DOI: 10.7343/as-2018-324

The KINDRA project: sharing and evaluating groundwater research and knowledge in Europe

Il progetto KINDRA: condivisione e valutazione delle ricerche e delle conoscenze idrogeologiche in Europa

Petitta M., Bodo B., Cseko A., Del Bon A., Fernandez I., García Alibrandi C.M., Garcia Padilla M., Hartai E., Hinsby K., Muller P., Mikita V., Szucs P., van der Keur P.

Riassunto: Le ricerche e la conoscenza sulle acque sotterranee nell'Unione Europea sono spesso frammentate e non standardizzate, in quanto facenti capo a soggetti diversi anche da stato a stato. Il progetto Horizon2020 KINDRA ha condotto una valutazione in tutta Europa di tutta la conoscenza sia pratica che scientifica relativa alle acque sotterranee, basandosi su un nuovo sistema di classificazione idrogeologica, che identifica oltre 280 parole chiave, attribuite a tre categorie principali (denominate Azioni Operative, Tematiche di Ricerca e Sfide Sociali), la cui intersezione attraverso un diagramma in tre dimensioni offre la possibilità di ulteriori analisi. La classificazione è funzionale ad un servizio web, l'Inventario Europeo della Ricerca sulle Acque Sotterranee, che è da intendersi non soltanto come un catalogo delle conoscenze ma anche come uno strumento di supporto per l'identificazione delle tematiche di ricerca più rilevanti, delle sue tendenze attuali e delle sfide più critiche della ricerca. Le informazioni sono state inserite nel database durante il progetto da 20 esperti nazionali facenti capo alle rispettive associazioni nazionali di geologi, sotto l'egida della Federazione Europea dei Geologi. Il numero totale di metadati inclusi nell'inventario è di circa 2300 alla fine del progetto, e l'analisi dei risultati è considerata utile per produrre sinergie tra ricercatori e professionisti, implementare le normative e ottimizzare la gestione della risorsa idrica sotterranea in Europa. Attraverso alcuni indicatori aggiuntivi, il contenuto del database è stato analizzato verificando l'occorrenza delle diverse parole chiave tematiche, del tipo di documento e del livello di innovazione raggiunto. Utilizzando i tre assi della classificazione, più facilmente comprensibili tramite diagrammi 2D, sono stati evidenziati sia la quantità che le relazioni dei differenti temi principali. Questo articolo riassume le caratteristiche del sistema di classificazione e i metadati inclusi nell'inventario, mostrando la distribuzione delle informazioni raccolte nelle differenti categorie e attributi (parole-chiave) identificati tramite la classificazione.

Keywords: *Groundwater Framework Directive, inventory, European Union, metadata, classification.*

Parole chiave: Direttiva Europea Acque Sotterranee, inventario, Unione Europea, metadati, classificazione.

Marco PETITTA
Andrea DEL BON
Earth Sciences Department, Sapienza University, Rome, Italy
marco.petitta@uniroma1.it

Balazs BODO, Adrienn CSEKO
La Palma Research Center for Future Studies, Santa Cruz de La Palma, Spain

Isabel FERNANDEZ, Peter MULLER
European Federation of Geologists, Rue Jenner 13, 1000 Bruxelles, Belgium

Clint GARCÍA ALIBRANDI, Mercedes GARCIA PADILLA
Agencia de Medio Ambiente y Agua de Andalucia, Sevilla, Spain

Eva HARTAI
European Federation of Geologists, Rue Jenner 13, 1000 Bruxelles, Belgium
Miskolc University, Faculty of Earth Sciences and Engineering, Miskolc,Hungary

Viktoria MIKITA, Peter SZUCS
Miskolc University, Faculty of Earth Sciences and Engineering, Miskolc, Hungary

Klaus HINSBY, Peter VAN DER KEUR
Geological Survey of Denmark and Greenland, Kobenhavn, Denmark

Ricevuto/*Received*: 07 March 2018-Accettato/*Accepted*: 26 March 2018
Pubblicato online /*Published online*: 30 March 2018

Abstract: *Groundwater knowledge and research in the European Union is often scattered and non-standardised, because of different subjects involved and different approaches from Member States. The Horizon2020 project KINDRA has conducted an EU-wide assessment of existing groundwater-related practical and scientific knowledge based on a new Hydrogeological Research Classification System, identifying more than 280 keywords related to three main categories (namely Operational Actions, Research topics and Societal Challenges) to be intersected in a 3D-diagram approach. The classification is supported by a web-service, the European Inventory of Groundwater Research, which acts not only as knowledge repository but also as a tool to help identify relevant research topics, existing research trends and critical research challenges. The records have been uploaded during the project by 20 national experts from National Associations of Geologists, under the umbrella of the European Federation of Geologists. The total number of metadata included in the inventory at the end of the project are about 2300, and the analysis of the results is considered useful for producing synergies, implementing policies and optimising water management in Europe. By the use of additional indicators, the database content has been analysed by occurrence of keywords, type of document, level of innovation. Using the three-axes classification, more easily understandable by 2D diagrams as bubble plots, occurrence and relationship of different topics (main categories) in groundwater research have been highlighted. This article summarizes the activities realized in relation to the common classification system and to the metadata included in the EIGR, showing the distribution of the collected information in different categories and attributes identified by the classification.*

DOI: 10.7343/as-2018-324

Introduction

Water is a key-topic in modern society, representing a topic requiring several interconnections in research and in practical application, as balancing human needs and environmental requirements, governing the water-food-energy-climate nexus, impacting the concepts of circular economy and smart cities, among others. Groundwater is the hidden component of the water cycle, difficult to assess, evaluate and communicate. It plays a fundamental role by sustaining the health of our ecosystems, ourselves and our industrial and agricultural production. Nevertheless, groundwater role is frequently underestimated and practical and scientific knowledge related to hydrogeology research and innovation are scattered amongst various actors in Europe.

