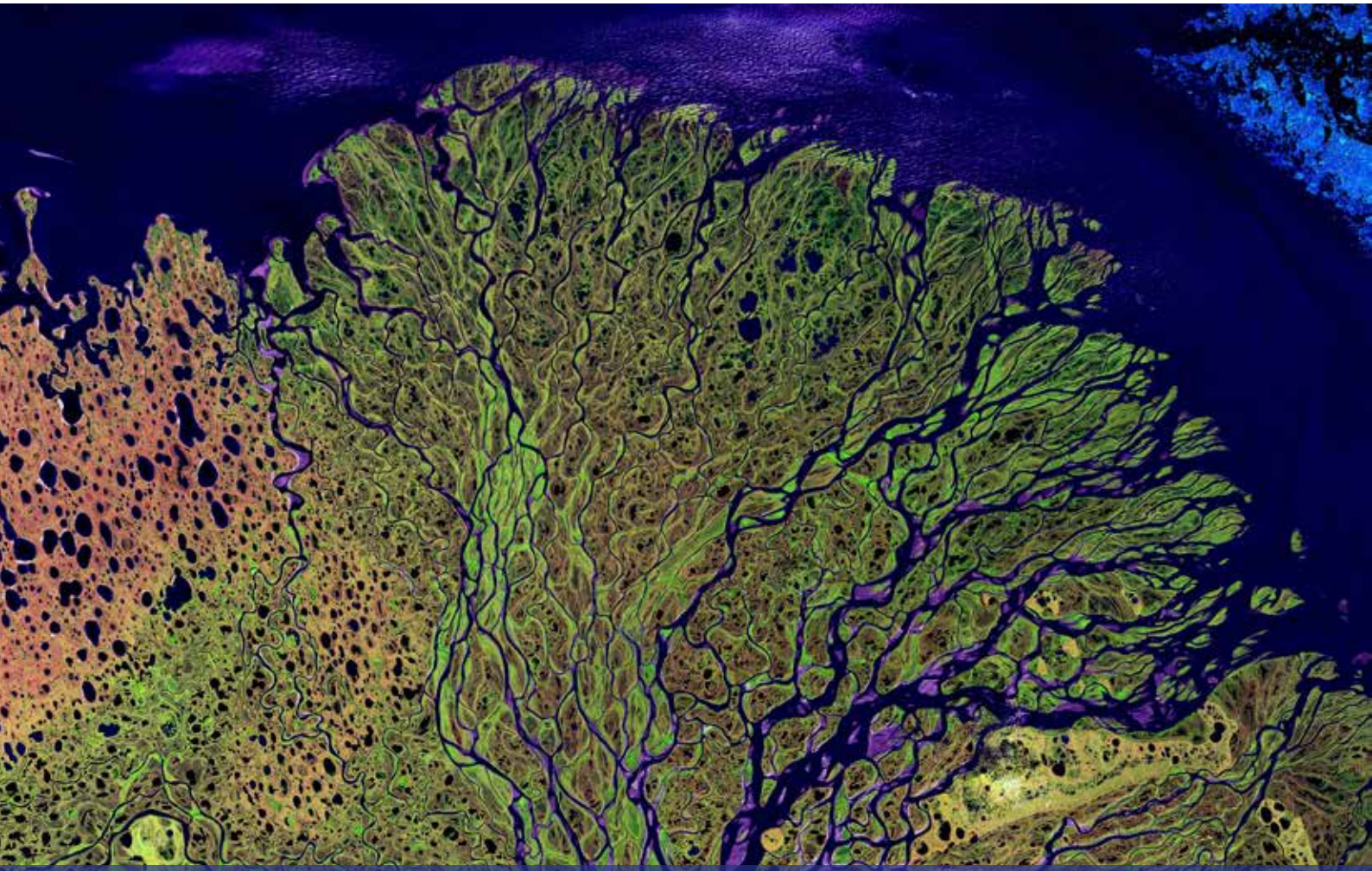
ONLINE CONFERENCE
IWRA 2020



Addressing Groundwater Resilience under Climate Change

28/30
OCTOBER 2020

FINAL REPORT

BY THE INTERNATIONAL WATER RESOURCES ASSOCIATION (IWRA)

www.iwra.org iwraonlineconference.org

ONLINE CONFERENCE IWRA 2020

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ACKNOWLEDGEMENTS

The International Water Resources Association (IWRA) would like to thank **UNESCO Intergovernmental Hydrological Programme (IHP)**, **the International Association of Hydrogeologists (IAH)** and **IHE Delft Institute for Water Education** for their support to help organise this event in 2020. Additionally, we would like to thank UNESCO-IHP and IAH for providing content and assistance for the creation of this report. We would also like to acknowledge and thank the seven rapporteurs who volunteered their time and efforts in writing and editing the 13 session summaries, which are compiled in this report. We would not have the wealth of information recording the key elements of this event without their contributions. These rapporteurs include: **Abi Attoumane**, **Priya Bhimjiani**, **Aditya Vikraim Jain**, **Ainur Kokimova**, **Gloria Mozzi**, **Jayson Gabriel D. Pinza** and **Sospeter Simiyu Wekesa**. Finally, we would like to thank UNESCO-IHP for their sponsoring of the 2020 Online Conference.

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MESSAGE FROM IWRA PRESIDENT, GABRIEL ECKSTEIN

On behalf of the International Water Resources Association (IWRA), I have the honour to present the final report of this very successful online conference on Addressing Groundwater Resilience under Climate Change, held from October 28 – 30, 2020. The report highlights messages from the two International Scientific Committee co-chairs, Drs. Jean Fried and Jacques Ganoulis. It also provides general figures and statistics on the conference, the complete list of ISC members, the thematic framework and final programme, session summaries and main findings, and conclusions and recommendations for future action and synergies as our Association reaches its 50th anniversary in 2021.

To say that the conference was a success is an understatement! Over 2,650 participants registered to attend the IWRA online conference. They came from more than 130 countries representing all regions of the world, including every inhabited continent on Earth. Thank you to all you who spent those two and one-half days with us attending and participating in the program. We sincerely hope that you found it beneficial, educational, and stimulating and we look forward to having you engage with us in future IWRA conferences and events.

At the conference, nearly 100 invited speakers, distinguished panellists, and poster authors shared their knowledge and experience, took part in stimulating dialogues, and imparted research results and new developments in ten regular sessions, two plenary sessions, a poster programme, and a high-level panel. The presentations, discussion, and expositions crossed a diverse set of academic sectors, geographic regions, technologies and methodologies, and policy dimension on the links between increased groundwater resilience and climate change, and focused on helping to bridge the science and policy interface for the sustainable use and management of water resources, globally. It truly was an interdisciplinary, global event that emphasized collaboration and engagement, and that focused on the critical challenges that we all face at the intersection of groundwater resilience and climate change.

On behalf of the Association, I want to thank IWRA's partners in this highly successful endeavour. The conference was organized with the support of the UNESCO Intergovernmental Hydrological Programme, and in collaboration both with the International Association of Hydrogeologists and IHE Delft Institute for Water Education. We are very grateful for their critical support and contributions to the program and look forward to continuing to strengthen the relationships that we have forged. I also must thank sincerely Drs. Fried and Ganoulis and the entire International Scientific Committee (ISC) for their hard work and dedication to making this conference a reality. Lastly, I must thank the staff at the IWRA Executive Office for their tireless work and diligence in developing this new conference format and on achieving such amazing results.

As IWRA reaches its 50th anniversary milestone in 2021, I urge everyone to stay tuned. There is much more to come! IWRA is dedicated to its mission to serve as a cross-disciplinary, membership-focused, international association that facilitates and inspires dialogue, knowledge sharing, and science-based solutions for the sustainable management of water resources globally. I hope you will join us for the various celebratory and exciting events that we have planned!

MESSAGE
FROM THE INTERNATIONAL SCIENTIFIC COMMITTEE CO-CHAIR, JEAN FRIED

For its first on-line conference, the IWRA has chosen to combine three most important features affecting water resources: groundwater, climate change and resilience. Each one has been a subject of passionate discussions and I hope that their combination in the present conference will contribute to a better understanding of their interactions and the identification of methods and practices to improve groundwater resilience, through the papers to be presented and the discussions.

Although groundwater is the most significant water resource on Earth, its legislation and management are nearly absent, with a lack of scientific and technical knowledge and its "out of sight, out of mind" nature adding to the complexity of its management.

Climate change is a very hot subject both scientific and political, with many debates on the responsibilities of humans versus nature. Groundwater is heavily affected and, often, we do not know how to react. On the other hand, groundwater can play a positive role, for instance as a rather protected water reserve.

Resilience is considered as the capacity to resist, absorb and recover when confronting disturbances and shocks, which depends on governance, economics, quantity and quality and, of course, climate, and is addressed by improving infrastructure, managing demand, reusing wastewater, improving governance to either adapt to the new conditions or to mitigate the effects.

Our conference aims at identifying and understanding how climate change affects groundwater, how groundwater reacts to the effects of climate change depending on its resilience, and how groundwater resilience can be improved. The themes of the conference, to be found in the programme, are the basis of efficient groundwater policy answering the effects of climate change, evaluating groundwater system resilience locally, and identifying what actions have to be done to improve this resilience.

Through the examples presented, the experience brought to the discussions or in the papers, this conference will be a milestone in the diffusion of good practices to solve the issues raised by the combination of groundwater, climate change and resilience.

I wish to conclude with two comments:

- Groundwater Resilience needs genuine groundwater policy in every country, supported by solid groundwater governance and implemented through groundwater sustainable management, of course within a surface water-groundwater integrated policy.

- A great focus should be put on improving the implementation of existing groundwater legislation and sustainability plans, for instance, and among others, solving the conflicts between stakeholders such as between public and private interests, and realizing genuine public participation in the policy making and the management of groundwater, much advertised but not necessarily implemented correctly.

MESSAGE
FROM THE INTERNATIONAL SCIENTIFIC COMMITTEE CO-CHAIR, JACQUES GANOULIS

Addressing the groundwater crisis under climate change was the main objective of this first Online Conference organized by the IWRA in cooperation with IAH and UNESCO-IHP. At the time of the conference, the epidemic infection was spreading around the world so that the benefits of organizing virtually this event became clear, in terms of avoiding the risk of travelling and saving the carbon footprint, organizational and other costs. The COVID-19 viral crisis created also an opportunity for thinking about global related challenges humanity is facing today.

Deriving from the same Greek word, crisis means at the same time endangerment and critical judgment. Thinking critically about the origin of groundwater decline in many regions around the globe we may conclude that the same cause is at the origin of reducing groundwater resilience and also producing anthropogenic climate change and public health viral infections. This common cause is the lack of harmonization between human activities and existing natural laws on renewable resources and ecosystem conservation.

The pumping of groundwater that exceeds the recyclable amount of water driven by the hydrological cycle, the overuse of fertilizers and pesticides in agriculture that violate natural processes millions of years old are the same causes of anthropogenic climate change and viral infections. Inversely, experts agree that the best way for preventing groundwater deterioration, climate change and viral infections is to comply with natural laws of sustainable groundwater use, limiting greenhouse gas emissions and restricting wildlife trade.

This conference was structured by the ISC in five general themes that can be summarised by five questions: 1) Are observations available to demonstrate the effects of climate change on groundwater quantity and is it possible to assess them? 2) How can we protect and restore groundwater quality deterioration from point and diffuse sources of pollution? 3) Can new ICT solutions help for increasing groundwater resilience? 4) How efficient groundwater governance can integrate management and policy practices into a participatory political process? 5) Are existing and new educational and capacity building methodologies available for addressing groundwater resilience under climate change?

The massive online participation of thousands of researchers, scientists and water professionals from around the world and the submission of many valuable papers by young people are good indicators of a successful conference. To conclude and avoid possible repetitions, I would adopt a more integrated and somewhat philosophical approach. For this, I would like to make two remarks:

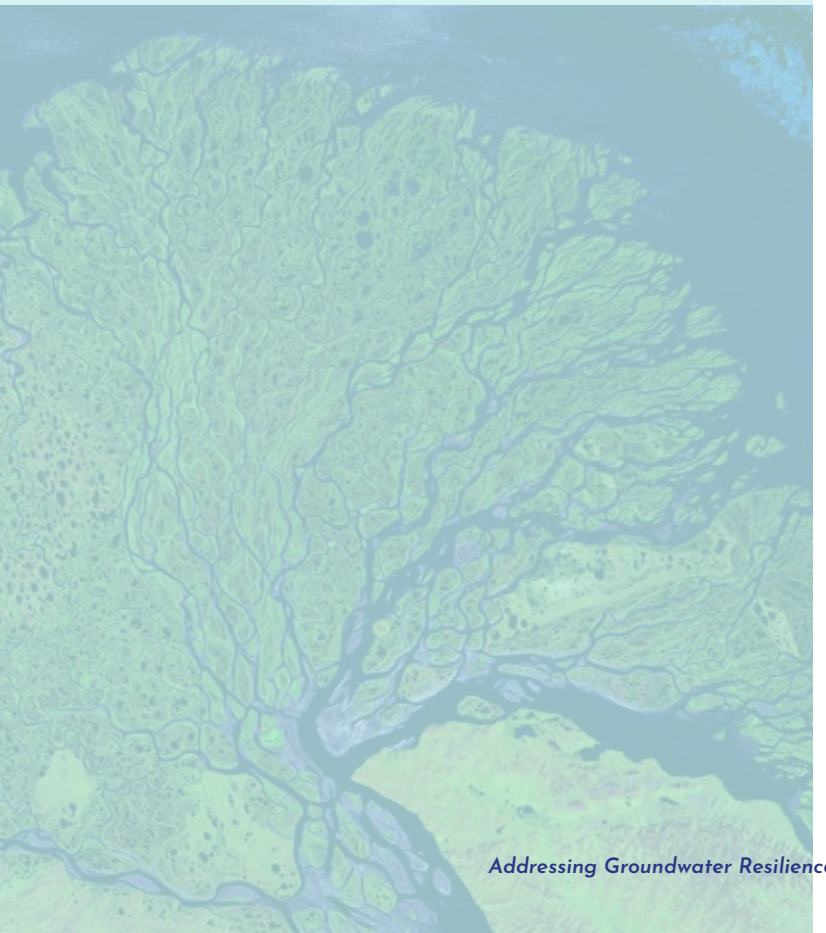
From the interesting scientific presentations, policy case studies and discussions during the conference, I noticed the following paradox: although a lot of progress was made in the use of new technologies, such as satellite observations, data collection and advanced groundwater modelling and simulations, still groundwater degradation, aquifer depletion and groundwater salinization persist in many parts of the world. Although advanced technology was able to send a man to the moon, still insufficient science and policy prevent achieving groundwater sustainability under climate change.

