KINDRA D3.4

Recommendations for groundwater research and the European Inventory of Groundwater Research in relation to EU water and research policies

Summary

This document, Deliverable D3.4, presents recommendations for groundwater research and knowledge based on the gaps and trends analysis conducted in deliverable D3.3 and bibliometric analyses of research and knowledge resources in the European Inventory of Groundwater Research (EIGR), Scopus and Web of Science. The research resources are organised by a research classification system (HRC-SYS) developed in the project based on EU research policies as expressed by the grand societal challenges of the Horizon 2020 programme.

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1 Introduction

Groundwater is the largest and most widely used resource for drinking water supply, globally, and is an important part of the hydrological cycle sustaining life on earth. The general understanding of the importance of groundwater is often low, even within related natural science disciplines partly because it is hidden below ground and the interactions with surface water is difficult to quantify.

The mission of KINDRA was to make groundwater visible by demonstrating its transdisciplinarity and importance to all the grand societal challenges of Horizon 2020 and EU water policies. The importance of groundwater is made visible by analysing groundwater research and knowledge available in the European Inventory of Groundwater Research (EIGR) developed in KINDRA (D1.3) and professional research databases and analytical tools, such as Scopus / SciVal[1], Web of Science[2] and VOSViewer[3].

Applied and scientific knowledge related to groundwater and hydrogeology research and innovation are scattered amongst various stakeholders in Europe. The overall objective of KINDRA was to develop an inventory and single access point to this knowledge-base (EIGR) primarily by adding grey literature, i.e., non-peer-reviewed documents as supplements to professional research databases of peer-reviewed scientific publications. This goal has been served also to identify existing and missing research and knowledge supporting the implementation of the Water Framework and Groundwater Directives.

The quality and quantity of groundwater have important implications for human health and wellbeing, as well as the status of dependent and associated terrestrial and aquatic ecosystems. Globally (Foster and Chilton, 2003, Steffen et al., 2015) groundwater is an important part of the Water – Food – Energy NEXUS (Bazilian et al., 2011). Generally, the "Value of Water" is immense and continuous research and development is of crucial importance to all societies (WssTP, 2016, 2018) especially in a world with increasing pressures on (ground)water resources and biodiversity (Foster and Chilton, 2003; Taylor et al., 2012; Steffen et al., 2015).

The year 2017 was one of the warmest and so far, most devastating and costly year ever recorded, globally, because of many extreme events including flooding and droughts according to the WMO[4]. Hence, groundwater flooding with respect to compliance to the EU Floods directive has gained considerable interest in recent years (e.g., Cobby et al., 2009), also in the urban environment (e.g., Macdonald et al., 2012).

Europe's contributions to mitigation and adaptation of climate change impacts at European and global scale are strongly needed, e.g., through development of science-based strategies to meet the UN sustainable development goals under global and climate change. Groundwater and the subsurface in general play a significant role herein and need further attention.

In the following, we summarise recommendations for further development of the European Inventory of Groundwater Research and new research for all the Societal Challenges in Horizon 2020

[1] https://www.elsevier.com/solutions/scopus
[2] https://clarivate.com/products/web-of-science/
[3] http://www.vosviewer.com/
[4] http://www.un.org/sustainabledevelopment/blog/2017/11/wmo-statement-on-state-of-climate-in-2017/

(named also Grand Societal Challenges), indicating and anticipating some possibilities for a mission-oriented approach (European Commission, 2018; Mazzucato, 2018) for groundwater research.

2 Recommendations

Currently, groundwater research in the EU performs very well compared to the rest of the world. EU28 produces more groundwater research than any other region in the world. While groundwater research stagnated in the United States of America (USA) around 2007, it has steadily increased in Europe, China and India since about 2000 (D3.3, 2018). From around 2007 the annual scholarly output related to groundwater research has been the highest in Europe. The increase in the annual number of publications is, however, higher in Asia when combined (mainly China and India). The combined scholarly output of China and India exceeded the output of the USA around 2010, and it will exceed the output of EU28 within the next couple of years if the current trends continue.

To keep Europe's leading role within water science and technology we, therefore, recommend and support the EU open science cloud initiative (EOSC, 2017), and to keep water research as an important part of European research by defining relevant water research missions for a new mission-oriented EU research policy (European Commission, 2018; Mazzucato, 2018) in line with the Sustainable Development Goals of the United Nations[5].