In this context, the KINDRA project (EC framework program H2020, Grant Agreement No. 642047) has the aim to help achieve a better understanding of the societal challenge of groundwater by providing an overall view of the scientific knowledge that exists across Europe and classify this in an open repository. This approach will also hopefully better raise the awareness of citizens of science affecting their daily lives and, at the same time, will allow the correct management and policy development of groundwater at EU scale, as recommended also by the Blueprint Document (European Commission, 2012). In fact, it is clear that the project provides a gap and trend analysis of hydrogeological knowledge in Europe, delivering recommendations to the European Commission for a correct implementation of Water Framework Directive (WFD, European Commission 2000) and of the daughter Groundwater Directive (GWD, European Commission 2006). Final results of the gap and trend analysis, which is still on-going, will be the subject of a further paper related to the KINDRA project.

The main product of the just ended KINDRA project is a unique knowledge-inventory, corresponding to a database not only including metadata of research papers, but a larger base of groundwater research results, activities, projects and programmes deemed essential for the identification of the state-of-the-art, future perspectives and research gaps in groundwater field. The activities performed in the project and their relationships are summarized in Fig. 1. The framework requires (i) the identification of keywords and categories for an effective and useful classification, 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 classification system on groundwater R&D results and activities (Hydrogeological Research Classification System: HRC-SYS) and an European Inventory of Groundwater Research EIGR have been developed along the project. The metadata have been collected along the project with the active support of the National Associations of Geologists throughout Europe, under the supervision of the European Federation of Geologist (EFG). Their work has facilitated comparable and consistent data across Europe as well as a scientific and professional peer review of the progress and the objectives of the KINDRA project. This common

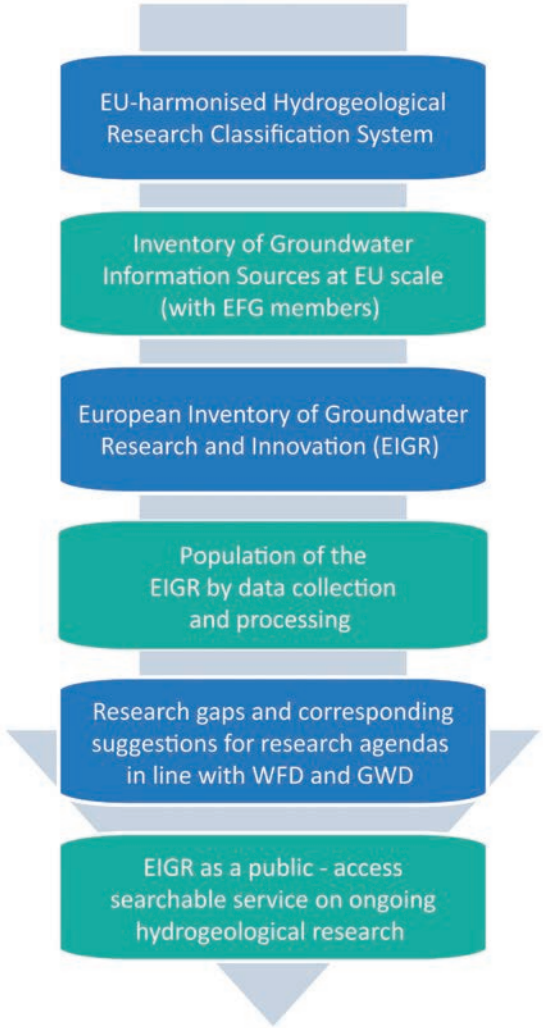

Fig. 1 - The KINDRA methodology line.

Fig. 1 - L'approccio metodologico del progetto Kindra.

effort has enabled networking, mutual recognition, trust and visibility across the hydrogeology communities in European Member States.

The deliverables for sharing scientific knowledge, research projects, articles and data, represent a concrete manifestation of Open Science in practice at European level (Fernandez et al., 2017). The EIGR database is available for use by researchers, policy makers and public at large. The classification of data has been elaborated in a user-friendly way in order to optimise the use of stakeholders. It has been widely accepted and welcomed by the scientific and broader community in hydrogeology. In this sense, KINDRA can be considered as a reference project in implementing Open Science which could be copied by other scientific areas.

To sum up, the created classification and the inventory are considered useful not only for indicating possible future improvements in EU policy, but at this stage the inventory represents a free web-access for searching and for uploading information about groundwater knowledge, to be used not only by groundwater scientists, but mainly by

hydrogeological practitioners, simple water users as citizens, as well as all classes of stakeholders, including water utilities, administrative and technical bodies at national levels, and environmental decision-makers. This paper is addressed to all these categories, hoping to stimulate them to use and implement the KINDRA database, available at http://kindraproject.eu/eigr/.

The harmonized classification system

The KINDRA project proposes a comprehensive approach with a new classification system (Van der Keur et al. 2016) specifically developed for groundwater field, tested and approved by the research community, the professional community in Geology and the wider public at large. It is a multistep venture from a well-defined thematic categorisation to the complete roll-out as an open searchable service.

The adoption of a classification system was necessary and clearly stated as a preliminary step, in order to have a comprehensive understanding on the groundwater theme, which as stated above, has several interdisciplinary and societal intersections. 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 classification starts from the definition of a keyword list, able to comprehend the different topics of groundwater research and at the same time to allow searching options among the database. To build a comprehensive list, the keywords identified in the WFD and GWD, in the recent Blueprint to Protect Europe's Water Resources (European Commission 2012), have been primary selected, reaching about 100 relevant keywords for the KINDRA project. By this way, 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, the Science-Policy feedback, the important links in the water-food-energy nexus, between surface and subsurface waters and dependent or associated terrestrial and aquatic ecosystems have been considered too (European Commission 2016). Hence, all the above mentioned topics emphasize 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.

Supplementary identification of relevant keywords and topics from the most important scientific journals publishing groundwater research has been performed, by detailed searches and comparison among existing keyword lists. Finally, 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 one counting about 240 selected keywords, which have been moderately updated along the project, reaching the final number of 284 keywords considered in the classification system.