If we compare the three challenges we faced during this conference, i.e. groundwater resilience, climate change and the COVID-19 pandemic, we may conclude that a non-effective policy on all these issues is mainly linked to existing epistemic uncertainties. A better understanding of the role of groundwater in the still-mysterious water cycle, the explanation of the climate change mechanism as related to greenhouse gases and the coronavirus molecular decryption are some remaining scientific challenges.

As a general conclusion, I can say that the progress in science and policy we noticed in this very successful conference should be further strengthened to bridge the gap between science and policy. Closing this gap may be achieved by an improved epistemic knowledge that can serve better policy and groundwater governance. In this endeavour, the role of IWRA is crucial for bringing together scientists from different disciplines, lawyers and policy makers to promote more knowledge and policy applications for groundwater resilience. In this context we should have in mind what Jacques Yves Cousteau, a French undersea explorer said, “Don’t forget that water cycle and life cycle are one”.

> LINK TO THE RECORDINGS

iwraonlineconference.org/recordings



ONLINE CONFERENCE STATISTICS

Over **2,650 registered participants** from more than **130 countries** representing all regions of the world, including Africa, Asia, Europe and the Americas

More than **95 speakers and moderators**

A total of **13 distinct sessions** held over 2 and a half days, namely:
- **10 Technical Sessions**
- **2 Plenary Sessions**
- **1 High-Level Panel**

Nearly **20 online poster presentations**

A diverse list of sponsors and supporters, including:

UNESCO Intergovernmental Hydrological Programme (IHP)

International Association of Hydrogeologists (IAH)

IHE Delft Institute for Water Education

INTERNATIONAL SCIENTIFIC COMMITTEE

Jean Fried, Co-Chair, IWRA Fellow member & University of California

Jacques Ganoulis, Co-Chair, Aristotle University of Thessaloniki & UNESCO - INWEB

Tibor Stigter, Coordinator, IAH & IHE Delft Institute for Water Education

Nader Al Khateeb, Water and Environmental Development Organization (WEDO)

Alice Aureli, UNESCO-IHP

Michael Campana, Oregon State University

Lilian del Castillo Laborde, University of Buenos Aires

Enrique Fernandez Escalante, IAH MAR Commission & Tragsa Group

Malcolm Gander, U.S. Department of Defence

Abror Gadaev, Samarkand State Architectural and Civil Engineering (SSACEI)

Dinis Juizo, Eduardo Mondlane University, Mozambique

Jeltsje Kemerink, IHE Delft, University of Amsterdam & Oregon State University

Neno Kukuric, IAH & IGRAC

Elena Lopez-Gunn, ICATALIST & University of Leeds

Renée Martin-Nagle, IWRA Treasurer, A Ripple Effect LLC, Eckert Seamans & Environmental Law Institute

Jodie Miller, University of Stellenbosch

Adrian Parr, University of Texas

Damien Serre, University of French Polynesia

Craig Simmons, Flinders University & National Centre for Groundwater Research and Training

Raya Stephan, IWRA Executive Board

Richard Taylor, IAH & University College London

THEMATIC FRAMEWORK
Addressing Groundwater Resilience under Climate Change

Currently, climate change has become an undeniable major additional factor influencing the world's freshwater resources. Yet, the effects of climate change on groundwater, the most significant freshwater resource on Earth, are still poorly understood. Somewhat neglected by policymakers and ignored by the public, groundwater management, governance and monitoring are less developed compared to surface water, globally. More up-to-date research and knowledge generation and sharing, as well as more efforts to raise awareness of the links between groundwater and climate change are also critical to ensure the sustainable management of this vital resource.

IWRA's Online Conference (28 – 30 October 2020) addressed these challenges and priorities in order to manage groundwater resources under climate change in a resilient manner. The conference's main goal was to promote the sharing and exchange of state-of-the-art scientific and policy knowledge of the links between an increased resilience of groundwater resources and climate change for the sustainable governance as well as the use and management of these resources in all regions of the world. It aimed to do so in an online format, as originally planned in September 2019, thereby aiming to reduce the carbon footprint and promote access to the conference for all people interested.

This new IWRA event had the overarching theme of "Addressing Groundwater Resilience under Climate Change" which was further explored in the following five sub-themes:

THEME I - *Groundwater natural resources assessment under climate change*

The intensification of precipitation in a warming world highlights the critical importance of water storage and the vital role played naturally by groundwater, the world's largest distributed store of freshwater, in sustaining ecosystems and enabling climate-resilient water supplies. This theme welcomed submissions that address the direct impact of climate change on groundwater systems and indirect impacts of climate change such as increased groundwater withdrawals for public water supplies, irrigation and industry. Studies assessing conceptually and quantitatively interactions between groundwater and other components of the hydrosphere and biosphere under climate change including conjunctive use of groundwater and surface water were of particular interest.

THEME II - *Climate change effects on groundwater resilience - Pollution and remediation*

Impacts of climate on nature and society call for science ingenuity for better planning and management. Where climate change is expected to affect important natural fluxes into and out of the system, such as (direct and indirect) recharge, evapotranspiration and discharge into surface water bodies, these impacts will alter hydro-geochemical dynamics, groundwater quality and pollution state. Sea level rise will modify hydraulic gradients and, possibly in combination with coastal storm surges, aggravate saltwater intrusion. Theme II addressed future trends in groundwater quality and associated health linked to climate change, with particular interest in remediation, through treatment, dilution and other methods.

THEME III - *Contribution of technology to groundwater resilience*

Technology has been used throughout the centuries for groundwater extraction, and gradually, tools have been developed to support monitoring (e.g. loggers), assessment (e.g. models) and management (e.g. water meters) of groundwater resources. Development of information and communications technology (ICT) has brought a variety of new applications such as cell-phone apps (e.g. for monitoring, water markets, governance), modelling environments, serious gaming, information portals, etc. Often, new technologies are developed in other sectors (e.g. remote sensing, drip irrigation, building info modelling, solar pumping, and thermal energy). Such technologies provide a significant contribution to better groundwater management and increase resilience to climate change. Accordingly, this theme welcomed contributions across sectors and disciplines.

THEME IV - *Groundwater governance, management and policy*

Strong governance and institutions are central to protect and safeguard groundwater and stimulate its resilience. Theme IV considered innovative groundwater governance models (polycentric, multilevel, network, etc.), legal systems and policy designs, including policy (and social) learning. It also considered the centrality of equity in groundwater governance, in the context of achieving the SDGs and issues related to (ground) water markets and pricing. It covered groundwater rights and resilience, related to community and ecosystem-based adaptation, nature-based solutions and green infrastructure. Finally, it looked at groundwater governance as an integral part of socio-ecological systems (public consultation, information systems, participation and co-management).

THEME V - *Groundwater education and capacity building*

As the largest liquid freshwater reservoir on earth groundwater plays a huge role in adaptation to climate and global change. At the same time its invisible nature makes groundwater difficult to assess and manage, which has already led to over abstraction and contamination by human activities. There is thus a growing need for trained and skilled professionals in this field. Theme V welcomed abstracts on the way in which education and capacity building are addressing groundwater resilience under climate change at different education levels, from national programmes to international cooperation and co-construction of knowledge, using a variety of tools, from face-to-face education to distance e-learning, which has proven to be particularly relevant in 2020.

> LINK TO THE RECORDINGS

iwraonlineconference.org/recordings

SESSION SUMMARIES

Plenary Session	Opening Ceremony
Date & Time	28-10-2020, 15:00-17:00 CET
Theme	Addressing Groundwater Resilience under Climate Change

Keynote Speakers & Panellists

Renée Martin-Nagle, IWRA Treasurer, Chair
Mary Trudeau, IWRA Officer, Co-chair
Gabriel Eckstein, IWRA President, Host
David Kreamer, IAH President, Co-host
Shamila Nair-Bedouelle, Natural Sciences ADG, UNESCO, Co-host
Jean Fried, ISC Co-chair, ISC speaker
Jacques Ganoulis, ISC Co-chair, ISC speaker
Jay Famiglietti, Executive Director, Global Institute for Water Security & Professor, School of Environment and Sustainability, University of Saskatchewan, Keynote speaker
Karen G. Villholth, Principal Researcher, Coordinator – Groundwater, International Water Management Institute (IWMI), Keynote speaker

Presentations

Renée Martin-Nagle

- Opened the session by thanking the partners and participants.
- Introduced the speakers and the overall organization of the conference.

Gabriel Eckstein

- Welcomed the participants and partners, emphasizing the generous support from UNESCO-IHP Program.
- Highlighted the efforts made by partners, both IWRA and ISC teams in making the online conference possible.

David Kreamer

- Welcomed the participants and partners and discussed the importance of water in different cultures and ethnic groups around the world.
- Emphasized the uneven distribution of water resources in the world and the commitment of IAH in building knowledge around groundwater.

Shamila Nair-Bedouelle

- Welcomed the participants and thanked the partners and organization committee of the online conference.
- Highlighted the historical role of UNESCO through their programme IHP, in the advancement of groundwater knowledge and management.

Jean Fried

- Discussed the significance of groundwater and the lack of legislation and management. Criticize the lack of scientific and technical knowledge as being “out of sight, out of mind”.

Jacques Ganoulis

- Presented the conflict between groundwater misuse and the hydrological cycle.
- Emphasized the lack of sound scientific knowledge regarding climate change.
- Explained the theory interconnecting the conference five themes.

Jay Famiglietti

- Presented about emerging threats to global groundwater security proving a space view.

Karen G. Villholth

- Presented on groundwater in a changing world.

Session Summary

More than 850 participants attended the Opening Ceremony. This significant number was made possible through the support of the conference sponsor, UNESCO Intergovernmental Hydrological Programme (IHP), allowing for free registration. Despite this large number of attendees, the online nature of the conference helped minimize the additional carbon footprint and COVID-19 contamination risks. With this achievement, the efforts and commitments of IWRA, in collaboration with UNESCO-IHP, IAH and the ISC Chairs, have been highlighted multiple times by the speakers.

The IWRA 2020 Online Conference brought together numerous professionals from different fields and sectors across the world to share their experiences, concerns, and expertise in groundwater as a natural resource. These fields were well-represented through the five themes of the conference, namely, (1) Groundwater natural resource assessment under climate change; (2) Climate change effects on groundwater resilience - Pollution and remediation; (3) Contribution of technology to groundwater resilience; (4) Groundwater governance, management and policy; and (5) Groundwater education and capacity building.

The speakers emphasized that citizens and policy makers should always take groundwater into consideration in their decisions. Groundwater is the most significant water resource on Earth and yet legislation and management of groundwater are nearly absent ("out of sight, out of mind"), despite growing scientific and technical knowledge. Climate change projections show (semi) arid areas becoming even drier and humid areas becoming wetter in the future, according to the Intergovernmental Panel on Climate Change (IPCC). As such, groundwater resources in the dry areas become more depleted, and increased presence of floods implies higher risk of groundwater contamination.

Jay Famiglietti's presentation on monitoring results of total global water storage variations using GRACE satellite produced multiple insights related to the scale of the issue. Some regions have seen their storage depleted, whereas in others, excess water storage has become more apparent through time. Many food-producing regions have also appeared to be in a state of chronic water scarcity. All this implies that some pressing groundwater issues might be regional in scale, and as such, require regional solutions coupled with national or even international cooperation.

To better understand the exact impacts of climate change on groundwater, Karen Villholth stressed the importance of dissecting these impacts into different types (direct or indirect) and the groundwater aspects being affected (i.e., quantity and quantity). With this, Villholth proposed a quadrant system that connects the type of impact with the certain groundwater aspect. Villholth then provided real-life examples around the world that fit each category.

SESSION SUMMARIES

Plenary Session	1
Date & Time	29-10-2020, 08:00-09:30 CET
Theme	Contribution of Technology to Groundwater Resilience

Keynote Speakers & Panellists

Neno Kukuric, ISC member, Moderator

Enrique Fernández-Escalante, ISC member, Co-moderator

Basant Maheshwari, Professor, Dean's Unit School of Science, Western Sydney University, Australia, Keynote speaker

Rafael Chavez, Doctoral Researcher, UFZ, Germany, Oral presenter

Kristyn Glanville, Doctoral Researcher, University of New South Wales, Australia, Oral presenter

Claudia Ruz Vargas, Researcher, IGRAC, the Netherlands, Oral presenter

Lu Wang, Post-Doctoral Researcher, ETH Zurich, Switzerland, Oral presenter

Philip Songa, Senior Water Resources Engineer, Arup, United Kingdom, Oral presenter

Presentations

Basant Maheshwari

- "Participatory groundwater monitoring and management at the village level – Enabling technology and people to work together for sustainable groundwater futures"

Rafael Chavez

- "GIS and data tools for estimating domestic self-supply groundwater use in urban Africa"

Kristyn Glanville

- "Policing water crime in Australia: Compliance, enforcement and technology"

Claudia Ruz Vargas

- "Groundwater data sharing: The challenge of spatio-temporal data"

Lu Wang

- "Monitoring groundwater abstraction using electric energy as proxy in an area of intensive agricultural pumping"

Philip Songa

- "The WASH basins toolkit and WASH connect IWRM app: Tools for integrated groundwater management through WASH projects"

Key Message

Groundwater management encompasses many processes that rely on cooperation and information exchange among experts, regulatory authorities, and water users. Technology can help by streamlining these processes. It allows for cheaper and more extensive data collection, organisation, sharing and communication among stakeholders.