In the following, we list additional recommendations related to 1) the European Inventory of Groundwater Research (EIGR) as developed in KINDRA and 2) the seven Grand Societal Challenges of Horizon 2020.

Recommendations for future development and functionalities of the European Inventory of Groundwater Research (EIGR)

The final conference of the KINDRA project, held in Brussels on the 27th of February 2018, confirmed the need for a European Inventory of Groundwater Research (EIGR) providing easy access to metadata on European groundwater research and knowledge by making data **F**indable, **A**ccessible, **I**nteroperable and **R**eusable according to the "FAIR" principles adopted by Horizon 2020 (European Commission, 2016; Wilkinson et al., 2016). Presentations from the conference from KINDRA project partners and relevant stakeholders, such as the European Commission, Working Group Groundwater within the Common Implementation Strategy of the Water Framework Directive, UNESCO (IGRAC and IHP), the International Association of Hydrogeologists (IAH), water supply companies, the EuroGeoSurveys, related projects and municipalities are available at the project website: http://kindraproject.eu/final-conference/ (D3.2, 2018).

The performed analysis of the records inserted during the project in the EIGR has demonstrated the advantages and the potential of the inventory and has led to recommendations for improvement and further development of the groundwater research and knowledge repository covering all relevant

[5] https://sustainabledevelopment.un.org/?menu=1300

research disciplines. The EIGR database includes additional data and has significant advantages, benefits and added value compared to existing research databases, such as Scopus, Web of Science and Google Scholar, including:

- Easy access to metadata on research projects, reports, databases and maps without formalised peer review, produced at international and national scales, not easily available, which have been classified according to European (Grand) Societal Challenges as defined in Horizon 2020;
- EIGR focuses exclusively on groundwater research and knowledge, increasing the precision and relevance of information retrieval conducted in the database;
- Access to a dedicated platform, integrating information on groundwater research and knowledge of relevance to the whole community of researchers and practitioners, extending across groundwater relevant disciplines and EU member states organisations and sectors to the benefit of all;
- Improvement of the overview of the vast amount of groundwater research, knowledge and data, especially within the non-peer reviewed segment, conducted in Europe, making access to related studies easier and duplication of work less likely;
- Additional web services for searches by selected key-words, e.g. related to the implementation of the Water Framework and Groundwater Directives and query functions for statistics, diagrams, and other dedicated data elaboration, making EIGR a potential tool for research analysis and evaluation within its field;
- Geolocalisation of the EIGR's data, offering a unique tool in information retrieval, a function that is pertinent for the groundwater research area, especially when considering the surveys and reports present in EIGR, which often are associated with a geographical location;
- Dynamical features, like adding new relevant keywords by users as they emerge in the future.

The contents and functionalities of EIGR cannot of course be fully developed and implemented during a three-years project and should be continuously developed and improved. We recommend sustaining EIGR and ensure the following developments in the near future:

- Develop EIGR as a European standard for common indexing of groundwater research reports and other types of grey literature making this information easily accessible ("FAIR");
- Upgrade the indexing schema and corresponding protocols to follow the Dublin Core Metadata Initiative (DCMI) in order to enable more advanced bibliometric analyses e.g. in combination with Scopus/SciVal and VOSviewer tools;
- Link EIGR to other related databases, e.g., making cross-references between metadata on groundwater studies and projects and the actual data collected, analysed and interpreted in the studies, which are available in other databases such as, e.g., the European Infrastructure for Geological Data – "EGDI" (http://www.europe-geology.eu/);
- Improve data upload procedures and guidelines to make them faster and less ambiguous, thus increasing data quality and inter-rater reliability (degree of agreement). Improve tools for statistical analyses and visualisation, both internal EIGR tools and data export to external tools;
- Improve the search and limit functionality relating to the geolocation data present in EIGR;
- Extend the current classification system to accommodate groundwater research relevant for all the seven Societal Challenges of Horizon 2020, as well as potential additional research topics and operational actions, and perhaps adding the option of assigning multiple SC's to one document to reflect the manifold applicability and relevance of some items;

- Continuously develop the EIGR thesaurus and keyword database[6];
- Solicit and invite public organisations, national and international associations, potential users, private companies, scientists and practitioners to contribute to the EIGR, both by using it for searching resources, and by updating the database with new records (including using data harvesting techniques), to increase the number of records and thereby the representativeness of the EIGR.