To compare and intersect research products in groundwater, the KINDRA project group has defined the categorisation of all groundwater research according to a 3D-approach, identifying three main categories: 1) Horizon 2020 societal challenges (which represents the impact of groundwater in the society) 2) Operational Actions (corresponding with the main activities of hydrogeologists and other groundwater scientists and practitioners) and 3) Research Topics (including the main natural sciences in an interdisciplinary approach). Each of these three main categories includes five overarching groups allowing for an easy overview of the main research areas (Petitta et al. 2015).

The seven Societal Challenges (SCs) identified in the H2020 European programme are related to groundwater research, except for SC 4 (Smart, green and integrated transport), which is not relevant. Furthermore, SC6 (Europe in a changing world - inclusive, innovative and reflective societies) and SC7 (Secure societies - protecting freedom and security of Europe and its citizens) have been grouped into one SC with the title "Policy, Innovation and Society". The resulting final five societal challenges selected as overarching themes 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 activities 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, 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, but considering 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 sub-division of each of these into five overarching groups are shown in Figure 2. The adopted list of keywords 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 3, while Operational Actions (OA), which are instrumental actions required for implementing groundwater related activities correspond to one of the horizontal axes (x).

Finally, interdisciplinary Research Topics (RT) are represented by the other horizontal axis (y). This 3D approach (described by a "cube" as depicted in Fig.3) enables analysis at a more detailed level, by slicing the 3D system in correspondence with each overarching keywords, e.g. representing intersections between OA and RT for each Societal Challenge.

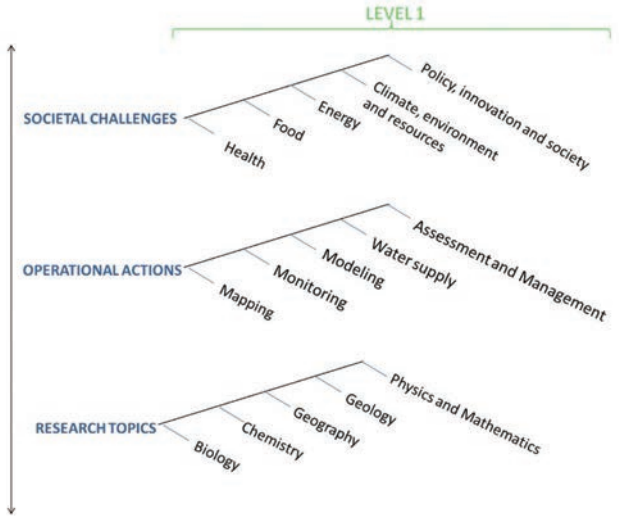

Fig. 2 - Tree hierarchy diagram.

Fig. 2 - La gerarchia ad albero del sistema di classificazione.

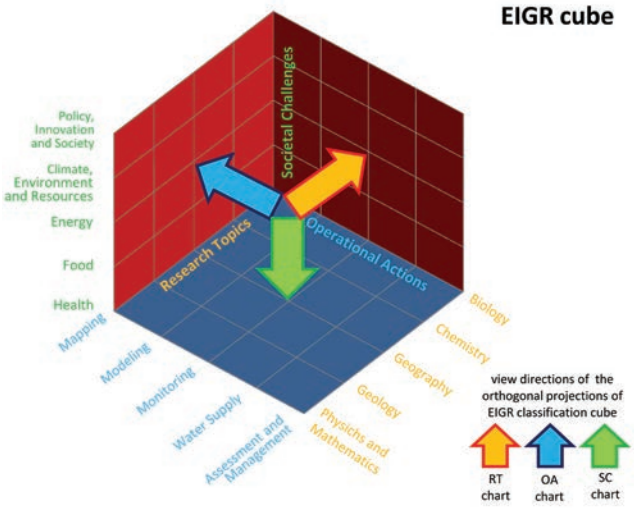

Fig. 3 - Three-dimensional representation of the classification system.

Fig. 3 - Rappresentazione tridimensionale del sistema di classificazione.

The European Inventory on Hydrogeological Research (EIGR)

After definition of the classification system KINDRA European Inventory on Groundwater Research (EIGR), a tool for classifying information sources regarding Research and Knowledge product in Europe has been realized (Garcia Alibrandi et al. 2016). The EIGR contains information sources not only related to scientific papers, but also including reports, maps, databases, etc., scattered around Europe and elsewhere at international and national levels. The EIGR will not contain data itself, but rather metadata, referring and providing links to research that has been performed in Europe since 2000, and at the same time allowing their classification under the uniform proposed KINDRA system. The EIGR is intended to be a permanent resource, publicly available at http://kindraproject.eu/eigr/ as open access searchable tool also after the end of the KINDRA project.

The EIGR can be used in three different ways:

i. for insertion of information pertaining to groundwater research and other available knowledge by Experts;
ii. for consultation also after the project by people and organizations dealing with groundwater research, but also possibly by non-experts;
iii. for analysing collected and stored information to identify trends, challenges and gaps in groundwater research, by the KINDRA partners during the project period and policy makers in the future.

The software applied for installing and setting up the EIGR is Geonetwork (open source, version 2.10.4, http://geonetwork-opensource.org/). Geonetwork is the recommended solution for the KINDRA project as it allows for information to be available, accessible and usable through services implementing relevant INSPIRE catalogue and download services. It serves as a data catalogue that allows for searching, consulting and downloading information which has been collected and stored. It can act as a "distributed catalogue" containing metadata records, where Users and Data Providers can create and modify their own metadata. It allows for the definition of ETL tools (Extract, Transform and Load), provides the capacity for query functions for data evaluation and the production of statistics, diagrams, and it follows ISO standards and guidelines for organizing and structuring information and metadata. It allows for the creation of categories and groups (as the three categories identified in the classification) and of a specific Thesaurus (a list of thematic keywords corresponding to the KINDRA keyword list). The adopted metadata profile is the ISO 19139 multilingual template.