Session Summary

Although the details vary depending on the requirements and scale, groundwater management can be broadly divided into the following: data collection and organisation; data interpretation; water management planning; and implementation and assessment.

Groundwater users, when empowered with knowledge and the necessary technology, can improve groundwater management by aiding all the processes mentioned above. For example, this is reflected on the success of the MARVI project in two watersheds in India. The project aimed to integrate communities, scientists, and government for effective management. Volunteers from villages were trained in basic hydrogeology, mapping, and field measurements. They were instrumental in collecting data, increasing water literacy in their communities, and exchanging information with researchers. Hydrological data were recorded, organised, and transmitted to researchers through a mobile application, who in turn coordinated their efforts with government bodies. Guided by the trained volunteers, the villages eventually started managing their water resources independently. They collected information, estimated water recharge and availability, and regulated their water use.

Data regarding groundwater use is challenging to collect. One of the proposed methods to overcome this challenge is the use of GIS and data tools for estimating urban population that used self-supplied groundwater for domestic purposes. The study conducted by Rafael Chavez estimated the maximum fraction, and the likely fraction of urban population in the African continent that could be meeting its domestic water needs through self-supplied groundwater. The 'maximum' fraction was estimated by first calculating the urban area in the continent with favourable hydrogeological conditions for abstraction. This area was then superimposed with the population density in the area. The 'likely' fraction was estimated in a similar manner, but the calculation of area where self-supplied groundwater use was likely linked to hydrogeology with other factors that could influence the favourability of this mode of water supply. These were lag areas of public water supply, socio-economic distribution, proximity to surface water, restrictions imposed on groundwater use.

Another study explored the use of electricity consumption as a proxy for groundwater abstraction for agriculture. According to the study conducted in the North China plain, the existing electricity monitoring infrastructure can be used to estimate the volume of abstracted groundwater through a conversion factor. The conversion factor is calculated through field pumping tests. Pumping tests conducted on the same well in different seasons can produce different conversion factors, but its relative error remains within 20%. An average conversion factor can be calculated for a region by conducting pumping tests on multiple wells in the region, preferably evenly distributed, and averaging the resultant conversion factors. The accuracy of this factor can be improved by conducting tests on more wells. For example, measurements from 17 wells in Guantao County, China gave a conversion factor with a 20% error threshold. This means that although individual wells showed variations, the relative error between observed individual electricity-to-water conversions and those estimated using the average regional conversion factor remained lower than 20%. This method could reduce the investment required for data collection and water use regulation.

Collecting groundwater data on geology, groundwater levels, water quality and their time series is important. However, groundwater data needs to be connected to spatial and temporal data, stored, and made accessible for effective use. Commercial software exists for this purpose, but they are either expensive or often do not integrate all parameters. Now, advanced open source platforms have been developed for this purpose (it should be noted that open source software does not necessarily mean that the data available on it is free or open source).

Technology can aid water law enforcement, but cooperation between regulators and water users is central to compliance. This is highlighted in a study from the University of New South Wales, Australia. Non-Urban water use is a complicated regulatory problem. The proposed solution, which is still in the process of execution, is the employment of telemetry and new meters for remote and real time monitoring. Although the study on the contribution of these new technologies to water crime policing is on-going, the findings obtained up till now were presented. It was found that while these technologies are celebrated for making law enforcement cheaper and faster, they raise privacy concerns among the regulated. Secondly, the adoption of these technologies can be deterred by short term-costs like purchasing these technologies. To overcome resistance from the regulated, regulators should aim to increase accountability and transparency, allow some flexibility in meter choice among those that allow for high level of telemetry, and highlight the long term benefits of adopting such technologies, such as better water management and reduced delays by inspector visits.

The final presentation aimed to improve long-term access to safe water and sanitation in India through the use of Integrated Water Resources Management (IWRM). The project designed and implemented groundwater recharge structures and developed long term plans to attract government support. The lessons derived from this project were used to develop an IWRM toolkit and mobile application, which could then be used to help local government agencies plan and execute different stages of water management collaboratively with other water-related ministries in India. The toolkit included a six-stage process for achieving inclusive WASH management and IWRM. The stages guided local governments through data collection, data management and analysis as well as developing Water resources management plan for each village.

SESSION SUMMARIES

Plenary Session	2
Date & Time	29-10-2020, 09:45-11:15 CET
Theme	Groundwater Governance, Management and Policy

Keynote Speakers & Panellists

Elena López Gunn, ISC member, Moderator
Jeltsje Kemerink, ISC member, Co-moderator
Aditi Mukherji, Principal Researcher and Research Group Leader, Climate Change, Adaptation and Resilience, IWMI, Keynote speaker
Praharsh M. Patel, International Water Management Institute (IWMI), Oral presenter
Mark Gideon, International consultant, Oral presenter
Eshwar Kale, The WOTR Centre for Resilience Studies, Oral presenter
Yan Yang, General Institute of Water Resources and Hydropower planning and design, MWR, China, Oral presenter
Oliver Kracht, International Atomic Energy Agency, Oral presenter

Presentations

Aditi Mukherji

- "Groundwater and resilience to climate change"

Praharsh M. Patel

- "Community's response to revive depleting groundwater in arid region of Kutch a self-propelled movement for the managed aquifer recharge through private defunct Bo"

Mark Gideon

- "Groundwater trustees"

Eshwar Kale

- "Building the resilience for managing groundwater under climate change: Lessons from the Water Stewardship Initiative"

Yan Yang

- "Groundwater pricing policies in the practice of groundwater over-pumping control in North China Plain"

Oliver Kracht

- "Improving needs assessment and project formulation with IWAVE – The IAEA water availability enhancement approach"

Session Summary

Groundwater governance refers to the framework of laws, regulations and customs on groundwater use, including the process of engaging relevant stakeholders – civil society, private sector and public sector. A robust governance approach involving coordinated administrative action across various jurisdiction levels is critical to mitigating groundwater depletion and contamination and ensuring equitable access. Legal and policy framework that can guide proper groundwater governance are still at the infancy stages in many nations of the world, making it difficult to effectively ensure sustainable exploitation of groundwater resources in the wake of climate change.

Several groundwater hotspots have been identified across the world with massive depletion linked more to the anthropogenic activities than to climate change. For instance, using a case study of India, Aditi Mukherji indicated that, although the projected increase in precipitation is expected to increase recharge, the expected irrigation expansion evident from historical trends is likely to negate the gain. Aditi therefore notes that sustainable groundwater resources management may require a multi-sectoral approach, i.e. looking for solutions beyond the water sector. The Water-Energy-Food Nexus is vital for groundwater resources management as food policies determine groundwater use, while energy policies impact groundwater use. With subsidized energy costs increasing the volume of abstractions, Aditi proposes re-alignment of food procurement policies, provision of incentives to grow low water consuming crops and adoption of more effective field water management techniques. Yang, on the other hand, using a case study in the North China Plain, noted that rising groundwater pricing and rewarding water-saving, including imposing higher water price in over-exploited areas, stimulated sustainable water use. While pricing strategies tend to increase volumetric charges geared towards discouraging over-abstraction, it may further decrease income from extensive and low-income crops.

Community and water users are capable of supporting the sustainable management of groundwater if viewed as trustees and not just consumers. As opposed to surface water, for which legal and policy framework is well developed and the trustee rite vested with the government, groundwater is tied to land ownership rite. This makes it vulnerable to over-exploitation, given the subsidies in energy and the high pricing for high water requirement crops such as rice. Mark Gideon with a case study of Delhi has indicated that community-based management approach that integrates common sharing (CS) of groundwater sources present an opportunity as an interim measure to sustainable use and management of the resource. Further, Praharsh M. Patel has illustrated in a case study in Kachchh, India, that community-driven responses present low-cost intervention for reversing depleted groundwater resources as opposed to independent government centred approaches. Good water stewardship ensures equitable and sustainable water use in the watershed context and shared risks with regards to governance, quality status and available quantity. Eshwer Kale with a case study of India has also demonstrated that water stewardship can indeed build community resilience for managing groundwater resources under climate change. Communities can be trained as water stewards to help collect relevant data such as precipitation and groundwater levels to support management.

With little knowledge of the potential of groundwater resources in many regions across the globe, academic and research institutions are challenged to provide underpinning scientific interventions and develop tools that can support discussions around governance, management and policy. The IAEA Water Availability Enhancement Approach (IWAVE) presented by Oliver Kracht from the International Atomic Energy Agency is a good illustration of such efforts. IWAVE aims to strengthen the national capacity of the member states to conduct comprehensive water resources assessment using isotopes and nuclear data. IWAVE helps to identify the existing gaps in national hydrological information and understanding, with an emphasis on groundwater, and to select suitable nuclear techniques that can help closing these gaps. It is thereby promoting confidence between water technologists and decision makers – through symposia, outreach and national consultations. Good groundwater governance that places policy and management into proper developmental political framework requires a collaborative involvement of stakeholders at all levels: community, government, academic and research institutions, among others.

SESSION SUMMARIES

Plenary Session	3
Date & Time	29-10-2020, 11:15-13:00 CET
Theme	Groundwater Natural Resources Assessment under Climate Change

Keynote Speakers & Panellists

Robinah Kulabako, Department of Civil and Environmental Engineering, Makerere University, Malaysia, Moderator

Richard Taylor, ISC member, Co-moderator

Sun Woo Chang, Senior Researcher, Korea Institute of Civil Engineering and Building Technology, Oral presenter

Simon Craig, MSc Student, IHE Delft Institute for Water Education, Oral presenter

Long Thanh Tran, Water Resources Engineering Department, Chulalongkorn University, Oral presenter

Mhambi Nyathi, MSc Student, IHE Delft Institute for Water Education, Oral presenter

Richard Taylor, Professor of Hydrogeology, University College London, Oral presenter

Sergey Grinevskiy, Hydrogeology division, Moscow State University, Oral presenter

Robert Reinecke, Acting Deputy Director, ICWRGC, Oral presenter

Presentations

Sun Woo Chang

- "Assessment of seawater intrusion affected by climate factors and anthropogenic activities: Case study of South Korea"

Simon Craig

- "Drivers of groundwater salinity and potential for freshwater abstraction on a semi-arid coral-limestone island in Sri Lanka"

Long Thanh Tran

- "The impact of climate change towards groundwater use and mitigation in The Upper Central Plain Basin of Thailand"

Mhambi Nyathi

- "Comparative assessment of small water storage structures in semi-arid regions considering hydro-climatic, geological and socio-economic contexts"

Richard Taylor

- "Groundwater recharge and the amplification of rainfall extremes under climate change"

Sergey Grinevskiy

- "The impact of modern climate changes on the groundwater recharge in the European part of Russia"

Robert Reinecke

- "Changes of groundwater recharge at different global warming levels: A global-scale multi-model ensemble approach"

Key Findings:

Science-policy elements

- *GIS-based vulnerability assessment – GALDIT is a tool to investigate seawater intrusion.*
- *Recharge is partially predictable and cyclical.*
- *Non-linear correlation between recharge and precipitation.*
- *Major effect of uncertainties in global scale models to estimate recharge comes from GHMs – improvement is needed.*

Session Summary

The dynamics of groundwater storage and its distribution is heavily influenced by rainfall events. These events also indicate direct impact of climate change on groundwater systems through recharge. This session was divided into two subtopics, namely seawater intrusion and recharge estimates. Local, regional and global scales were considered in analysis.

The first speaker, Sun Woo Chang, introduced her research on seawater intrusion on Jeju Island in South Korea. Population growth and land use change are some of the drivers of seawater intrusion. The study aimed to investigate long-term saltwater-intrusion caused by climatic and anthropogenic factors. The investigation was conducted on a shallow unconfined aquifer which is the main fresh water source on the island. The methods used included groundwater level monitoring, numerical modelling and a GIS-based vulnerability assessment called GALDIT. GALDIT considers six parameters to assess vulnerability where groundwater level and salinity are considered to be time-dependent parameters. The results indicated that vulnerable areas where freshwater had reduced were located mainly on the North-Eastern part of island. Other vulnerable areas were located along the Western coast. The study also suggests likelihood of seawater intrusion in the next 10 years under dry climatic conditions.

The next presenter, Simon Craig, showcased his research conducted on Delft Island in Sri Lanka together with co-author Chen Lester Wu. Here, fresh groundwater reserves are threatened by population growth and tourism in the short-term, and by sea-level rise in the long-term. The island community is highly dependent on groundwater resources. The evaluation of fresh and saline groundwater on the island was conducted using the vertical electrical sounding (VES) and isotope analysis. The resultant map indicated two main areas of fresh groundwater location. The results indicated occurrence of preferential recharge during the wet season. The effect of distributed fresh water abstraction was compared to that of point abstraction on saline water upconing using water quality indicators. The results showed that distributed abstraction of groundwater further from the coastline will lead to lower rates of upconing. The suggested measures for securing freshwater availability for the island residents were artificial recharge and horizontal abstraction.

The third speaker, Long Thanh Tran, presented the research in a study area in the northern part of Thailand. The aquifer evidenced a large groundwater level decrease in three hotspot areas, namely Sukhothai in the north, Phitsanulok in the middle, and Nakhonsawan in the south. Two climate models (MRI-CGCM3 and IPSL-CM5A-MR) were used to estimate future rainfall availability and distribution under RCP 2.6, 4.5 and 8.5 scenarios. The results from GCM MRI suggest a decrease of 10% for the whole area in the next 20 years. However, the IPSL model suggests a 10% increase in rainfall in the upstream area and a decrease of 5% in the downstream area in the next 20 years. Projected future groundwater levels corresponding to MRI-RCP2.6, MRI-RCP8.5 and IPSL-RCP 2.6 climatic conditions are expected to continue declining for the next 20 years following recent droughts. The effect of existing artificial recharge projects on expected future groundwater levels was investigated. Overall, existing mitigation measures with artificial injection do not provide an efficient solution for groundwater recharge due to a large scale of the area. However, recharge at Phitsanulok has the potential to increase groundwater levels to 0.17 – 5 meters if high volumes are applied. 12 injection wells with rates of 4500 m3/day proved necessary to reach the local target groundwater levels.