Main recommendations to the European Commission, based on findings of the analysis of the available records in EIGR, are the following:

- The strong presence of groundwater knowledge in the societal challenge 'Climate, Environment and Resources', and others as well, should be operationalised in order to be widely used by groundwater authorities and managers to tackle the demanding challenges;
- Integrating groundwater knowledge in EU policies to support societal challenges including drinking water supply, environmental protection, remediation of pollution and monitoring would provide evident benefits, which until now is considered but not completely integrated in policies;
- While hydrogeology is still (historically) one of the main research fields dealing with groundwater, it is recommended to become part of a multidisciplinary suite of skills to promote interdisciplinary technical studies, working groups, think tanks, and other initiatives to share knowledge at national and European levels.

The above mentioned recommendations, merged with analysis of larger research databases, such as Scopus, allow us to develop specific recommendations for research and knowledge on groundwater, in relation to the Societal Challenges defined in the EU Horizon 2020 research programme.

Groundwater research recommendations for the Societal Challenges of Horizon 2020

In the following, we describe recommendations for future groundwater research within each of the Societal Challenges (SCs) of Horizon 2020[7]. Note that these do not correspond 1:1 to the societal challenges used in the classification system (HRC-SYS) as described in D1.2 and D3.3, where SC6 and SC7 described below were merged into SC5 in HRC-SYS and SC4 was excluded.

SC1 - Health, demographic change and wellbeing

Bibliometric analyses conducted in KINDRA show an increasing number of observations of new emerging contaminants in groundwater and the rest of the hydrological cycle, with a rapid increase in papers and citations that study these, thus supporting the development of a Watch List for these

[6] more than 100,000 keywords are listed as keywords in the more than 120,000 groundwater research papers published after 1996, and less than 300 are currently included in EIGR (covering more than 99 % of the research publications though)

[7] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges

emerging contaminants for the Groundwater Directive (European Commission, 2016b; Kozel et al., 2018). Recent papers on emerging contaminants are among the most cited papers on groundwater research globally (e.g., Lapworth et al., 2012). Other papers indicate severe health effects (Kassotis et al., 2016) and related disease costs of several hundred billion Euros annually of human-made micro-organics, such as pharmaceuticals and endocrine disruptors (EDCs) in the European Union (Trasande et al., 2015), as well as for groundwater 'pollutants' occurring as a results of human activities, such as nitrate, arsenic, fluoride, manganese, uranium, mercury and lithium (Frisbie et al., 2015; Kessing et al., 2016). These pollutants and elevated concentrations of naturally occurring elements, such as trace metals, potentially have negative effects on human fertility (Ortiz-Perez et al., 2003; Frisbie et al., 2015; Kassotis et al., 2016), physical and mental health at concentrations up to an order of magnitude lower than the present water quality / drinking water standard (Schullehner et al., 2018; Wens et al., 2016; Ohgami et al., 2009; Kessing et al., 2016). Data and knowledge on their contents in groundwater is scarce and sporadic and most of the European countries have very limited data for groundwater and for the relation between contents in groundwater and drinking water and human health. Hence, there is a strong need for collation of new data and studies on the relation between groundwater and drinking water quality (Reimann and Birke, 2010) and human health (Frisbie et al., 2015), e.g., the occurrence of cancer, infertility and mental illness. We specifically recommend new studies and data compilations for the occurrence and health effects of the following pollutants and elements in groundwater and drinking water:

- Emerging contaminants, such as pharmaceuticals, endocrine disruptors, nanoparticles, microplastics;
- Agricultural pollutants, such as nitrate, pesticides and pesticide degradation products;
- Naturally occurring trace elements, e.g., arsenic, lithium, fluoride, manganese, molybdenum, nickel, mercury, uranium, selenium, etc.

Generally, additional research on the chemical status of groundwater in relation to human health effects of, for example, cocktails of emerging contaminants/micro-organics, arsenic and nitrate in relation to SC1 as well effects of agricultural pollutants, such as emerging contaminants, metals and nutrients on groundwater dependent terrestrial and associated aquatic ecosystems related especially to SC2 is warranted.

SC2 - Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the Bioeconomy

There is a close link between water and food security, as expressed, for example, by the Water-Food-Energy NEXUS (Bazilian et al., 2011), the concept of the global boundaries and the most imminent environmental problems, such as loss of genetic diversity/biodiversity, biochemical flows/nutrient cycles, climate change and water, etc. (Steffen et al., 2015). This is acknowledged by EU research programmes and water and environment policies, such as the Water Framework and Groundwater Directives, and it is reflected by the bibliometric analyses performed in KINDRA, which show that groundwater research has increased significantly since the adoption of the Groundwater Directive in 2006. However, although EU water policy is a research driver, the analyses also demonstrate that

limited research is conducted to provide knowledge and data for groundwater status assessments according to the Groundwater Directive, e.g., in relation to the derivation of groundwater threshold values and environmental flows established to protect the good status of groundwater dependent terrestrial and associated aquatic ecosystems.