The structure and the content of the EIGR tool have been reviewed, implemented and optimized to adapt the general standard Geonetwork 2.10.4 to the KINDRA requirements, with particular references to the overarching categories and to the KINDRA keyword list. Suggestions made by the National Experts and by the partners have been considered in realizing this current final version of the Inventory. A User Manual has been produced for facilitating searches and insertions of records in the inventory. In fact, users can be distinguished in two groups: simple users, able to search and extract information from the database, and contributors (editors) who, after a registration process, can upload themselves additional records, enlarging the database and actively contributing to the inventory.

There are clear added values in presenting the research in the KINDRA EIGR, namely: a) visibility in the first online

tool exclusively on groundwater research and knowledge; b) contact enhancement among like-minded professionals; c) classification of the research, products, papers and projects; d) exposition of the research to database analysis for EU Policy support and water directive implementation.

Uploading information on the EIGR requires completion of four main sections (Garcia Alibrandi 2017), to be filled in as completely as possible:

– IDENTIFICATION INFORMATION: This section includes all relevant information regarding the publication title, acronym, abstract, authors and their contact details, collaborating organizations and/or programmes, funding sources and amounts, geographical extent covered as well as other relevant details which help identify or provide information regarding the publication (e.g. ISBN, ISSN, etc...) and if there might exist any legal restrictions or limitations to access the information; in this section the KINDRA Keywords and Overarching Categories are defined and indicated
– DISTRIBUTION INFORMATION: This section indicates users the delivery or distribution methods available. It describes if there are any online or physical distribution methods that exist for the publication. Contents distributed online may be downloadable.
– DATA QUALITY INFORMATION: This section provides an overall assessment on the quality of the resources by classifying the work according to Research and Knowledge classes defined by KINDRA, as specified below. Also other indicators as Technology Readiness Levels (TRL) and Policy Readiness Level (PRL) are included in this section.
– METADATA INFORMATION: This final section is dedicated to the overall information concerning the metadata, i.e. about the people/organization who inserted the record related to the research/knowledge product.

The users can access the EIGR by the KINDRA website, landing on home page of the EIGR (Fig. 4). The main field on the screen shows the results of the search by visualizing the records to be selected and analysed. The right side of the screen has the quick access to the map function, for geographical reference searches. It also offers two tabs for selecting the simple search functions or the advanced search functions of the EIGR. Below this section one can find an options menu which offers the possibility to define basic quick search criteria options such as: sorting by relevance, number of hits per page and the type of output (full content of the resource or simply a text version). The advanced search tab opens a menu in which the users can define the search criteria by indicating specific terms, title, abstract, keyword, geographical location (either setting coordinates of the bounding box area or selecting a specific area or region on the map) and even by defining the temporal extent of either the metadata record uploaded to the EIGR or the timestamp of the resource itself. Additional searches can be performed by the list of overarching categories which have been defined by the HRC-SYS.

As stated above, the EIGR allows for the insertion of different information products (papers, technical reports, database, project, maps, guidance, books and proceedings, etc.). A fundamental novelty in KINDRA, respect with other existing scientific databases, is the inclusion of documents different from peer-reviewed papers. In fact, the inventory aims to consider not only the research products, but also the knowledge products, which includes national reports and documents and the grey literature in general.

For this reason, in the process of inserting information in the EIGR, users are guided to classify the uploaded information and distinguish between 'research' and 'knowledge' according to four different classes of "knowledge" and "research" identified by the level of the performed quality assurance the uploaded work has received, as explained in Fig. 5. The

Fig. 4 - Screenshot of the EIGR home page.

Fig. 4 - Schermata della home page dell'inventario EIGR.

"research" classes include not only the papers in peer reviewed journals (class 1) but also conference proceedings and books included in international scientific databases as Web of Science and Scopus. In the "knowledge" group there are Class 3, including reports and information having a review, which act as a Quality Assurance (QA), as reports from national official organizations, and Class 4 which refers to reports, journals, and newsletter with no certain Quality Assurance.

Additional indicators have been adopted in the EIGR for evaluating the research & knowledge products. Firstly, the Technological Readiness Levels (TRL) classification method as an indicator of innovation: TRLs are based on a scale from 1 to 9, with 9 being the most mature technology. The use of TRLs enables consistent, uniform, discussions of technical maturity across different types of technology. For this reason, it has been adopted as an additional standard indicator of quality, supporting comparison with other TRL categories in groundwater science within the scope of KINDRA. A different indicator, separately created for analyzing the KINDRA results is the Policy Readiness Level (PRL), with a scale of four classes, to evaluate the transferability of the research products into policy adoption. The four classes range from 1 (not relevant for policy implementation) to 4 (ready for policy implementation).

Finally, the EIGR includes some quick tools for the exploitation of the information uploaded, available online, as: a) a Keyword cloud be based on the frequency and recurrence of the use of selected keywords of the KINDRA thesaurus; b) a map where the contents of the EIGR are distributed throughout EU countries can be visually identified; c) graphic representations of the EIGR contents according to the classification system by 2D slices of the three main axes; d) an extraction tool, which allows to download the results of a search in CSV file format, for further elaborations.

The content of the inventory and consequent results of the project

During the project, the active support of member National Associations of the European Federation of Geologists, from EU Member States and beyond (namely EFG Linked Third Parties), produced the data collection and assessment in collaboration with the project partners (Fernandez and Bisevac 2017). In total there were 20 countries participating in the KINDRA Inventory population: Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, The Netherlands, Poland, Portugal, Serbia, Slovenia, Spain, Switzerland, UK and Ukraine. The national experts have been trained during a workshop, when the EIGR was tested, and detailed guidelines for populating the EIGR were provided.

Based on the data provided, the EIGR has been populated in the form of a web-service, with a total of more than 2300 records, most of them completely public available (2200 records).

The National Experts used different sources on regional, national and international level to collect the relevant information for their EIGR entries. The most important sources were the national databases, reports and journals, responsible governmental bodies, universities and national geological surveys (Hartai 2016). The data type/resource category are dominated by "National and local reports containing facts and data" with the 47.9% of the metadata. The "Position papers and/or important papers in peer reviewed journals" data type reached 26% of the records. The remaining 26.1% distributed between the "National databases" (2.9%), "Hydrogeological maps" (4%), "Technical reports, guidelines, manuals, etc." (2.9%), "Books and book chapters (6.4%)" and "Other" (9.9%) topics.