Mhambi Nyathi presented a study on assessing small water storage structures (SWSS) in Sub-Saharan Africa. GIS and remote sensing techniques were used to map existing structures and potential areas for construction. Comparative assessment of those structures was done on storage capacity, sedimentation, water quality, costs and management. Criteria such as slope, geology of the structure foundation and source material, and stream order were used to identify potential suitable locations for sand dams. The results for Chacalanga sand dam quantitative assessment pointed out that evaporation loses occurred up to a certain storage depth. When water is extracted only for population needs, the storage can satisfy demands up to 5 months; similar trends were observed in micro reservoirs. A literature review showed that sand dams, and in particular sand rivers, are less vulnerable and more reliable compared to micro reservoirs. Other findings indicate that the involvement of a community on all stages of a project is an important aspect for future maintenance. The research recommends constructing sand dams in 0.3 m stages, paying attention to proper siting for micro reservoirs, and building wider, deep river channels composed of coarse sediments for sand rivers.

Richard Taylor discussed the effects of climate change on groundwater recharge. One consistent observation among studies is increased episodes of heavy precipitation and fewer light precipitation events, especially in the tropics. The effects of such shifts were studied in Uganda and Benin. There, an increase of groundwater levels was observed. Analysis of stable isotope ratios in groundwater indicated that this increase can be due to traced heavy rainfall events, exceeding 10 mm/day. In semi-arid Tanzania recharge occurs episodically and disproportionally from extreme rainfall events that generate ephemeral stream flows. Pan-Africa piezometric analysis confirmed the recharge bias towards heavy rainfall events, the importance of focused recharge in drylands, along with recharge episodicity and its links to large-scale climate controls. In the near future, groundwater will serve as a freshwater buffer for climate change adaptation, especially in the tropics. It is important to remember that groundwater becomes more vulnerable due to rapid heavy rainfall infiltration and further recharge. Focused recharge is not reflected in global large-scale models, thus undermining the validity of recharge projections.

In Russia, groundwater recharge under changing climate was analysed in its European part, stretching from the Black Sea in the south to the White Sea in the north. Sergey Grinevskiy discussed latitudinal change of seasonal precipitation and temperature, where the two variables show increasing trends. Interestingly, wind speed observations showed a predominant decrease. SurfBal together with HYDRUS-1D codes were used to simulate groundwater recharge. The model provided results for surface runoff, actual evaporation, transpiration, and recharge. Two periods, 1965-1988 and 1989-2018, were used to identify the change of annual water balance. Model output for recharge indicated no significant change in the south and an increase in the central and northern of parts of European Russia. Grinevskiy's explanation of this phenomenon was the lack of significant increase in evapotranspiration despite higher temperatures. The increase in temperatures is compensated by decreased wind speeds. The other explanation highlights the effect of changes in winter climate on recharge. Increase in winter temperatures and precipitation leads to an increase in moisture absorption during thaws and absence of evapotranspiration.

The next speaker, Robert Reinecke, introduced global scale groundwater recharge estimations using multi-model ensembles. He highlighted the importance of groundwater resources as a reliable source of drinking water, especially under drought conditions. Uncertainties of groundwater recharge estimates at different global warming levels were analysed. An ensemble of 96 models was created using 8 Global Hydrological Models (GHMs) driven by 4 bias-adjusted outputs from Global Circulation Models (GCMs), 4 warming levels and 3 Representative concentration pathways (RCPs). Uncertainties in recharge estimates occur especially in dry areas. The results showed a 19% recharge increase in northern of Europe and a 10% decrease in the Amazon at 3°C compared to pre-industrial period. The research explored the inclusion of CO2-driven vegetation processes which resulted in recharge changes of 100 mm/year in some regions. The model also detected milder decreases in groundwater recharge when CO2-driven vegetation processes were included.

SESSION SUMMARIES

Plenary Session	4
Date & Time	29-10-2020, 15:00-17:00 CET
Theme	Climate Change Effects on Groundwater Resilience - Pollution & Remediation

Keynote Speakers & Panellists

Tibor Stigter, ISC member, Moderator

Dinis Juizo, ISC member, Co-moderator

John Cherry, Director, The University Consortium Adjunct, Professor, University of Guelph & Distinguished Professor Emeritus, University of Waterloo, Keynote speaker

Walid Chmingui, National Research Institute for Rural Engineering, Water, and Forestry, Carthage University, Tunisia, Oral presenter

Josep Mas-Pla, Professor at University of Girona, Spain, and Catalan Institute for Water Research, Oral presenter

Felix Ortmeyer, Researcher, Hydrogeology Department, Ruhr-Universität, Germany, Oral presenter

Teresa E. Leitão, Senior Research Officer, Laboratório Nacional de Engenharia Civil (LNEC), Portugal, Oral presenter

Presentations

John Cherry

- "The need for passive strategies for groundwater remediation during climate change"

Walid Chmingui

- "Pharmaceutical active compounds in groundwater: contamination and related risks under reclaimed water reuse in agriculture"

Josep Mas-Pla

- "Expected effects of future hydrological water balances on the antibiotic and ARG occurrence in groundwater"

Josep Mas-Pla

- "Governance and groundwater modeling: Addressing governance gaps on nitrate pollution"

Felix Ortmeyer

- "Projection of groundwater nitrate evolution under different climate scenarios in NW Germany"

Teresa E. Leitão

- "Precipitation pattern changes impact in the groundwater quality at Aluviões do Tejo aquifer, Portugal"

Key Messages

- *When evaluating possible solutions for remediation of polluted groundwater bodies, it is crucial to understand the hydrological and hydrogeochemical processes involved. This can be done using monitoring networks and groundwater models.*
- *Remediation interventions should be selective and driven by a comprehensive characterization of the hydrogeological system, focusing on the assimilation capacity of an aquifer.*
- *Passive remediation systems can be effective in cases of point-source contaminations and might be crucial in areas which will face water scarcity in the future.*
- *Diffusive sources of contamination – such as nitrate – would be more difficult to remediate and likely to be impacted by climate change.*

Session Summary

Many groundwater bodies worldwide are in critical conditions due to depletion and pollution. Except for geogenic pollution, aquifers are at risk due to contaminants resulting from human activities (so-called anthropogenic pollution). In this session, new tools for monitoring and understanding groundwater resilience are discussed, with a focus on resilience to climate change.

The remediation of groundwater sites affected by point-source contamination is often addressed with an active approach, with methods requiring continuous inputs of energy and engineering activity. Different case studies conducted in North America showed that a passive approach might be more effective. In this case, it is essential to establish a monitoring network able to indicate the current status of contaminant plumes and their evolution through time. A combination of monitoring data and groundwater modelling can allow researchers to track the state of contaminant plumes and ensure that essential locations such as drinking water sources are not affected. This kind of approach should be considered especially in sites where climate change will likely increase drought periods. This is because active remediation solutions imply the disturbance of hydrogeological systems that might increase their strategic value in time.

Agriculture is undoubtedly one of the most common sources of groundwater contamination. Despite the extensive research done in this respect, the increase of emerging pollutants in wastewater is a rising concern for water-recycling. A case study from North-Eastern Tunisia investigated how irrigation from treated wastewater can affect groundwater in terms of pharmaceutical active compounds (PACs). The analysis for three pharmaceuticals showed the presence of these compounds in samples of treated wastewater as well as in groundwater. This study provides an example of how irrigation from low-quality water can increase risks for farmers and for ecosystems.

In western Catalonia, Spain, it was shown that the occurrence of antibiotics was strictly linked with the hydrodynamics of the aquifer. Data showed that some compounds were found after heavy rainfall events, suggesting some soil retention and subsequent release in infiltration. This mechanism could be affected by climate change in the future, because of the decrease of aquifer recharge and/or the increase of heavy rainfall events. Antibiotic-resistant genes (ARG) did not show significant seasonal behaviour, being more land use-dependent, with highest concentrations in the proximity of farms.

Groundwater flow and transport models can support governance principles in addressing challenges for nitrate pollution. In fact, these models can help in filling the gaps for a successful strategy. With this regards, two case studies were presented for northern Italy and North-West Germany respectively. Both studies used solute transport models to identify areas with high nitrate concentration and to analyse the effect of different possible managements of land, crops, manure, and livestock. Aquifer resilience under different climate change scenarios was also addressed, highlighting the importance of solute transport modelling to support effective long-term decision-making.

A different approach was taken to study how changes in precipitation patterns affect groundwater quality in an aquifer nearby Lisbon, Portugal. In this study, past precipitation and water quality records were used to investigate the impacts of annual rainfall on groundwater contamination. Despite the difficulties in isolating the effect of weather conditions to other factors (i.e. land-use change, implementations of new regulations etc.), the study showed that contaminants are retained and accumulated in the subsoil in times of droughts, suggesting potential impacts of climate change on water quality.

SESSION SUMMARIES

Plenary Session	5
Date & Time	29 October 2020; 16:30 –18:00 CET
Theme	Groundwater Governance, Management & Policy

Keynote Speakers & Panellists

Elena Lopez Gunn, ISC member, Moderator

Peter van der Keur, Senior Scientist, Geological Survey, Denmark and Greenland, Co-moderator

Aysha Peterson, PhD Candidate, University of California, USA, Oral presenter

Ruth Meinzen-Dick, Researcher, International Food Policy Research Institute, Oral presenter

Wolfgang Kinzelbach, Professor, ETH Zurich, Switzerland, Oral presenter

Greg Sixt, Research Manager, MIT, USA, Oral presenter

Fernando Gonzalez Villareal, Researcher, Universidad Nacional Autónoma, México, Oral presenter

Jenny Gronwall, Advisor, SIWI, Sweden, Oral presenter

Presentations

Aysha Peterson

- "Contesting water injustice farmworker activism, climate change, and groundwater governance in California"

Ruth Meinzen-Dick

- "Gaming the system stimulating rules and behaviour change for governance of groundwater and conjunctive use in India"

Wolfgang Kinzelbach

- "A path towards sustainable use of an overpumped aquifer example the North China Plain"

Greg Sixt

- "Water diplomacy at the macro scale groundwater governance in the high plains aquifer region of the United States"

Fernando Gonzalez Villareal

- "Groundwater governance in Guanajuato, Mexico towards an effective regulation of the Pénjamo-Abasolo aquifer"

Jenny Gronwall

- "Groundwater and the human right to water coping through self-supply"

Key Messages

The session is dedicated to the analysis of the importance of the groundwater governance, management and policy framing aspects. Often, too much emphasis is placed on technical knowledge and too little on the policy framing which results in unsustainable groundwater use. The session enlightens the following key messages:

- *High variability of water regulations, governance, and policy frameworks.*
- *Vital role of community and grass-root involvement for more efficient policies implementation.*
- *Encouraging and innovative ways to present policies to make them interesting.*
- *Inter-dependence of science, management, and policy.*

Session Summary

The session is covering the groundwater sustainable path in different parts of the world, from India and China to Mexico and the USA. It also discusses groundwater governance during climate change and human rights.

Ayesha Peterson's ethnographic research in the agricultural land of California discusses groundwater exploitation. The residential areas are highly contaminated with nitrate leaching from agricultural fields causing health problems, specifically cancer. The wells were also contaminated with other organic compounds, causing several diseases already by 2005. This motivated the formation of water remediation groups and the implementation of better groundwater governance. In 2012, a quarter million people lived in the risk area, due to agriculture. The focus of such action was to find the interrelation of social aspect in hydrology.

The next speaker, Ruth Meinzen-Dick, presented an approach that aims to change behaviour for better groundwater management by playing behavioural games. She highlighted high subtractibility and fugitivity of groundwater resources as well as its shared use by communities. In her work, collective action is challenged by experiments and games. Different seasons and external factors were implemented in the development of the game. The games were played by a group of five men or five women observing different crops and effects on water table fluctuation among others. The major idea behind such an approach is to learn on practice, to rethink, to look at a problem from different perspectives and offer space for people to understand. The games were piloted in states such as Andhra Pradesh, Rajasthan, and Madhya Pradesh in India. Such expansion leads to the rise of awareness and building a positive attitude towards sustainable water management.

Wolfgang Kinzelbach presented a case study on re-establishing sustainable use in the over-exploited aquifer system of the North China Plain. Aquifer over-pumping due to irrigation is a worldwide phenomenon, and the North China Plain is one of the hotspots. Between 2003 and 2012, the depletion of the aquifer system (i.e. recharge minus pumping) amounted to between 60 and 80 billion m3 of groundwater. The abstraction rate was about 20 percent more than the estimated sustainable amount. To reach the goal of sustainable use, a groundwater management plan has been set up as a cycle of monitoring, decision support by modeling and policy implementation. The monitoring of pumping is a challenge; electricity was used as a proxy to estimate groundwater abstraction. The data was processed and modelled to estimate the groundwater budget. The policy framework considers subsidies for fallowing of winter wheat and water saving irrigation equipment to promote groundwater sustainability. Collection of water fees are introduced, according to a three-tiered scheme with fees increasing from 0 for sustainable use to 0.20 CNY per cubic meter for excessive use.

Greg Sixt presented another case of overexploited aquifer in the USA and how water diplomacy was implemented on a macro scale there. The High Plain Aquifer is the most intensively used aquifer in the USA, and it is facing a considerable water level decline. Water diplomacy is an interdisciplinary, collaborative process that engages state and non-state stakeholders to address and resolve water conflicts. Water diplomacy has two scales-micro and macro. At the macro scale, water diplomacy considers the factors within governance institutions that support sustainable water management outcomes. In the USA, groundwater is governed at the state level with two principles: water rights and water allocation rules. In Kansas, for example, groundwater is a property right and is allocated by the prior appropriation principle. In Nebraska, groundwater is state owned "for the benefit of its citizens" with allocation being a hybrid of reasonable use and correlative rights. In Texas, groundwater is a property right with the principle of rule of capture. Thus, within the same aquifer, there are three different approaches to groundwater governance yielding different degrees of sustainability concerning groundwater management. Demonstrating almost all the principles of water diplomacy, Nebraska's groundwater governance system looks well positioned to address emerging groundwater quantity and quality challenges, including those posed by climate change. Further research is warranted to explore its potential as a model for collaborative, adaptive groundwater governance.