Nitrate and pesticides (including pesticide degradation products) are the pollutants most frequently causing European groundwater bodies to fail the good chemical status objectives. As the current decreasing trend in nitrate concentrations in Europe in general is not steep enough to ensure good groundwater chemical status by 2027, additional data and research is strongly needed. We, therefore, recommend to strengthen research and studies of:

- Efficient measures to reduce nitrate concentrations in European groundwater bodies to protect human health as well as dependent terrestrial (mainly related to SC5) and associated aquatic ecosystems (SC2 - this SC);
- Methods to control the impact of modern agricultural practices on groundwater quality, e.g., specifically in relation to nutrients (besides nitrate mainly phosphorus), pesticides and their degradations products, metals and emerging contaminants (antibiotics). In this respect, more transdisciplinary research between hydro(geo)logists, ecologists and agronomists on understanding the interaction between agriculture, ecosystems and groundwater is strongly advised;
- Improved methods for reducing impacts of irrigation and ensure environmental flows in streams and rivers, which requires additional research on surface water - groundwater interaction and development of environmental flow indicators.

SC3 - Secure, clean and efficient energy

Although traditional carbon-based energy supply is still very important, the bibliometric analyses within KINDRA demonstrate that research activity has shifted from fossil fuels towards renewable energy resources all over the world. This tendency is also recognised in the co-occurrence analysis of the keywords connected to energy. The most frequently co-occurring keywords connected to SC3 are hydrogeology, geothermal energy, geothermal flow, geothermal fields, groundwater pollution, groundwater resources, energy resources, water supply, soil, environmental monitoring and carbon dioxide.

There are many regions, globally, where the natural conditions are favourable for producing geothermal energy. Hydrothermal systems cannot be operated in a sustainable manner without the proper knowledge of hydrogeology and reliable monitoring. We, therefore, recommend the following in relation to groundwater for securing clean and efficient energy:

- To improve the understanding of pollution risks from geothermal energy and other deep and shallow energy exploitation related activities;
- To assess water resources needs for geothermal energy and other deep and shallow groundwater and energy exploitation related activities;
- To develop improved methods for protecting groundwater resources in areas with competing / conflicting interests of deep and shallow geo-energy exploitation and waste disposal;

- To establish monitoring programmes for derivation of natural backgrounds and groundwater threshold values, as the basis for assessment of groundwater chemical status in areas with geo-energy exploitation, CO_2 storage and nuclear waste disposals, etc.

SC4 - Smart, green and integrated transport

Groundwater research in relation to SC4 is not as abundant as for the three previous SCs. However, we still found in SCOPUS more than 2600 research publications for the period 1997-2016 considering these issues, which include topics related to both groundwater quality and quantity and infrastructure, e.g., roads, railways, airports and fuel storage. Considering the projected climate change impacts we recommend stimulating research on the following groundwater related research topics associated with mainly land and air transportation:

- Climate proofing of roads, railways, airports and the built environment in general, e.g., in relation to groundwater flooding, mitigation of cloudburst events and nature-based solutions;
- Geohazards, e.g., related to landslides, land subsidence, flooding and urban development;
- De-icing of roads and airports;
- Fuel storage and pollutant transport.

SC5 - Climate action, environment, resource efficiency and raw materials

Recommendations for the Societal Challenge 'Climate action, environment, resource efficiency and raw materials' are seen against the background that the scholarly output in this societal challenge is high, especially in the fields of "assessment and management" and to a lesser degree "water supply" and "modelling". Research fields on "monitoring" and "mapping" are less represented. Scopus data analysis also reveals that the prominent research areas are ‘groundwater resource’ and ‘Aquifer’. Research areas on “groundwater pollution” and “water quality” are closely linked to the ‘groundwater resource’ and ‘aquifer’ clusters, which is expected and useful. It is recommended that:

- The linkage between groundwater quantity and quality and the status of groundwater resources is maintained as it warrants an integrated view on a wider scale, which is important when interregional scale groundwater research is considered;
- Groundwater research maintains the current path of linking specialised biochemical research to groundwater management, water supply and water quality, thereby upscaling knowledge on (bio)chemical processes from small (laboratory) scale to the wider environment;
- Research pertaining to groundwater and integrated hydrological modelling is sustained and possibly extended to better understand the pathways of contaminants, such as nitrate and pesticides in groundwater aquifers, and test nitrate, pesticides and emergent contaminants leaching to groundwater bodies for spatially varying vulnerability and tailored chemical usage towards less vulnerable groundwater recharge areas;
- Research on climate impacts on groundwater quantity and quality is strengthened, of importance to groundwater security for drinking water, industry and agriculture;

- More research is conducted on the dynamics of shallow groundwater and its impact on aquatic and terrestrial ecosystems, including maintaining ecological flows and derivation of groundwater threshold values (and development of innovative indicators) needed to comply with the WFD;
- More research is performed on cost-efficient methods for climate change adaptation, reuse of water and inter-seasonal subsurface storage of water by, e.g., managed aquifer recharge (MAR) and other integrated surface and subsurface water solutions;
- More research is performed to increase knowledge in the field of shallow groundwater in urban environments and how nature-based solution and green infrastructure developed to mitigate urban flooding, aggravated by cloudburst events, interact with shallow urban groundwater.

SC6 - Europe in a changing world - inclusive, innovative and reflective societies

Groundwater research and knowledge may have the least relevance for this SC and it was not specifically evaluated in the KINDRA project. Many of the issues relevant in this SC, such as climate change impact assessment and adaptation for cost-efficient protection of societies are partly covered by other SCs (especially SC5 and SC7). However, some groundwater research interests definitely exist within SC6. These interests are most probably mainly related to:

- The general importance of easy access to sustainable use of freshwater resources for the developments of innovative and reflective societies;
- The development of resilient societies in a changing world with projected significant global and climate change;
- New forms of innovation in public and private sectors, public-private-partnerships, open government, ICT for learning and inclusion, “cloud computing”, the Internet of Things (IoT) and the European Open Science Cloud (EOSC, 2017);
- Public participation in scientific research, participatory monitoring of groundwater relevant variables such as water table and river discharge as part of citizen science.

SC7 - Secure societies - protecting freedom and security of Europe and its citizens

Research areas in this societal challenge cluster around topics including aquifer, "groundwater pollution" and "groundwater resource", and embrace a large variety of subsurface uses and interrelated environmental, policy and societal issues. Multidisciplinarity is pronounced with emphasis on environmental impact and monitoring and the presence of topics including "sustainable development" and "environmental protection", but also direct impacts on and risks to human health, e.g., in relation to exploitation of subsurface resources and land subsidence. We consider the following

recommendations for groundwater research of importance to best support the security of European citizens:

- Increase research on risks related to the use of groundwater resources potentially causing severe water table decline and land subsidence;
- Research areas around topics including aquifer, "groundwater pollution", "groundwater resource", environmental impact and monitoring need to be sustained and strengthened;
- Multidisciplinarity and broadly supported integrated approaches in groundwater research must be embraced with strong links between environmental, policy and societal issues;
- Continuous assessments are needed of interactions within the Water-Food-Energy NEXUS and risks of related subsurface activities, such as nuclear waste disposal, CO_2 storage and shale gas exploitation;
- Conflicting or competing interests in the use of the subsurface, including groundwater resources, raw materials, geoenergy and space (e.g., in urban / built environments) should be object of more studies.

Technological Readiness Level (TRL) and Policy Readiness Level (PRL)

The European Commission requests classification of research and products according to the Technology Readiness Level (from TRL1 to TRL9, as classified by the European Community[8]). We refer to D3.3 for a further description.

The TRL classification refers to targeted technical products and is generally not very informative or applicable for most of groundwater research publications. The importance of TRL is mainly concerned with the translation of research outcomes into exploitable products and their transfer to the market and to industry. While groundwater research has demonstrated direct application in technologies (e.g., in remediation and in water treatment, and geophysical applications including electromagnetic aided mapping of groundwater resources), the large mass of knowledge on groundwater issues gravitates to the interaction between human needs and environmental requirements, which requires applied and integrated policies more than technical solutions only (this tendency clearly emerges from EIGR and more generally in the SCOPUS data analysis).

Hence, the Joint Panel of Experts proposed to introduce a Policy Readiness Level (PRL), and with the project team the following four classes were identified:

- PRL 1: Not relevant for EU policy implementation;
- PRL 2: Potentially relevant for EU policy but additional research needed;
- PRL 3: Relevant for implementation of EU policy, basic research conducted but guidance need to be developed, and
- PRL 4: Guidance available: ready for implementation of EU policy.