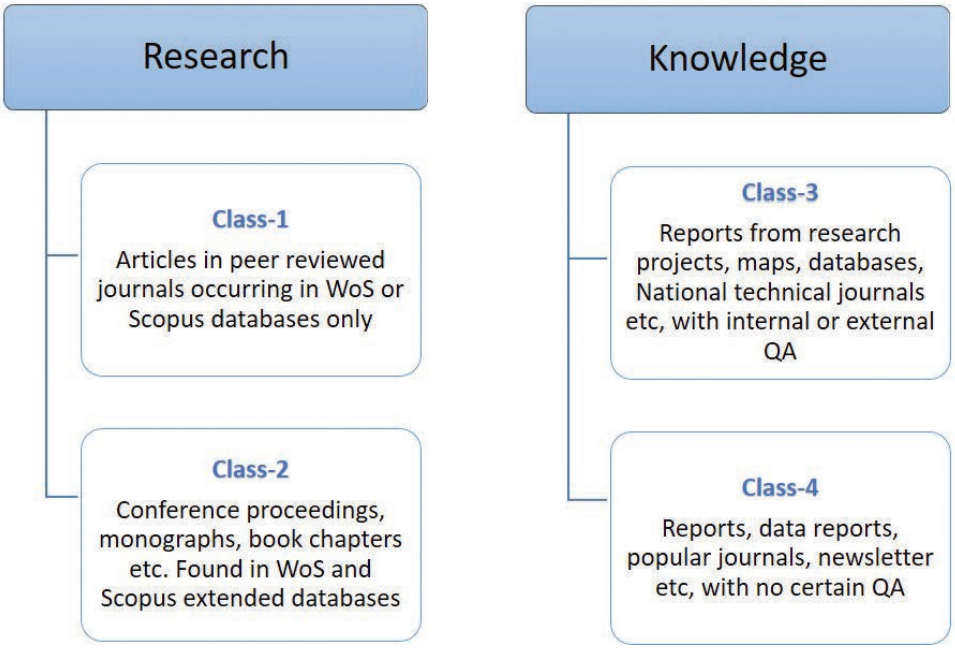

Fig. 5 - Definition of research and knowledge classes 1 to 4.

Fig. 5 - Definizione delle classi di ricerca (1-2) e di conoscenza (3-4).

DOI: 10.7343/as-2018-324

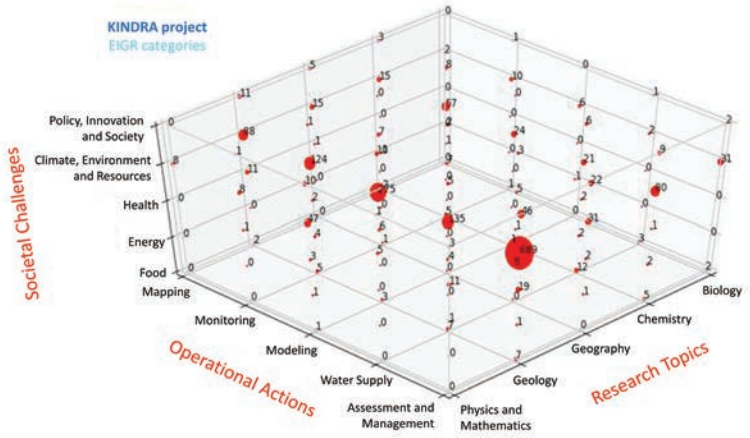

Fig. 6 - The EIGR content described by the 125 intersections along the 3D classification, showing the occurrence (red dots) of the records among the three main categories.

Fig. 6 - Il contenuto dell'inventario EIGR descritto dalle 125 intersezioni nel sistema di classificazione tridimensionale, che mostra il numero dei record (punti rossi) per l'insieme delle tre categorie principali.

The records included in the EIGR database can be summarized selecting the main categories of the classification system. A 3D visualization (Fig. 6) shows a distribution scattered among the 125 intersections resuming the five OA, the five RT and the five SC. Some positions in the 3D classification system are still empty, partially for not relevant intersections (topics which are not related between them) and sometimes for absence of uploaded records, which testifies the need to enlarge the record number also after the end of the project.

Easiest 2D visualizations for each category help in analysing the EIGR content. Bubble plots of each of the 15 overarching categories have been realized, in addition to three main plots related to the total of each main category (e.g.: OA vs RT for the whole SCs, Fig. 7). This type of plots illustrates in a visible manner how the societal challenges and operational actions correlate in the inventory. If the geographic areas, local, regional or national data are added, then a comparative analysis is facilitated. It becomes possible to detect which knowledge areas need additional efforts and which knowledge area is already available. When a temporal dimension is considered too, it is also possible to visualise trends and changes over time.

Looking at the 2D plot between OA and RT (Fig. 7), the RT Geology is clearly prevailing (up to 75%) of records, testifying that the majority of information available on the inventory are related to hydrogeology. Clearly minor occurrences have the other disciplines, which are frequently linked to specific Operational Actions, as happen for Chemistry and Monitoring, Physics & Mathematics and Modelling, Geography and Assessment & Management.

Among Societal Challenges (Fig. 8), the most frequent overarching category represented in the EIGR is "Climate, Environment and Resources", with 87%, obviously strictly related to groundwater topic; it is followed by SC "Policy, Innovation and Society", confirming the societal impact of groundwater and its close relationship with climate and environmental topics, which are daily correlated with the challenges of citizens, households, industry and cities. SC Energy, Food and Health are less represented, underlining the need to additionally develop research and knowledge in these fields. Looking at the Operational Actions, in the EIGR the "Assessment and Management" covers about 53% of the records, while the remaining metadata are distributed among the other four overarching OA. This fact remarks that hydrogeologists are mainly asked to provide management solutions for groundwater use and preservation.