The next speaker, Fernando Gonzales Villareal, analysed Mexican groundwater governance in the context of Penjamo Abasolo Aquifer. The purpose of this research is to analyse the governance system and identify the elements that inhibit sustainable management of the aquifer. With 653 aquifers, 105 of them are

over-exploited, irrespective of regulation. The Penjamo Abasolo Aquifer is an overexploited aquifer with intensive pumping for agriculture that resulted in groundwater pollution. The aquifer sustainability is not set as a priority. From a governance perspective, the aquifer lacks financial support for monitoring and efficient management. The proposed approach suggests the integration of the components: technical (improve efficiency in agriculture), policy (using internet of things), institutional and implementation (to enact regulation). The need is to develop policy, to create an abstraction fee and other regulation for industrial purposes. Finally, the groundwater management plan includes establishing a deadline and regulation acts to balance withdrawals.

Jenny Gronwall discussed the human rights in water governance. Around 2.5 billion people solely depend on groundwater as a source of drinking water. Self-supply is a global trend in rural, urban and peri-urban areas. The analysis of international human rights law and UN documents was conducted to explore the state duty for the human right fulfilment of water through direct water service. According to human rights and the UN, the right to water must be respected, protected and fulfilled by the state. As a general rule, services provision is a last resort solution, and groundwater self-supply is a norm under the human right to drinking water. However, exception holds where people cannot reasonably be expected to have their own water source. A case study from Argentina illustrates the duty to provide drinking water after a wastewater treatment plant contaminated the groundwater. The conclusions of this research are that the state must have robust governance policies to ensure sustainable resource management and adequate awareness at household level of when their groundwater is safe.

SESSION SUMMARIES

Plenary Session	6
Date & Time	29-10-2020, 18:30-20:00 CET
Theme	Groundwater Natural Resources Assessment under Climate Change

Keynote Speakers & Panellists

Richard Taylor, ISC member, Moderator

Renée Martin-Nagle, IWRA Treasurer & ISC member, Co-moderator

Bridget Scanlon, Senior Research Scientist, Bureau of Economic Geology, Jackson School of Geosciences, USA, Keynote speaker

Jana Levison, Associate Professor, University of Guelph, Canada, Oral presenter

Chinchu Mohan, Postdoctoral Researcher, Global Institute for Water Security, University of Saskatchewan, Canada, Oral presenter

Mary Hingst, Doctoral Student, University of Delaware, USA, Oral presenter

Robert DiFilippo, Doctoral Researcher, Loughborough University, United Kingdom, Oral presenter

Carolina Martinez Salvador, Post-Master scholarship holder, Universidad Nacional Autónoma, México, Oral presenter

Presentations

Bridget Scanlon

- "Impact of climate extremes and human water use on water resources in major U.S. aquifers using GRACE satellite data"

Jana Levison

- "Agriculture, groundwater use, and climate change: A subwatershed-scale investigation in southern Ontario, Canada"

Chinchu Mohan

- "Uncertainties in groundwater recharge projections using CMIP5 data – a global study"

Mary Hingst

- "Driving Mechanisms and Timescales of Saltwater Intrusion near Dover, DE (Delaware)"

Robert DiFilippo

- "Inter-Disciplinary Freshwater Lens Assessment Protocol for Karst Islands (Bantayan Island, Cebu Province, Philippines)"

Carolina Martinez Salvador

- "Vulnerability indexes in groundwater assessment - The case of the GOD index in Mexican aquifers and its relationship with mine tailing projects"

Key Messages

- *Results from state-of-the-art research techniques showed that natural factors such as climate change and saltwater intrusion will exhibit a long-term impact on the availability of groundwater resources.*
- *The impacts of these natural factors, however, can be minimized by controlling anthropogenic factors such as irrigation through evidence-based and site-specific policy formulation and decision-making.*
- *To minimize the impacts of these natural factors, concrete approaches were suggested such as conjunctive groundwater-surface water use, reduction of pumping, implementation of managed aquifer recharge techniques, proper land management, and long-term groundwater monitoring.*

Session Summary

The session focused on the assessment of groundwater availability, which is influenced by natural (e.g., climate change, saltwater intrusion) and anthropogenic factors (e.g., irrigation) in local to global scales. Some evidenced-based approaches towards sustainable water resource management are also recommended in order to adapt to climate change impacts.

As noted by Bridget Scanlon who used data from Gravity Recovery and Climate Experiment (GRACE), regional climate can strongly influence the changes in quantity of water stored in regional aquifers. The impact of droughts can either be amplified by extensive irrigation use or be dampened by conjunctive use of surface and ground waters, the latter of which is one of the recommended approaches to prolong aquifer lifespan. Other suggested approaches include reduction of irrigation pumping and employment of managed aquifer recharge techniques.

The integrated hydrologic modelling work by Jana Levinson demonstrated that some sub-watersheds can be naturally resilient to long-term climate change because of their favourable hydrology. Even though these watersheds can offer more opportunities in terms of better agricultural production, they can still impose challenges as their aquifers can remain stressed depending on nature of groundwater use. Furthermore, they can exhibit significant changes in the timing of water availability. Thus, long-term groundwater monitoring will be crucial.

Climate model studies of Chinchu Mohan estimated significant ranges of uncertainty in projected global groundwater recharge values. Even though global groundwater recharge is expected to increase by the year 2070, it will be non-uniform across the globe through time.

The seawater intrusion modelling done by Mary Hingst showed that surface water bodies (associated with surface inundation techniques such as irrigation ponds) can serve as pathways for saltwater intrusion. This could be worsened if the place is frequently visited with storms, as the aquifer will take longer time to return to normal salinity levels.

The models of freshwater aquifer in a small island by Robert DiFilippo emphasized the impending threat from surrounding saltwater intrusion, as aggravated by groundwater abstraction. The island's vulnerability to this threat, however, can be altered by well field management, land development, and groundwater use and recharge. These three activities, in turn, depend on the current vulnerability state of the island. This reflects a feedback loop where water and environmental agencies and other related government units from local to national scales will play a big role.

Finally, the assessment of groundwater vulnerability indices done by Carolina Martinez Salvador proved that using these indices may not always reconcile well with the results from other related indices (e.g., climate change index) and data from existing reports (e.g., water storages and overexploitation). As such, these vulnerability indices must be refined, and their spatial resolution is one aspect that can be checked.

SESSION SUMMARIES

Plenary Session	7
Date & Time	30-10-2020, 08:00-09:30 CET
Theme	Groundwater Natural Resources Assessment under Climate Change

Keynote Speakers & Panellists

Richard Taylor, ISC member, Moderator

Sara Nowreen, Assistant Professor, Institute of Water and Flood Management (IWFM) & University of Engineering and Technology (BUET), Bangladesh, Co-moderator

Jonathan Mackay, British Geological Survey (BGS), United Kingdom, Oral presenter

Rouyan Gong, School of Geography and Planning, Sun Yat-sen University, China, Oral presenter

Alan Ricardo Patlan Hernandez, Foundation Action Contre la Faim, France, Oral presenter

Nasser Tuqan, The Centre for Territory, Environment and Construction (CTAC), University of Minho, Portugal, Oral presenter

David MacDonald, British Geological Survey, United Kingdom, Oral presenter

Abdelkader Larabi, Regional Water Centre of Maghreb, Mohammed V University, Morocco, Oral presenter

Presentations

Jonathan Mackay

- "Proglacial groundwater storage dynamics under climate change and glacier retreat"

Rouyan Gong

- "Propagation from meteorological to groundwater drought response to global warming"

Alan Ricardo Patlan Hernandez

- "Investigate the relationship between hydro-climatic monitoring and health indicators in a context of chronic drought, Madagascar"

Nasser Tuqan

- "Assessment of the impact of agricultural water use under changing climate on an aquifer"

David MacDonald

- "Tools to reconstruct past and project future groundwater levels to inform groundwater resource management in sub-Saharan Africa"

Abdelkader Larabi

- "Assessment of climate change impacts on groundwater resources using RICCAR Data in the Beni-Amir Aquifer (Tadla Complex, Morocco)"

Session Summary

Session 7 summarised different methods applied in estimating the effects of climate change on groundwater resources, starting with rarely researched proglacial groundwater systems and finalised with aquifers located in semi-arid and arid regions. Along the narrative of this session, we could observe the importance of groundwater level fluctuations. Such events as groundwater droughts or large multi-decadal patterns could inform decision-makers for a better resource management. Modelling tools play a significant role in assessing natural groundwater resources under changing climate.

The first speaker, Jonathan Mackay, started the session with the study on rarely investigated proglacial groundwater systems and their change under climate change. These systems are usually present under overburden materials, alluvial valley aquifers, and mountain wetlands. They play an important role in ecological and mountain water cycle, providing water downstream. The observation was conducted at the foot of Virkisjökull glacier in Iceland where it feeds a river downstream. This river further flows to the alluvial, unconsolidated and unconfined aquifer. Runoff is driven by the glacier melting and occurs seasonally and thus water flows over the land and contributes to the groundwater recharge. The research aimed to identify drivers of the proglacial groundwater storage dynamics and its response to climate change and glacier retreat. Integrated climate-glacier-groundwater models were used with different climate scenarios. The output of glacio-hydrological models served as boundary conditions for distributed groundwater models (MODFLOW). The findings for groundwater storage projected fall of groundwater levels, and both groundwater levels and storage driven by diffuse recharge. Overall, glacier retreat could hinder river recharge, and groundwater storage dynamics are resilient to changes in river recharge. Moreover, groundwater buffers proglacial river runoff under climate change.

The second speaker, Rouyan Gong, presented her work on investigation groundwater droughts under global warming. The study area is located in the very south of China, and it is a coastal area. Standardized Precipitation Index was used to analyse the number and severity of meteorological droughts. For this particular case study Gong found out that meteorological droughts were occurring more often comparing to groundwater droughts. The propagation time from meteorological to groundwater droughts had different performance in shallow and deep aquifers. This was explained by the slow groundwater cycle and groundwater exploitation. The occurrence of groundwater droughts was also happening in line with continuous meteorological droughts (> 3 months).

The research project of Alan Ricardo Patlan Hernandez connects public health and hydro-climatic monitoring in Madagascar. The population is directly and indirectly vulnerable to malnutrition and climate change. The main objective of the study was to find the relationship between hydro-climatic monitoring data and nutritional and morbidity indicators in the District of Betioky-Atsimo. The target group of the study were children from 6 to 59 months. The data on monthly pluviometry, piezometric index, leaf area index, number of admissions to Centres for Outpatient Nutritional Rehabilitation for Severe Malnutrition (CRENAS), and number of screened children with acute malnutrition, were collected. Analysis was conducted using correlation coefficient, regression model, and time series analysis. Preliminary results indicated a lagged impact of hydro-climatic indicators on malnutrition in the District of Betioky-Atsimo. However, the state of evidence is still not strong and more research is needed.

Another study that assessed the impact of agricultural water use under changing climate on an aquifer was conducted in the West Bank by Nasser Tuqan. The Easter Aquifer Basin is located in a water scarce area challenged by complex geopolitical situation. Agriculture is the main sector withdrawing groundwater. That is why the analysis was done to understand the impacts of agriculture water use using sufficiency approach. Credible sources of climate information together with interview results of farmers and decision-makers were used to estimate water use efficiency. Efficiency considers water quality, quantity and beneficence, and it also looks on macro, meso and micro scales. Climate Change Projections were adapted from the National Adaptation Plan to Climate Change published by the Palestinian Environment Quality Authority in 2016. The results showed that 3°C increase

in temperature with 20% of precipitation decrease in the near future might lead to 10% increase of evapotranspiration, and this cycle would drive the abstraction to be increased for 30% to get the same yield production. The sustainability of the aquifer can be ensured only by managing it taking into account transboundary character of the aquifer.

David MacDonald spoke about tools to reconstruct past and project future groundwater levels for informed groundwater management in sub-Saharan Africa, in Ghana, and Burkina Faso. Such tools are needed to quantify climate-driven changes in groundwater systems. Simple lumped parameter model and linked simple conceptual models were used due to lack of data. The advantage of a lumped model is that it provides a range of parameters, and runs quickly. The model technique was then applied in Burkina Faso, a country with an extensive groundwater monitoring network. The set of groundwater level observations fall into three groups: long term declines, short term fluctuations and longer-term changes. The last two might by controlled by hydrogeology. Large multi-decadal patterns of groundwater levels can be seen similar to climate observations, and ideally, they should be considered for water resources management. Future projections showed that there is a wide variability of groundwater level changes due to uncertainties in using climate models, especially in arid regions. Long-term groundwater monitoring is necessary to estimate changes in groundwater levels.

Abdelkader Larabi presented another method of assessing the impact of climate change on groundwater using the Regional Initiative for the assessment of Climate Change Impacts on water resources and Socio-economic vulnerability in the Arab Region (RICCAR) Data. The study area is located in the Beni-Amir Aquifer (Tadla Complex), Morocco. The aquifer has a high value for drinking water supply, agriculture, and industry. The research targeted to identify the availability of groundwater in the aquifer under changing climate and potential extension of irrigated zones as well as exploring the best management schemes. Climate and hydrological models were coupled and used as basis for 3D groundwater model in MODFLOW to analyse the impacts of climate change on the Oum Er Ribia basin. Future projections for recharge under RCP 4.5 and 8.5 indicated the increase. The simulations were run for 2020 – 2100. Aquifer piezometry as model's output resulted in dried areas for both RCPs in the second and third layers of the aquifer. The model predicts the decrease of recharge that might lead to decreased water availability, specifically for scenario RCP 8.5. Observed simulated groundwater levels drop from 10 to 25 m. Adaptation strategies that account such changes are needed to satisfy all water demands in the future.