These PRL definitions were used for classification of the resources uploaded to EIGR (D.3.3, 2018). The Policy Readiness level has similarities to the “Societal Readiness Level” recommended in a consultation on science with and for society of the European Commission[9] and further developed and

[8] https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf
[9] http://ec.europa.eu/research/consultations/swafs/general_findings.pdf

applied by Innovation Fund Denmark[10], which, inspired by the more widely used TRLs, is developed at 9 levels.

We find that both the concepts of "Policy Readiness Level" and "Societal Readiness Level" generally are more suited for classification of groundwater research than the "Technology Readiness Level". Due to the more applied notion of "Policy Readiness Level" as compared to "Societal Readiness Level" and as PRL is more in line with the scope and intention of policy documents as the WFD and GWD, we recommend advancing the application of PRL in addition to the Technology Readiness Level.

Groundwater patents, innovation and groundwater research agendas

The KINDRA project partners conducted a limited assessment of existing international groundwater related patents occurring in PATENTSCOPE. PATENTSCOPE is a database of national and international patents established by WIPO, which is a global forum for intellectual property services and a self-funding agency of the United Nations. A patent is an exclusive right granted for an invention, which is a product or a process that provides, in general, a new way of doing something, or offers a new technical solution to a problem. To get a patent, technical information about the invention must be disclosed to the public in a patent application.

The analysis demonstrated that the number of patent applications (intellectual property) related to groundwater research and innovation is overwhelmingly dominated by the USA. To describe, analyse and address the reasons and consequences of this complex fact, including regulations, private initiatives and institutional framework, has shown to be out of scope for the KINDRA project and prevented the project to develop recommendations. The only recommendation to convey is that the reasons and implications for this situation is certainly worthwhile exploring. Considering the ambitions of a European Open Science Cloud (EOSC, 2017), it may also be interesting to note that all international patent applications related to groundwater and emerging services, such as "Cloud computing" and "Internet of Things", have been filed by the USA.

[10] https://innovationsfonden.dk/sites/default/files/societal_readiness_levels_-_srl.pdf

3 Conclusions

Significant amounts of groundwater research are conducted within all the Societal Challenges of Horizon 2020 with SC5 “Climate action, environment, resource efficiency and raw materials” being the largest. This clearly emerges from analyses of the contents of both the EIGR and Scopus databases.

Research and knowledge in the field of groundwater, the largest freshwater resource globally, is historically oriented at solving challenges related to water quantity and quality, protection and management. Although it is abundantly generated and applied in and outside Europe, the importance of this resource is still underrated in water related EU research agenda prioritisations, compared to other issues e.g., water network optimisations, water reuse, etc. and this needs to be addressed.

A clear impact of groundwater exists on the Societal Challenges “Health”, “Food”, “Energy” and especially “Climate, environment and resources”, as expressed by the ‘Water–Food—Energy’ NEXUS concept. Therefore, the need emerges for mainstreaming groundwater knowledge in a wide range of policies to boost efficacy of actions and implementation, in particular in the context of the Sustainable Development Goals of the United Nations.

The advice to reinforce the role of groundwater in the European Research and Knowledge framework is underlined. This is required to cost-efficiently protect water resources and the environment in general against pollution and the many competing interests in the subsurface domain. Consequently, actions aimed at standardising the relevant questions addressed in this topic by societal challenges (synthesised as assessment, management and protection of groundwater resources) are recommended, by applying appropriate and innovative tools for cost-efficient implementation of water policy and governance. Part of these actions can be represented by additional EU efforts in standardising groundwater knowledge, by the implementation of best practices at EU level.

To keep and strengthen Europe’s leading role within water science and technology we, therefore, recommend and support the EU open science cloud initiative (EOSC, 2017) and advice to keep (ground)water research as an important part of European research by defining integrated and relevant water research missions for a new mission-oriented EU research policy (European Commission, 2018; Mazzucato, 2018). The important role of groundwater must be mentioned specifically whenever relevant to avoid important water related research gaps, and to keep the importance of groundwater for society clearly understood and clearly visible.

Finally, we suggest the following groundwater mission for the coming EU research programme:

> to make groundwater quality and quantity data and their role for human health and ecosystems, and the related research resources, easily visible and accessible for all EU citizens via innovative cloud-based services.

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