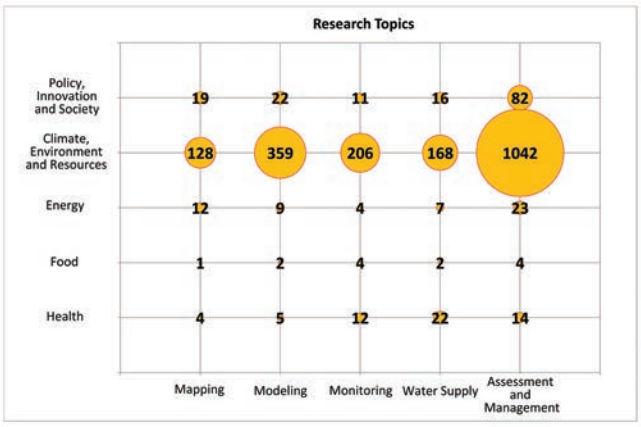

Fig. 7 - The 2D diagram (bubble plot) showing occurrences in EIGR by Research Topics and Operational Actions, for the whole field of Societal Challenges.

Fig. 7 - Diagramma 2D del numero di record nell'inventario EIGR per i Research Topics e le Operational Actions, rispetto al campo complessivo delle Societal Challenges.

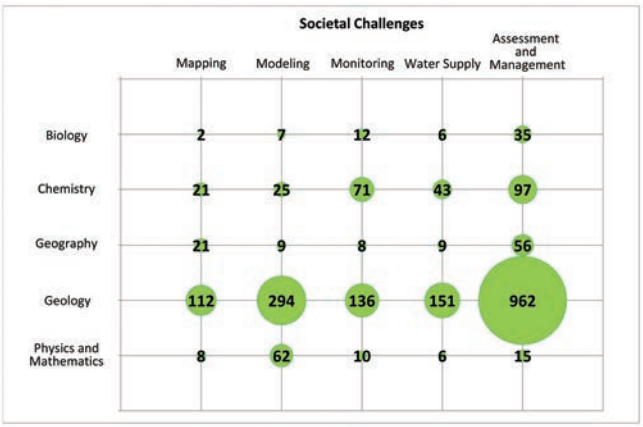

Fig. 8 - The 2D diagram (bubble plot) showing occurrences in EIGR by Societal Challenges and Operational Actions, for the whole field of Research Topics.

Fig. 8 - Diagramma 2D del numero di record nell'inventario EIGR per le Societal Challenges e le Operational Actions, rispetto al campo complessivo dei Research Topics.

The distribution in research & knowledge classes (Fig. 9) highlights as universities and research institutes were ranked as Class 1 or Class 2, while the information gathered from the regional authorities usually valued as Class 3 and Class 4. In total, 45.6 % of the metadata are related to Class 4. The number of peer-reviewed articles in scientific journals (Class 1) and the number of reports from research projects and publications in national technical journals (Class 3) has a similar occurrence, 23% and 24.2% respectively. The Class 2 has the lowest number of EIGR records inserted by LTPs, only 7.2%. The reason for that, is that the LTPs focus on publications and data sources which are not already available through the well-known and most appreciated research databases (i.e. Web of Science and Scopus).

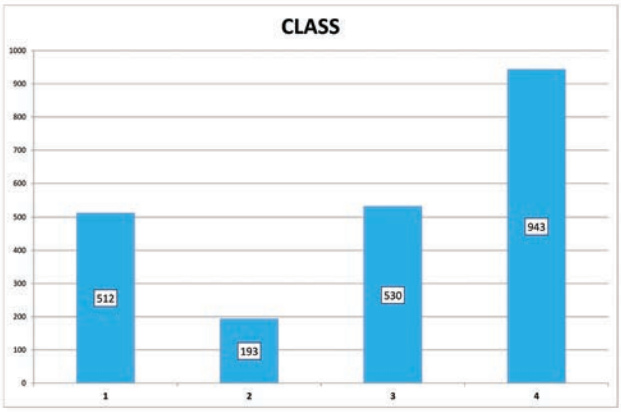

Fig. 9 - The distribution of the EIGR records among the four classes of Research & Knowledge (see fig. 4 for their definition).

Fig. 9 - Distribuzione dei record dell'inventario EIGR nelle 4 classi di ricerca e conoscenza (definizione in Fig.4).

The analysis of the adopted additional indicators (Fig. 10) clearly evidences the limited maturity from the technological point of view of the inserted records. TRL classes in the database are concentrated in the 1-4 TRL group, while only 12% can be attributed to mature technological levels; in several cases (27%) the metadata are not clearly connected with TRL classification. For PRL indicator, a similar trend can be inferred, with a large majority of records not well developed for policy application, and only 16% showing useful information to be adopted by a policy approach.

Beside the content analyses above summarised, EIGR records have been subjected to more detailed evaluation, conducted on keywords distribution among the main categories, occurrence of national contribution, even including distribution with time of the records. Detailed results of this final analysis, aimed at identifying gaps and trends in groundwater research and knowledge, are out of the scope of this paper. In order to demonstrate the potential applicability of the approach followed, two maps related to the co-occurrence and connection between the keywords used in the KINDRA EIGR are enclosed. Elaborations have been performed with the open source VOS viewer tool (Van Eck and Waltman 2017), as summarized in Fig. 11, showing the density map of the keywords used in the entire KINDRA database, and in Fig. 12, where the network map related to SC "Climate, Environment and Resources" is shown. The density map contains the keywords describing the 2178 metadata available in the EIGR, illustrating their occurrence and their relative relationships. The network map shows direct links between keywords and by the bubble size their occurrence.

Conclusions

The KINDRA project aims to achieve a large societal impact, given the extensive use of groundwater for our households, industry and cities. At the same time, it is expected to have significant impacts also on the hydrogeologist community, promoting its networking, its visibility and mainly the transferability of its researches in useful applications, and for policy and governance improvements. Because it considers not only scientific papers, but more generally the entire knowledge in groundwater topic (including national reports, maps, projects, etc.), it offers significant added value with respect to other scientific literature databases.