SESSION SUMMARIES

Plenary Session	8
Date & Time	30-10-2020, 09:45-11:15 CET
Theme	Climate Change Effects on Groundwater Resilience - Pollution & Remediation

Keynote Speakers & Panellists

Tibor Stigter, ISC member, Moderator

Jared van Rooyen, Stellenbosch University, South Africa, Co-moderator

Hafsa Mahmood, PhD Student, Geoscience Department, Aarhus University, Denmark, Oral presenter

Sikandar Hayat, Eötvös Loránd University, Hungary & Erzsébet Tóth Endowed Hydrogeology Chair, Hungary, Oral presenter

Gontle Rankgomo, MSc Student, Pan African University Institute of Water and Energy Sciences (including Climate Change), Oral presenter

Paul Pavelic, Senior Researcher, International Water Management Institute (IWMI), Oral presenter

Pham Van Tuan, Water Resources System Research Unit, Faculty of Engineering, Chulalongkorn University, Thailand, Oral presenter

Enrique Fernández Escalante, IAH MAR commission & Specialist, TRAGSA, Oral presenter

Zsóka Szabó, Hydrogeologist, PhD student, Department of Geology, Eötvös Loránd University, Hungary Oral presenter

Presentations

Hafsah Mahmood

- "Managed Aquifer Recharge as a source of emerging pollutant in groundwater"

Sikandar Hayat

- "Site suitability mapping for Managed Aquifer Recharge (MAR) implementation in Poralai and Hangol, the coastal basins of Baluchistan, Pakistan"

Gontle Rankgomo

- "Assessing the potential of artificial groundwater recharge: Case study of Palla Road well fields, Botswana"

Paul Pavelic

- "Co-managing floods and droughts on the Gangetic Plain through a novel MAR approach"

Pham Van Tuan

- "The impact assessment of climate change on groundwater resource development in the Vietnamese Mekong Delta. Case study: Tra Vinh Province"

Enrique Fernández Escalante

- "Water quality regulations and guidelines for Managed Aquifer Recharge—International synopsis, contrast and lessons learned"

Zsóka Szabó

- "Preliminary results of Rooftop Rainwater Harvesting and shallow well infiltration pilot project in the Danube-Tisza Interfluve, Hungary"

Key Messages

- *The increasing pressure on groundwater resources by an increasing water demand as well as climate change is imposing the finding of solutions to sustainably satisfy water demand*
- *Managed Aquifer Recharge (MAR) is an established adaptation solution for water supply and could represent a promising strategy for addressing flood mitigation and groundwater depletion*
- *MAR interventions should be designed according to the suitability of the site and technique*
- *Legislation on water quality of MAR is crucial to protect and preserve groundwater bodies*

Session Summary

The global rising of water demands and climate change is increasing the pressure on aquifers around the world. An example of this challenge is presented in a case study from the Tra Vinh Province in the Mekong Delta, Vietnam. Here, different climate change scenarios, as well as different socio-economic scenarios, are used to foresee the state of groundwater resources in the area. Forecasts show severe groundwater depletion in case of business as usual scenario, with subsequent increase in salinity.

Innovative solutions are needed in order to sustainably satisfy water demands and avoid aquifer depletion. A study from Eastern Botswana investigated the potential of managed aquifer recharge (MAR) in coping with water scarcity issues in the African country, which is highly dependent on groundwater resources. The spatial analysis of groundwater recharge, as well as the analysis of water balance, highlighted the potential of storing water from intense rainfall events.

However, it is important to note that MAR planning should follow the suitability of the site in terms of hydrogeological and climate characteristics. A study presented in this session illustrates the selection of the most effective MAR techniques for a basin in Baluchistan, Pakistan, and the method used to select the favourable sites for the implementation of these measures. Suitability mapping with GIS-MCDA was performed based on precipitation, land cover, topography, geology and drainage density. The resulting suitability maps showed the most promising sites for specific MAR interventions.

In the Gangetic Plain in India, a pilot project is investigating a novel solution of MAR called Underground Transfer of Floods for Irrigation (UTFI). This intervention consists of storing runoff water, captured during flood events, into the aquifer for later use for irrigation purposes. This approach would allow mitigating flood damages and the replenishment of the aquifer storage at the same time. Three-year results of UTFI have demonstrated the potential of this technique. In fact, in case of consistent upscaling of the technique in the Ramganga river basin, seasonal flood risk is predicted to decrease as well as groundwater declines reversed.

Another small-scale pilot project is presented from a case study in Hungary, where shallow well infiltration is investigated as a local-scale solution for water shortage. Water collected from the roof of a family house, in a small agricultural town, was infiltrated to the shallow aquifer. Groundwater levels, water quality and water temperature were monitored throughout the time in the shallow well and two monitoring wells located near the site. The first results of the water-level time series show an increase of the water storage.

Another essential aspect to consider when designing MAR intervention is the avoidance of groundwater quality deterioration. A study conducted in northeast Tunisia investigates the occurrence of emerging pollutants (EP) in an aquifer as a result of an MAR system which uses treated wastewater as a water source. The pollutants detected in the treated wastewater were also found in samples collected in different parts of the aquifer. Groundwater flow and solute transport models were used to identify the scale and the propagation of contamination such as Carbamazepine. Results revealed concentration values that are ten-fold lower than that of treated wastewater, suggesting that absorption processes are dominant.

With regard to the control of groundwater quality in MAR system, countries around the world have implemented different sets of regulations. A study presented in this session provided a global overview of water quality regulations for MAR. It is shown that maximum allowable concentrations (MAC) vary significantly between countries for different parameters and compounds. The suggested recommendations involve the use of common terminologies as well as a distinction in the limits imposed according to the MAR technique used and the source of water for MAR (e.g. rainwater, river runoff or treated wastewater).

SESSION SUMMARIES

Plenary Session	9
Date & Time	30-10-2020, 11:30-13:00 CET
Theme	Groundwater Education and Capacity Building

Keynote Speakers & Panellists

Jorge Ellis, Programme Specialist, Eco-hydrology, Water Quality and Water Education, UNESCO-IHP, Moderator

Raya Stephan, ISC member, Co-moderator

Eddy Moors, Rector, IHE Delft, Oral presenter

Brighton Munyai, Researcher, South African SADC-GMI, Oral presenter

Laurens Thuy, Programme Management Officer, WWAP, Italy, Oral presenter

Christoph Henrich ,Project Manager, IAEA, Austria, Oral presenter

Kerstin Danert, RWSN Team Leader, Professional Drilling, Ask for Water, Switzerland, Oral presenter

Subrata Singh, Project Manager, Fd for Ecological Solutions, India, Oral presenter

Ronjon Chakrabarti, Project Manager, Adelphi, Germany, Oral presenter

Presentations

Eddy Moors

- "Developing capacity for groundwater under climate change: Some reflections on the 2020 Delft Agenda for Action and the UN Water Accelerator Framework"

Brighton Munyai

- "Towards a road map for groundwater management capacity development for the SADC region"

Laurens Thuy

- "The gender perspective of groundwater governance"

Christoph Henrich

- "Enhancing regional capacities for the isotope based assessment of water resources in the context of adapting to climate change"

Kerstin Danert

- "Improving the capacity to manage & drill water wells in sub-Saharan Africa: 16 years of collaboration and experiences"

Subrata Singh

- "Communing water – co-creating knowledge and institutions for conjunctive use of water"

Ronjon Chakrabarti

- "Development of a web-supported MAR concept for a pilot study in Recife, Brazil"

Key Messages

The session is inclined towards the importance of groundwater knowledge and awareness. The panellists enlighten the following key messages:

- *Need of groundwater education in higher education across the world.*
- *The interdisciplinary knowledge and approach to manage groundwater and to enhance capacity.*
- *The importance of innovation in the education system at the grassroots level in developing countries.*

Session Summary

The session is concerned about the education and capacity building of freshwater including groundwater, which is critical with respect to SDGs, mainly SDG 4, 5 and 13. Being an invisible resource, it is very challenging to decipher the dynamics of groundwater where technology and science play a crucial role. In the way forward, usage and distribution of groundwater come in play where the sociological and economical knowledge play an important role. This finally leads to the enhancement of groundwater knowledge and capacity for the benefit of society and environment.

Eddy Moors mentions the main reflection on the UN water acceleration framework and 2020 Delft action. The buffering capacity, quality and invisibility make groundwater unique. From historical water witching to GRACE satellite usage, the need for groundwater education was also mentioned in the World Economic Forum Global Risk Landscape 2020. The water risk and the role of groundwater are underestimated and need extensive research. Accordingly, the capacity development in people and institutions needs to be improved. Climate change, groundwater salinization and recharge are major emerging challenges in groundwater. Experience learned between 2015 and 2020 highlight the need to improve data analysis and interpretation along with data collection. Another need is to increase capacity building in people and institutions.

From the 2020 Delft agenda of action, major key points are breaking the counting heads mentality for measuring capacity development impact, focusing on inclusiveness and blended approaches and funding for capacity development. The Erasmus Mundus GroundwatCh program is one such a program, focusing on knowledge and skills in the field of hydrogeology, global change, impacts and adaptation.

In the SADC region, in Africa, the need of groundwater is huge and increasing rapidly. Therefore, the need for groundwater management capacity in the SADC region is urgent. Previous groundwater capacity assessments have concluded that capacity needs are required in various fields of groundwater science. In the 15 member states meeting, the project approach and methodologies were defined, including challenges, data collection challenges, human and resource capacity and availability, and access to information and science. The common area of interest was to enhance data collection and sharing through various platforms, pilot projects, literature archives and portals. Mutual and cooperative research and education will mitigate the challenge of groundwater overexploitation.

The UNESCO-IHP Programme focused on gender and water prospective under the WWAP initiative. From the desk review of literature and policies to the ground-truthing, extensive research has been carried out which shows that woman play a crucial role in groundwater usage.

The case study from Stampriet transboundary aquifer system reveals that in Botswana, some water laws are outdated, as well as institutional gender, legal pluralism leading to unequal access to water, while, on the other hand, more advanced regulations exist in Namibia. Several gender field surveys were carried out to find the ground truth. The results reveal that from the methodological point of view, gender-responsive indicators passed the test. From the desk research, there exists a weak legal basis for strengthening women's participation despite advancements, mainly due to legal pluralism and lack of gender balance in decision-making. The speaker sheds a light on the capacity strengthening and concludes that incorporating gender mainstreaming in national legislation is the way forward.

The better understanding of complex aquifer systems using isotope hydrology techniques is indispensable for effective integrated water management. Proficiency in isotope-based techniques and capacity to apply them differs significantly among countries in the Europe and Central Asia region. Through a new Technical Cooperation project in the Europe and Central Asia region, the IAEA is supporting 27 countries in order to increase awareness on isotope techniques, to transfer knowledge and build capacity on the use of isotope hydrology, to address sub-regional and transboundary questions, and to enhance monitoring networks in the region. Within the project, several case studies will be conducted to enhance inter-regional capacity building and facilitate knowledge transfer between participating countries. The studies focus on the determination of climate change impacts on

karst aquifers and groundwater/surface water interactions in the Western Balkans, groundwater nitrate contamination in Eastern Europe and Caucasus, vulnerability of stratified transboundary aquifers to over-abstraction and pollution, contamination problems of selected European costal aquifers, water balance and quality control in Central Asia, and others. Climate change cannot be fought alone. Isotope techniques are a proven tool for characterizing and understanding aquifer systems and thus should be widely applied to enhance the scientific basis for evidence-based decision-making in integrated water management decreasing the pressure of over-depletion of groundwater, quality deterioration and pollution.

The reality is that drilled boreholes are vital for SDG 6.1 particularly in sub-Saharan Africa (SSA). Poor design, inadequate siting and poor construction quality leads to premature failure of water supplies. An initiative by the Rural Water Supply Network (RWSN) from 2004 to 2020 to raise drilling professionalism in SSA undertook assessments in 13 countries, developed guidance materials, undertook face to face and online courses, as well as hosting blogs, webinars, and more. The approaches used there can inform understanding, materials, training, sharing and inspiring knowledge sharing for the future. The hard work put the otherwise neglected topic of drilling professionalism on the map providing considerable materials and literature for free. The development of RWSN, a professional drilling collaboration is a huge achievement indeed.

Water commons is a term defining the high subtractability and low excludability of water. Irrespective of the high investments on water management, many communities still fail to sustain over time. The importance of self-governance by the communities can be very effective for water management. For improving the situation, certain tools are needed like mapping socio-economic-ecological interactions-influencing livelihoods, analysis and synthesis of data, and finally groundwater modelling. The development of an android app CLART is an easy colour coded platform to guide people on groundwater storage, recharge areas and more. The development of crop water budgeting games is a very innovative approach to tackle this situation to enhance awareness and enhance capacity.

Managed Aquifer recharge is an efficient tool to prevent water scarcity, salt-water intrusion and others. However, several risks are involved when applying MAR, thus the idea of SMART control projects comes forward to address the needs and understanding of these risks. The risks of MAR are studied and mitigated through SMART techniques. The project is implemented in five steps with bilateral meeting, training, technology transfers, transfer-concept for the application of tools, presentation of solutions to create enabling environments and finally project developments and implementation. The case study in Recife, Brazil, is one such pilot project for transferring concepts in a public market. For the development of solutions, feasibility studies were carried out and the results showed that there are various limitations. The capacity building on SMART control tools will address public risk and efficiently address water quality, technical risk, automatic risk and advanced system management.

In a nutshell, the session sheds light on different aspects of education and capacity development in the field of groundwater. From the highly technical SMART and isotopic methods to more sociological awareness, the goal is to integrate these different subjects to manage and enhance the groundwater knowledge and capacity.

