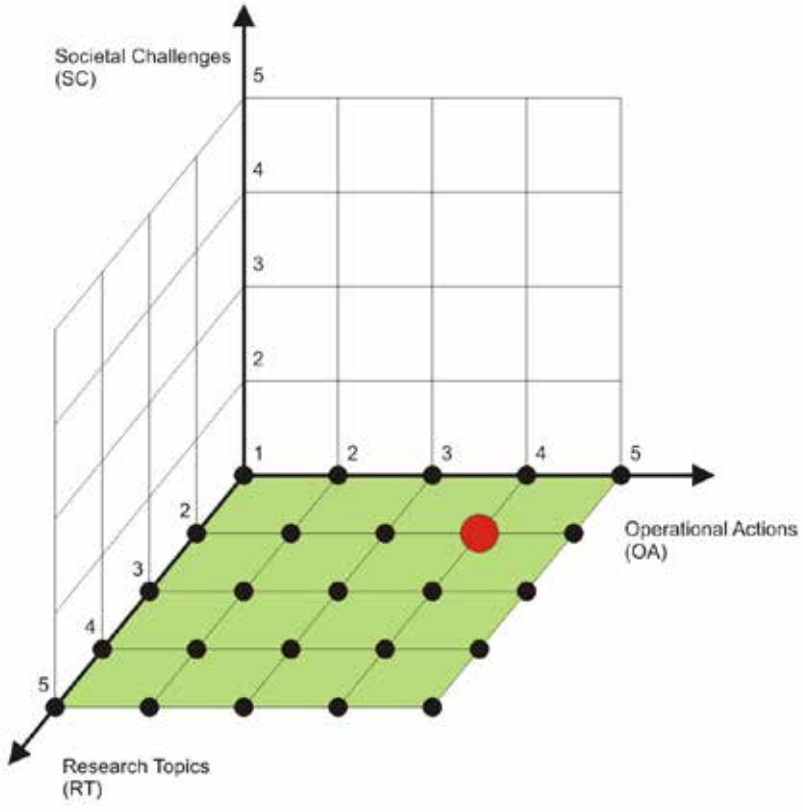

Figure 2: Two- and three-dimensional representation of the HRC- SYS. The 2D level corresponding to SC1 Health is shown in green. The red dot shows the intersection of OA4 (Water supply) with RT2 (Chemistry).

actions required for implementing groundwater related activities (e.g. implementation of the Water Framework directive and the development of river basin management plans) correspond to one of the horizontal axes (x). Finally, Research Topics (RT) – identified from (a) the EC policy document, Water Framework Directive and its daughter the Groundwater Directive, and (b) the scientific literature – are represented by the other horizontal axis (y).

This also results in a 2D representation for each of the Societal Challenges, where Operational Actions and Research Topics intersect in a 5x5 matrix. The 2D structure of each one of the five Societal Challenges allows for a 2D analysis and report of the relationships between the three main categories. Taking for instance ***Figure 2***, let us consider one of the five selected 'Societal Challenges", say, Health (SC1); it is then possible to identify all possible intersections for 'Operational Actions' and 'Research Topics' within this layer. Each sub-category on Research Topics and Operational Actions for the same Societal Challenge SC1 Health can be represented and analysed at a more detailed level. At this point it becomes easier, as well as friendlier to the end user, to use two-dimensional representations, i.e. tables, to study intersections on different levels (1, 2 & 3). An example of this detailed 2D representation is shown in ***Figure 3***.

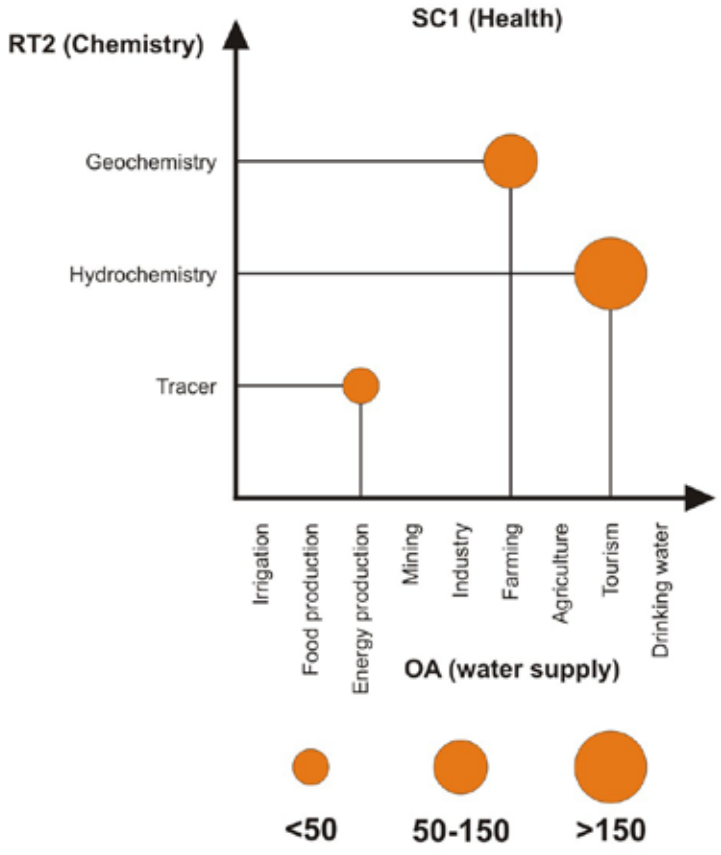

Figure 3: Two-dimensional representation of the HRC- SYS for SC1-Health: example related to the intersection between Research Topic 2 (Chemistry) with Operational Actions 4 (Water Supply) (see Figure 2). Circle size represents number of publications for each of the third-level intersections.

4. Conclusions

In order to develop the common terminology on which to base the EIGR through the HRC-SYS, a merged list of keywords characterising research on groundwater has been selected. Through this list, the KINDRA project group defined the categorisation of all groundwater research according to three main categories: 1) Societal Challenges, 2) Operational Actions and 3) Research Topics. Each of these three main categories includes five overarching groups, allowing for an easy overview of the main research areas. The classification system previews the interaction among the three main categories through a 3D approach, where along each axis the five overarching groups are indicated. This also results in a 2D representation for each of the Societal Challenges, where Operational Actions and Research Topics intersect in a 5x5 matrix. The 2D structure of each of the 5 Societal Challenges allows for a 2D analysis and report of the relationships between the three main categories. In detail, for each vertical layer (Societal Challenges), a first-order table is built intersecting the five Operational Actions with the five Research Topics. Each of these intersections, also at lower levels (2, 3 and 4), facilitates summarising the state of the art of the corresponding groundwater research and knowledge. This HRC-SYS classification system will be implemented and tested in the following steps of the project, when developing the EIGR tool.

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