The proposed classification system tentatively includes the most used keywords in groundwater topic, selecting about 250 of them, by a hierarchical approach which deals with a 3D classification scheme where the three main axes are represented by the typical activities of hydrogeologists (Operational Actions), by the natural science disciplines (Research Topics) and finally, along the Z-vertical axis, by the Societal Challenges identified by the European

Fig. 10 - Occurrence in the EIGR of TRL, Technology Readiness Level (left) and PRL, Policy Readiness Level (right) indicators grouped in main classes.

Fig. 10 - Distribuzione dei record dell'inventario EIGR per i due indicatori TRL (Technological Readiness Levels, a sinistra) e PRL (Policy Readiness Level, a destra), raggruppati nelle classi principali

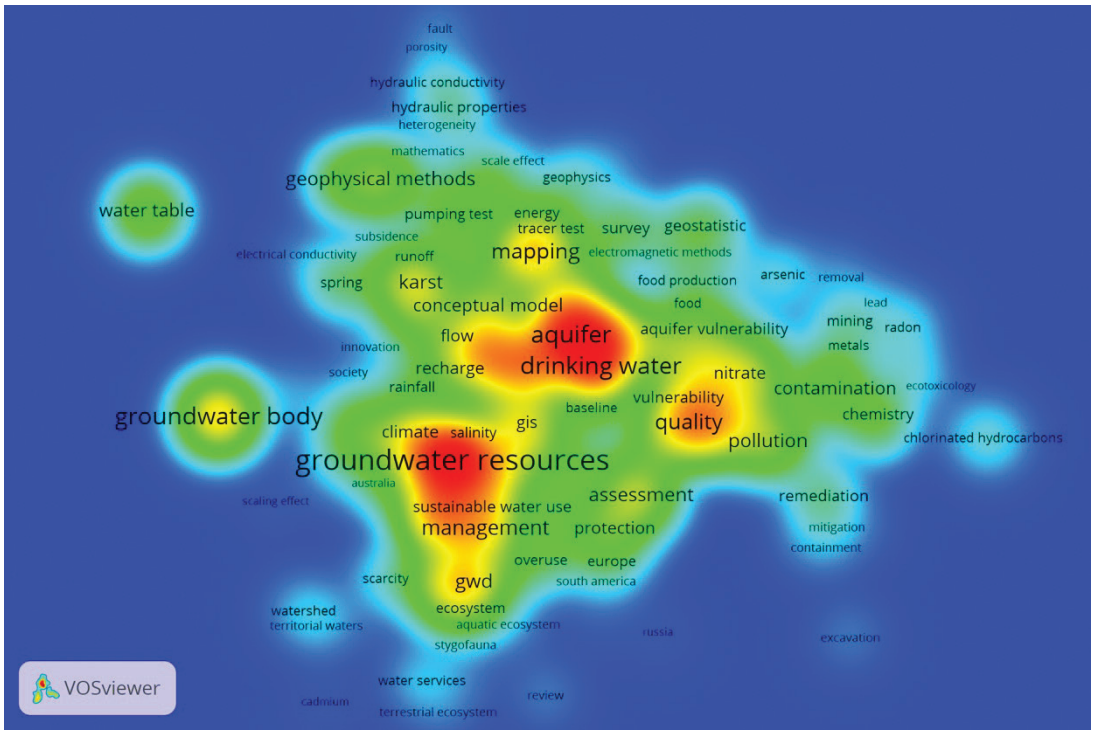

Fig. 11 - Density map of the keywords of the KINDRA thesaurus in the EIGR. Colour scale from red to blue indicates occurrence of each keywords, corresponding with the text dimension. The proximity among keywords indicates their relationships in terms of co-occurrence in describing each record.

Fig. 11 - Mappa di densità delle parole chiave del thesaurus KINDRA per l'inventario EIGR. La scala di colori da rosso a blu indica la frequenza di ciascuna parola chiave, corrispondente alla dimensione del testo. La vicinanza tra le parole chiave indica la loro relazione in termini di presenza concomitante nella descrizione di ogni singolo record.

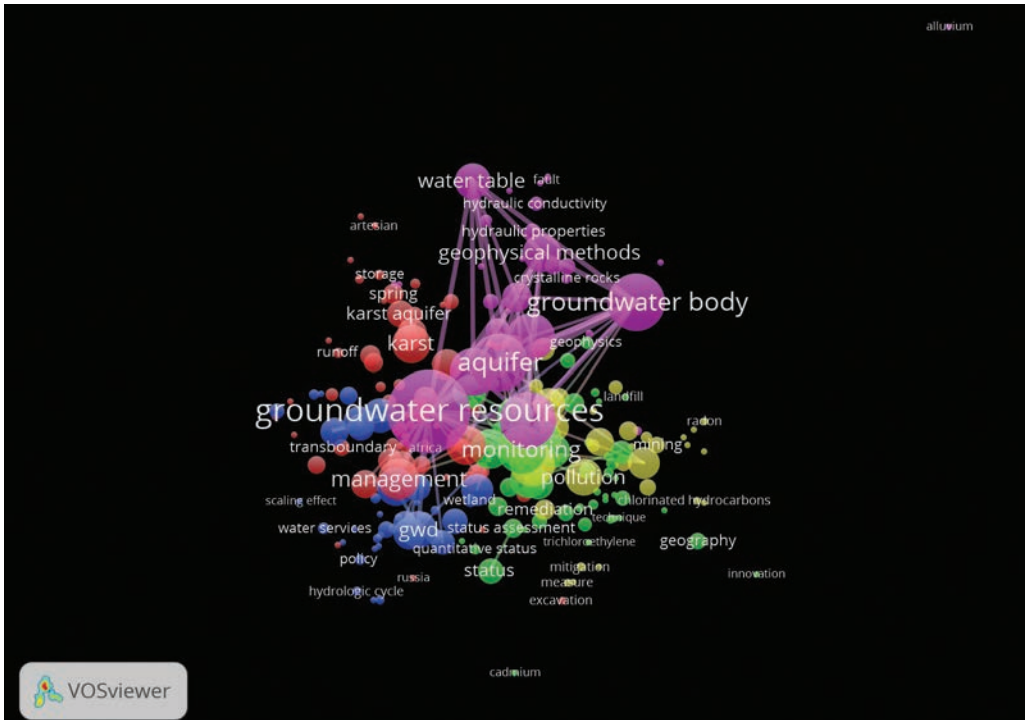

Fig. 12 - Cluster map of the keywords of the KINDRA thesaurus in the EIGR, related to Societal Challenge 4 "Climate, Environment and Resources". The size of the bubbles is related to keyword occurrence, their proximity and links express co-occurrence of keywords in the records. Different colours identify clusters to be intended as families of the same keywords due to their co-occurrence among records.