SESSION SUMMARIES

Plenary Session	High-Level Panel
Date & Time	30-10-2020, 15:00-16:30 CET
Theme	The Science-Policy Interface

Keynote Speakers & Panellists

Gabriel Eckstein, IWRA President, Moderator

Rosario Sanchez, Senior Research Scientist, Texas Water Resources Institute, USA, Co-moderator

Kirstin Conti, Public Sector Specialist, World Bank Group, USA, Panellist

Yuanyuan Li, Vice-President & Professor, General Institute of Water Resources and Hydropower Planning and Design at the Ministry of Water Resources, China, Panellist

Jorge Rucks, former National Director, National Directorate of the Environment, Ministry of Housing, Spatial Planning and the Environment, Uruguay, Panellist

Conor Quinlan, Scientific Officer, Hydrometric and Groundwater Section, Environmental Protection Agency, Ireland, Panellist

Presentations

Kirstin Conti

- "The involvement of the World Bank as a stakeholder in many groundwater projects in different countries for water governance"

Yuanyuan Li

- "North China case study in water governance and policy making to fight against groundwater over-exploitation"

Jorge Rucks

- "The effectiveness of the centre for groundwater management for Latin America and the Caribbean in solving problems of water management and over-exploitation"

Conor Quinlan

- "The European Commission which deals with climate change impacts on water systems: water governance and policy"

Key Messages

- *Scientists should communicate to other relevant stakeholders in a more understandable and effective way*
- *Communication and transparency are key elements for good water governance and policy making*
- *Groundwater should be considered as a strategic water resource and priced wisely*

Session Summary

Because of the hidden quality of groundwater, over-exploitation and pollution of aquifers may progressively increase in total ignorance. In fact, many countries where groundwater is easily accessible have witnessed uncontrolled drilling, leading to aquifer depletion and contamination. As a result, many wells are abandoned, and groundwater-dependent ecosystems are being devastated. This situation is further exacerbated by the lack of regulations, miscommunication between stakeholders, and misunderstandings of the groundwater replenishment processes by decision-makers.

In order to mitigate or avoid such problems, institutions, managers, and policy-makers need reliable and science-based information. For that, scientists need to communicate more effectively by making their message understandable via the conversion of technical aspects into common language. In fact, panellists have highlighted the challenge of communication between policy-makers, scientists and beneficiaries.

On one side, policies need an agreement within current scientific knowledge. On the other hand, scientific progressions are sometimes influenced and challenged by political requirements and “policy to action frameworks”.

Within the process of decision-making for groundwater governance, it is crucial to involve different actors such as politicians, academics, beneficiaries, and other stakeholders. Panellists have cited some good examples around the world, namely, North China groundwater rehabilitation system, the centre for groundwater management for Latin America and the Caribbean and The European Commission on climate change impacts on water systems.

SESSION SUMMARIES

Plenary Session	10a
Date & Time	30-10-2020, 16:40-17:30 CET
Theme	Contribution of Technology to Groundwater Resilience

Keynote Speakers & Panellists

Neno Kukuric, ISC member, Moderator

Enrique Fernández Escalante, ISC member, Co-moderator

Ben Kerr, Founder, Foundry Spatial Ltd., Canada, Oral presenter

Michael Campana, Professor of Hydrogeology and Water Resources Management, Oregon State University, USA, Oral presenter

Yu Li, Post-Doctoral Researcher, ETH Zurich, Switzerland, Oral presenter

Presentations

Ben Kerr

- "Connecting surface water and groundwater supply and demand over time and space to support sustainable water management2

Michael Campana

- "Enhancing groundwater resilience by harvesting glacial meltwater with Managed Aquifer Recharge"

Yu Li

- "Leveraging environmental data and models with web-based decision support systems (DSS): A case study of DSS application for groundwater management in Guantao, China"

Key Messages

- *Groundwater pumping can cause flow losses in nearby streams. The analytical depletion function is a simple yet accurate method for calculating these losses. It can easily be integrated into a Web-based decision support system to help decision makers plan operation of pumping wells and their construction.*
- *Depending on the local conditions, managed aquifer recharge using glacial meltwater can store water, distribute water availability in regions affected by unsustainable melting of glaciers.*
- *Decision Support Systems may be effective tools for water managers, they should be developed in a user-friendly way, easily maintainable and simplify workflow. Designing DSS with their target users allow the developer to balance technicality with usability.*

Session Summary

Groundwater pumping reduces flow in nearby streams by reducing or reversing groundwater discharge into them. This loss has implications for water management. There are many ways to calculate stream flow losses. Accuracy of estimates increase when computationally expensive and data-intensive methods are adopted, but the rate of increase is not constant. Calculations of streamflow-losses obtained by the Analytical depletion function method were comparable to numerical models in accuracy, but required far less effort and time. The method requires the distance(s) between the pumping well and the stream segment(s) along with a few other hydraulic properties to evaluate whether pumping will affect the stream's flow and by how much. Therefore, it is well-suited for evaluating impacts of existing and proposed future wells quickly. Considering the method's benefits, The Foundry Spatial Water Framework developed a web-based Decision Support System (Web DSS) to facilitate quick, simple, and transparent decision making.

Amid the current problem of unsustainable melting rates of glaciers, using glacial meltwater for managed aquifer recharge (MAR) is a solution. The excess meltwater can be injected into aquifers to increase water storage. Possible benefits include flood hazard reduction, better spatial and temporal distribution, and storage for irrigation and ecosystem requirements. To evaluate its success and sustainability, one must identify suitable sites, evaluate cost and local requirements and lastly identify legal or institutional issues, for example downstream requirements. One success story of MAR using glacial meltwater comes from the Yakima River Basin in the USA. The project helped agriculture and other water needs in the region, ensured sufficient ecological flow in the river during the salmon season and was welcomed by the members of the Yakama nation.

The Decision Support System (DSS) is a useful platform for structuring information and consolidating research tools for decision makers. It is important to design these systems along with the target user to balance technicality and usability. A case study of DSS application for groundwater management was conducted in Guantao County in the North China Plain. In this county groundwater resources are over-exploited to meet the water requirements of growing two crops annually. The DSS was designed for local water managers who were tasked with water planning and water fee collection but has little experience in GIS or modelling software. The DSS was designed to simplify workflow, have friendly User Interface and easy maintainability. It used open source software to develop this Web-based DSS app such as RShiny and Docker. This makes the programming aspect of DSS development easier for environmental scientists and allows easy maintainability. The DSS integrated groundwater modelling and irrigation calculation for water quota planning. It also has automated crop mapping, and it is integrated with data on precipitation and water use for better monitoring.

SESSION SUMMARIES

Plenary Session	10b
Date & Time	30-10-2020, 17:25-18:15 CET
Theme	Groundwater Education & Capacity Building

Keynote Speakers & Panellists

Jorge Ellis, Programme Specialist, Eco-hydrology, Water Quality and Water Education, UNESCO-IHP, Moderator

Alice Aureli, ISC member, Co-moderator

Adrian Parr, ISC member, Co-moderator

Moshood N. Tijani, Groundwater Desk Officer, Nigeria & African Ministers' Council on Water (AMCOW), Special lecture

Kevin Pietersen, Associate UNESCO Chair in Geohydrology; Institute for Water Studies, University of the Western Cape & L2K2 Consultants (Pty) Ltd., South Africa, Special lecture

Margaret Irungu, Transboundary Water Resources Department, Ministry of Water and Irrigation, Kenya, Panellist

Alberto Manganelli, Regional Centre for Groundwater Management for Latin America and the Caribbean CeReGAS, Uruguay, Panellist

Christian Severin, Senior Environmental Specialist, GEF-IWLEARN, Global Environment Facility Secretariat, USA ,Panellist

Mary Khimulu, Former Permanent Delegate of Kenya to UNESCO, Panellist

Lectures

Moshood N. Tijani

- "Pan African Groundwater Program (APAGroP): A new AMCOW agenda to improve capacities and education on groundwater resources in Africa"

Kevin Peitersen

- "An occupationally-directed capacity building model to support groundwater resilience technical support in Africa"

Session Summary

In the African Continent, groundwater availability is estimated to be 20 times more than surface water. Developing and managing groundwater resources are necessary for Africa amidst increasing population, water demands for agriculture and industry, and climate change. The access to safe and sufficient water, improved food security, climate resilience and socio-economic conditions need to be increased among the populace. Countries currently lack the capital, policy framework and human resource to achieve this. Further, groundwater literacy should be improved to promote effective utilisation of the source without compromising the asset at the local level. It was suggested that water education be included at different levels, including schools.

Recognising this, The African Ministers' Council on Water (AMCOW) has developed the PAN AFRICAN GROUNDWATER PROGRAM (APAGroP). The program has two branches, namely capacity development and knowledge management. Capacity development includes strengthening of policy and institutional systems, investment in developing tools and technical solutions, and developing human capacity aimed at promoting sustainable management and effective utilisation of groundwater. Knowledge management encompasses facilitating exchange of knowledge, experience and best practices among member states in the field of groundwater, groundwater advocacy and gender inclusion.

The FETWATER programme was established in 2002 to increase human capacity in the water sector. Its implementing agent is the Water Research Commission with partners as the Department of Water and Sanitation, Republic of South Africa and UNESCO IHP. The Programme is currently in its third phase. The results of first two phases include the development of seven professional networks. The lack of linkage to sector skills planning and delivery systems for professional and career development i.e. the over-emphasis of academic orientation of the networks was observed as a challenge in the water sector. Consequently, compared to the previous phases the third phase took an occupationally directed approach to capacity building aligning with sector skills priorities. The occupational priorities of FETWATER include professionals in Water Resource Management, Water Use Authorisation, Water Regulation, Water Liaison, and Water Infrastructure Management.

In Latin America, investment in groundwater education is disproportionately lower than other fields. It is not a well-known field of study. Enterprises, water companies and government agencies lack appropriately trained personnel in the field of groundwater. It has been suggested that required skilled personnel could promote groundwater education by demanding training programmes and contributing resources to them along with the government.

Transboundary aquifer management requires cooperation, trust and honest information sharing. Tools should be developed to enable communication, information sharing and conjunctive water management among different stakeholders.

SESSION SUMMARIES

Plenary Session	Closing Ceremony
Date & Time	30-10-2020, 18:30-20:00 CET
Theme	Groundwater Natural Resources Assessment under Climate Change

Keynote Speakers & Panellists

Renée Martin-Nagle, ISC Treasurer, Chair
Mary Trudeau, IWRA Officer, Co-chair
Rafael Bernardo Carmona Paredes, General Coordinator of the Mexico City Water Agency, Mexico, Keynote speaker
Richard Taylor, ISC member. Theme 1: *Groundwater natural resources assessment under climate change*, Session reporting
Tibor Stigter, ISC member. Theme 2: *Climate change effects on groundwater resilience - Pollution and remediation*, Session reporting
Neno Kukurić, ISC member. Theme 3: *Contribution of technology to groundwater resilience*, Session reporting
Elena Lopez Gunn, ISC member. Theme 4: *Groundwater governance, management & policy*, Session reporting
Alice Aureli, ISC member. Theme 5: *Groundwater education & capacity building*, Session reporting
Jacques Ganoulis, ISC co-chair, Closing messages
Jean Fried, ISC co-chair, Closing messages
Gabriel Eckstein, IWRA President, Final words

The IWRA 2020 conference, attended by more than 1,400 groundwater specialists and stakeholders around the world, ended successfully after two and a half days.

Renée Martin-Nagle expressed her satisfaction with the outstanding contribution of this conference to a better understanding of GW in the context of climate change. The conference provided a good platform for professionals to share and exchange knowledge on novel ideas on the GW resource management.

Through his presented case study of Mexico City on "Groundwater Governance, Management and Policy in Mexico", Rafael Bernardo Carmona Paredes highlighted the unique and vital role of groundwater because of its resilience. In Mexico City, aquifer overexploitation and maintenance delays and failures in the hydraulic infrastructure have contributed to groundwater losses, resulting to land subsidence, water quality deterioration, and decline in ecological flow. To address this complex issue, a multi-sectoral and diverse policy framework involving proper groundwater management, governance, and monitoring is necessary.

Various thematic leaders then summarized the overall insights gained from the presentations from each of the five conference themes. The main topics for each theme are the following:

THEME I

Groundwater natural resources assessment under climate change

- Decline in storage in drylands
- Suggested urgent demand-and-supply solutions (e.g., conjunctive groundwater – surface water use, managed aquifer recharge (mar), etc.)
- Threats in coastal areas and islands (e.g., seawater intrusion, seawater inundation from storm surges)
- Documented improvements in projections of ground water recharge
- Remaining challenges in ground water recharge projections (e.g., uncertainties from global climate models); effective ground water recharge representation)
- Extreme meteorological events (e.g., intensified precipitation) to ground water management

THEME II

Climate change effects on groundwater resilience - Pollution and remediation

- Passive strategies for ground water remediation (for point-source contaminants)
- MAR's high potential of passively attenuating pollution
- Challenges related to MAR (e.g., threats from micropollutants (e.g., pharmaceutical), tailoring standardized water quality guidelines to consider the proper context (purpose, type, site), upscaling)
- Role of climate change in water quality (e.g., leaching & dilution for higher ground water recharge, more concentration & travel time for higher evapotranspiration)
- Reduction of demand as way to reduce impact on ground water quality

THEME III

Contribution of technology to groundwater resilience

- New device and applications for better accessibility and processing of data
- Remote sensing technology for assessment of ground water resources
- Information systems and mobile applications to promote stakeholder participation
- Role of technology in assisting remote users
- Other issues in the use of technology (e.g., economics, privacy)

THEME IV

Groundwater governance, management & policy

- Self-organizing emergent behaviour and multiscalar governance
- Consideration of multiple pressure points (legal, incentives and policies), water-energy-food nexus, and indirect pressure points (electricity, fallowing land, etc.)
- Adaptive learning (e.g., collective mental models and behaviour - systems thinking)

THEME V

Groundwater education & capacity building

- Investments in ground water education, training, and capacity development
- Stronger participatory approach involving more stakeholders
- Role of citizen science
- Capacity development as a specific objective of SDG 6 Global Acceleration Framework

Jacques Ganoulis emphasized the paradox of having developed the advanced technology needed for sending a man to the moon, but not for implementing better policies and dynamics for groundwater processes. He concluded his speech with three quotations that highlight the importance of water and its sustainable management:

(1) "Water is the origin of everything." (Thales of Miletus);

(2) "Water is the mirror of our future." (A French Philosopher and Founder of French Water Academy);

(3) "We cannot recognize the value of groundwater until the well goes dry." (Benjamin Franklin).