Fig. 12 - Mappa dei gruppi (cluster) delle parole chiave del thesaurus KINDRA per l'inventario EIGR, relativa alla Societal Challenges 4 (Climate, Environment and Resources). La dimensione dei cerchi è proporzionale alla frequenza di ciascuna parola chiave, mentre la loro vicinanza e le linee di collegamento esprimono la loro relazione in termini di presenza concomitante nella descrizione di ogni singolo record. I diversi colori identificano gruppi di parole chiave tra loro parenti in termini di concomitante presenza nei record.

Commission in the Horizon2020 research programme. This new classification system provides immediately how to locate a research or an activity in the KINDRA three-dimensional approach, highlighting its relevance with respect to society and daily life of European Citizens.

Beside the classification, the insertion of metadata in the inventory EIGR gives the possibility not only to inform about knowledge progresses the scientific and practitioner community working on hydrogeology and more generally on groundwater, but by analysing the content of the inventory (2200 records available at the end of the KINDRA project), useful information can be extracted for improving the research activities, enhancing those having direct correlations with societal challenges. At the same time, the possibility to analyse the content by several indicators, including the 15 identified overarching keywords dealing with the three main categories, will probably improve the future policy at national and European level.

To sum up, the EIGR is a powerful bi-directional tool for groundwater science and knowledge, which from one side is able to deliver useful information to the users and policy-makers for addressing modern challenges, both from the technical and societal point of view. By another side, the content of the inventory, to be continuously updated by uploading new information also in the future, is representing a repository where scientists and practitioners can look and extract the state-of-the-art, the gaps and the trends in every discipline related to groundwater. By this way, the aim of the project to make groundwater visible, accessible and treasured can be considered completely achieved.

Acknowledgment: The KINDRA project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642047 (call WATER-4a-2014 - Coordination and Support Action). The partner team of the project includes Sapienza University of Rome (coordinator), European Federation of Geologists, Geological Survey of Denmark and Greenland, University of Miskolc, La Palma Research Centre for Future Studies and the Agencia de Medio Ambiente y Agua de Andalucia. The Authors would thanks the anonymous reviewers for their useful suggestions.

REFERENCES

European Commission 2000. Directive 2000/60/EC (Water Framework Directive) of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. OJ L 327, 22.12.2000, pp 1- 51.

European Commission 2006. Directive 2006/118/EC (Groundwater Directive) of the European Parliament and of the Council, Official Journal of the European Union L 372/19.

European Commission 2012. Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions – A Blueprint to Safeguard Europe's Water Resources, COM(2012) 673, SWD (2012) 381-382.

European Commission 2015. Technical Report on Groundwater Associated Aquatic Ecosystems. Technical Report no. 9, Directorate-General for the Environment, Unit C1-Water, B-1049 Brussels, 49 pp.

Fernandez I, Bisevac V (2017). KINDRA Deliverable 2.3 - Country Reports, http://kindraproject.eu/wp-content/uploads/KINDRAD2_3_FINAL-_web_.pdf - last access 23/03/2018

Fernandez I, Petitta, M, Hinsby K, Cseko A, Szucs P, Garcia Padilla M, Hartai E, Biševac V, Stein A, Bodo B, van der Keur P, Mikita V, Van Leijen G and García Alibrandi C. (2017) The KINDRA project – towards Open Science in Hydrogeology for higher impact. European Geologist 44, 38-43

Garcia Alibrandi C, García Padilla M, Fernández I, Hinsby K, Mikita V, Petitta M, Szűcs P, van der Keur P (2016) KINDRA Deliverable 1.3 – EIGR Guidance Document. Available from: http://kindraproject.eu/wp-content/uploads/D1-3-WEB-1.pdf, 49 pages - last access 23/03/2018

Garcia Alibrandi C (2017) KINDRA Deliverable 1.6 – European Inventory of Groundwater Research. Available from: http://kindraproject.eu/wp-content/uploads/D1-6-WEB-revised-1.pdf , 66 pages - last access 23/03/2018

Hartai E (2016) KINDRA Deliverable 1.4 - Inventory of Information Sources. Available from: http://kindraproject.eu/wp-content/uploads/D1-4-WEB-1.pdf, 39 pages - last access 23/03/2018

Petitta M, Bodo B, Caschetto M, Colombani N, Correia V, Csekő A, Di Cairano M, Fernández I, Garcia Alibrandi C, Hartai E, Hinsby K, Madarász T, Mikita V, García Padilla M, Szűcs P, van der Keur P (2015). The KINDRA project: a tool for sharing Europe's groundwater research and knowledge. European Geologist 40, 5-8.

Van der Keur P, Caschetto M, Hinsby K, Di Cairano M, Mikita V, Petitta M, Szűcs P (2016) The new EU-harmonised Hydrogeological Research Classification system, KINDRA. Deliverable 1.2. - HRC-SYS. Available from: http://kindraproject.eu/wp-content/uploads/D1-2_versionrevisedFINAL-WEB.pdf, 47 pages - last access 23/03/2018

Van Eck Nees J, Waltman L (2017) VOSviewer Manual 1.6.6. Available from: www.vosviewer.com/download/f-y2z2.pdf - last access 23/03/2018