Jean Fried stated that climate resilience for groundwater resources requires genuine governance supported by genuine policy frameworks and management approaches. A great focus must be put on improving the implementation of existing groundwater legislations and sustainability plans, for instance and among others solving the conflicts between stakeholders, for instance between public and private interests, and realizing a genuine public participation in the policy making and the management of groundwater, much advertised but not necessarily implemented correctly.

In closing, Gabriel Eckstein conveyed his immense gratitude to conference participants, to organizers, moderators, panellists, and presenters. He remarked that expectations for this conference were exceeded based on the number of registrants (22,600). He encouraged the people to join the IWRA by enumerating its membership benefits and the IWRA members to join two newly created IWRA taskforces (groundwater and water quality). He also announced that the 18th Congress will be held in Daegu, South Korea in 2021.

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MAIN FINDINGS

THEME I - *Groundwater natural resources assessment under climate change*

1) Declining groundwater storage in dry lands is observed and projected under climate change where groundwater is used intensively for irrigated agriculture. Adaptation measures require urgent demand- and supply-side solutions, such as conjunctive groundwater and surface water use, and Managed Aquifer Recharge (MAR), as well as trust where these resources are shared.

2) Groundwater abstraction in coastal environments and small-island states exacerbates risks posed by both seawater intrusion and episodic seawater inundation from storm surges.

3) Projections of groundwater recharge under climate change remain constrained by General Circulation Model uncertainty and effective representation of recharge processes but there is progress!

4) The intensification of precipitation driven by climate change is observed to amplify groundwater recharge in many environments, highlighting the importance of extreme events to groundwater sustainability and enhanced risk to groundwater quality from human activity.

THEME II - *Climate change effects on groundwater resilience - Pollution and remediation*

1) Passive strategies for groundwater remediation can be effective for point source contaminants. The idea is to focus on natural attenuation, through adsorption, degradation and dilution, so as to remediate groundwater without unnecessary pumping and treatment, thereby minimizing aquifer depletion and disruption. On the other hand, monitoring of complex contaminants in often complex geological environments needs to be comprehensive and is therefore not necessarily less expensive.

2) Managed Aquifer Recharge (MAR) can have high potential for (passive) attenuation of pollution, but micro-pollutants (e.g. pharmaceutical compounds) can also be found in groundwater, posing questions around the health and ecological risks associated.

3) MAR water quality guidelines need to be more common in terms of terminology and monitoring techniques, but specific to purpose, type of MAR and hydrogeological/ climatic setting.

4) The large challenge with MAR is upscaling, as it requires significant investment. Remote sensing and GIS tools can help assess the upscaling potential of MAR, and flow and contaminant transport modelling tools can help bridge the gap with groundwater management and governance, which requires strong collaboration between natural and social scientists.

5) Climate change is increasing rainfall intensities, which can be both beneficial and problematic for water quality:
- Higher recharge promotes leaching, problematic for shallow wells and short travel times, but also dilution, beneficial for diffuse and persistent contamination;
- Lower recharge and higher evapotranspiration promote concentration, but may also increase travel time and associated attenuation potential.

6) To reduce negative impacts on water quality from overexploitation, we also need to reduce (ground)water demand.

THEME III - *Contribution of technology to groundwater resilience*

1) Rapid advancement of technology has improved monitoring and collection of data and information relevant for understanding of groundwater resources change due to climate variability.

2) Information and communications technology (ICT) has brought variety of new devices and applications, often originating from other sectors, providing a

significant contribution to information accessibility, faster processing and better understanding of measures required to increase resilience to climate change.

3) Remote sensing technology provides important proxy data for assessment of groundwater resources, to be interpreted only in combination with terrestrial measurements.

4) Information systems and mobile applications are narrowing the gap between the regional data and solving local groundwater problems, also increasing stakeholder's participation.

5) Technology assists geographically remote groundwater users, privacy needs consideration, initial costs could be high, but technology does not need to be expensive.

THEME IV - *Groundwater governance, management and policy*

1) Increased importance of self-organizing emergent behaviour of people and communities to address groundwater problems (bottom-up).

2) Multiscalar governance from households (water justice in California), to neighbour communities (Indian collective Wells); groups of farmers (spontaneous MAR movements), to state (USA macroscale diplomacy) and national level planning (covering knowledge gaps for better national planning and action) to international global norms (human rights and self-supply).

3) Groundwater governance has no silver bullet, as there are tailored needs to multiple pressure points (China and Mexico) with legal, policy and financial needs to be considered. As well, the interlinkages with the Water-Energy-Food nexus should not be forgotten together with indirect entry points (e.g. electricity, fallowing land) (South Asia).

4) Adaptive and social and institutional learning will be critical, particularly collective mental models and behaviour systems thinking.

THEME V - *Groundwater education and capacity building*

1) Investments in groundwater education, training and capacity development, at the individual and institutional levels, remain issues of universal relevance, that need to be constantly adapted and renewed, especially under the increasing pressures of humanity and climate change. This will help more research and understanding of climate change impacts and improvement of adaptation measures.

2) The African Ministers' Council on Water (AMCOW) agenda is looking how to improve capacities and education on groundwater resources in the African continent, and with the support of UNESCO's IHP they will implement a road map for groundwater management capacity development. Actions are already taken in the Southern African Development Community (SADC) region.

3) There is a need to explore more in depth participatory approaches regarding groundwater, informed participation of more stakeholders, as well as groundwater and citizen science to ensure that no one is left behind!

4) Water is a connector to all SDGs of the 2030 Agenda and the SDG 6 Global Acceleration Framework, and has the capacity development as one of its specific objectives.

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CONCLUSIONS

IWRA's Online Conference addressed assessment, pollution and remediation, technology, governance, policy and management, and capacity building and education challenges and priorities in order to manage resiliently groundwater resources under climate change in all regions of the world, including Africa, Asia, Europe and the Americas.

The main outcome of this conference was the sharing and exchange of state-of-the-art scientific knowledge within and across natural and social science disciplines, on the links between groundwater resilience, human impacts and climate change, for the sustainable use, management and governance of these resources globally.

The conference debates and results contributed to the achievement of the objectives of the thematic areas – "Groundwater in a Changing Environment" and "Education Key to Water Security" – of the eighth phase of the UNESCO-IHP programme "Water Security: Responses to Local, Regional, and Global Challenges.

Adaptation measures from governments, organizations and institutions or local stakeholders require urgent demand and supply-side solutions, particularly were groundwater storage is declining, and seawater intrusion and episodic seawater inundation occurs.

Groundwater resilience and potential is high in many parts of the world, but the sustainability of this resource can be largely affected by human activities. Climate change can play an important role through increasing droughts and freshwater demand in certain regions of the world, whereas other areas may benefit from more intense rainfall and recharge episodes.

In the context of climate change and groundwater resilience, pollution needs to be prevented and remediated, ideally through low-cost passive techniques. Managed aquifer recharge can play a role in remediation, but also needs to follow clear guidelines to avoid disruption. Climate change impacts on pollution will be mostly felt through increased leaching (negative), dilution (positive) and attenuation potentials.

Improvements on technology and information as well as in communication technology are still needed to monitor, collect and analyse data on groundwater due to climate variability, as well as to provide support for measures to increase resilience to climate change. These improvements also help to reduce regional gaps, engage stakeholders, access remote areas and complement with other terrestrial technologies. Costs and privacy issues need to be considered.

The relationship between climate change and groundwater needs to be further studied and more research and knowledge must be shared and generated, as this may help understand if these linkages are indeed a threat or, in fact, an opportunity for better governance, policy and management.

Finally, groundwater education, training and capacity development remain issues of universal relevance requiring significant investment in time and resources at different levels. On top of this, there is a need to explore more in depth participatory approaches involving citizens and stakeholders, in particular in areas where the pressures on groundwater resources are high and there are additional risks from climate change.

RECOMMENDATIONS FOR FUTURE ACTION

The two and a half day IWRA Online Conference on "Addressing Groundwater Resilience under Climate Change" was the first significant IWRA event to bring together key groundwater and climate change academics, organisations, experts, partners and the private sector. Based on the discussions and exchanges between invited speakers, distinguished panellists and participants, various lessons and recommendations were identified for future initiatives to replicate (and further improve) the conference event:

1. More events and forums are needed, at international national, and local levels, within the international water and climate change communities and among multiple stakeholders to further grasp and discuss the effects of climate change on groundwater, as well as groundwater's crucial role in adaptation as the most significant freshwater resource on Earth.

2. The appropriate use of online platforms and channels, as well the possibility for free participation in such relevant events, is of utmost importance for promoting access, sharing knowledge, generating research, facilitating project collaboration and creating synergies. This is of particular relevance in uncertain times created by pandemics and climate change. Such open online events reduce the carbon footprint and are also very stimulating for people with generally more limited access to travel.

3. Addressing the conference theme from both natural and social science perspectives in single (non-parallel) sessions provided additional relevance to the event, and should continue to be promoted. It served to encourage discussion and collaboration among academics and water actors within and across different disciplines, thereby providing more comprehensive and integrated diagnoses and ideas for solutions and adaptation measures.

4. Holding the conference in other widely spoken languages besides English is important. It proved difficult for this event to use other languages, but a future online conference should explore the use of simultaneous translations to some languages such as Chinese and Spanish, in order to include a broader audience, deliver messages clearer for and from all parties, and obtain more outcomes.

5. This conference and future events on the topic of groundwater resilience and climate change should contribute to subsequent discussions and activities in the framework of COP26 in 2021, and UN Water's theme in 2022 dedicated to groundwater.

ANNEX 1. ABSTRACTS

- Ascott, M., Macdonald, D., Black, E., Verhoef, A. & Nakohoun, P. *Tools to reconstruct past and project future groundwater levels to inform groundwater resource management in sub-Saharan Africa*
- Campana, M. E. & T. Gibson, M. *Enhancing groundwater resilience by harvesting glacial meltwater with Managed Aquifer Recharge*
- Chang, S. W., Chung, I. M., Cho, H. S. & Hong, S. H. *Assessment of seawater intrusion affected by climate factors and anthropogenic activities: case study from South Korea*
- Chavez Garcia Silva, R., Grönwall, J., van der Kwast, H., Danert, K. & Foppen, J. W. *GIS and data tools for estimating domestic self-supply groundwater use in urban Africa*
- Chmingui, W., Mahjoub, O., Brienza, M., Jemai, A., Rmili, M. & Chiron, S. *Pharmaceutical active compounds in groundwater: contamination and related risks under reclaimed water reuse in agriculture*
- Craig, S., Wu, C. L., Stigter, T. & Groen, K. *Drivers of groundwater salinity and potential for freshwater abstraction on a semi-arid coral-limestone island in Sri Lanka*
- Conrad, A., Gico Lima Montenegro, S., Araújo Fernandes, L., Stefan, C. & Chakrabarti, R. *Development of a web-supported MAR concept for a pilot study in Recife, Brazil*
- Danert, K. *Improving the capacity to manage and drill water wells: Sixteen years of collaboration to build a foundation*
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- Gideon, V. M. *Groundwater trustees of groundwater resources: A case for decentralized response towards climate change*
- Glanville, K., Mutongwizo, T., Holley, C. & Sinclair, D. *Policing water crime in Australia: Compliance, enforcement and technology*
- Gong, R. & Chen, J. *Propagation from meteorological to groundwater drought response to global warming*
- González Villarreal, F., Arriaga Medina, J. A. & Mendoza Mata, A. *Groundwater governance in Guanajuato, Mexico towards an effective regulation of the Pénjamo-Abasolo aquifer*
- Grinevskiy, S., Pozdniakov, S. & Dedulina, E. *The impact of modern climate changes on the groundwater recharge in the European part of Russia*
- Grönwall, J. & Danert, K. *Groundwater and the human right to water coping through self-supply*
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- Henrich, C. *Enhancing regional capacities for the isotope based assessment of water resources in the context of adapting to climate change*
- Hernandez, A. P., Heath, T., Nassur, A. M., Lapègue, J. & Carrière S. *Investigate the relationship between hydro-climatic monitoring and health indicators in a context of chronic drought, Madagascar*
- Hingst, M., McQuiggan, R., Peters, C., Scott Andres, A. & Michael, H. *Driving mechanisms and timescales of saltwater intrusion near Dover, Delaware*

- Kale, E., Souza, M. D., Pinjan, H. & Tozzi, A. *Building the resilience for managing groundwater under climate change: Lessons from the Water Stewardship Initiative, India*
- Kerr, B., Gleeson, T., Zipper, S., Li, Q. & Shabani, S. *Connecting surface water and groundwater supply and demand over time and space to support sustainable water management*
- Kinzelbach, W., Li, Y., Wang, L., Li, N., Burlando, P., Wang, H., Marti, B. & Ragettli, S. *A path towards sustainable use of an overpumped aquifer example the North China Plain*
- Kracht, O., Ortega, L., Terzer Wassmuth, S., Zouari, K. & Araguas, L. J. *Improving needs assessment and project formulation with IWAVE - The IAEA water availability enhancement approach*
- Larabi, A.,Tomaszkiewicz, M. & Khayat, Z. *Assessment of climate change impacts on groundwater resources using RICCAR Data in the Beni-Amir Aquifer (Tadla Complex, Morocco)*
- Leitão, T. E., Henriques, M. J. & Oliveira, M. M. *Precipitation pattern changes impact in the groundwater quality at Aluviões do Tejo aquifer*
- Levison, J., Larocque, M., Gagné, S. & Saleem, S. *Agriculture, groundwater use, and climate change: a subwatershed-scale investigation in southern Ontario, Canada*
- Li, Y., Kinzelbach, W., Wang, L., Li, N., Wang, H., Marti, B. & Ragettli, S. *Leveraging environmental data and models with web-based decision support systems (DSS): A case study of DSS application for groundwater management in Guantao, China*
- Mackay, J., Barrand, N., Hannah, D., Krause, S., Jackson, C., Everest, J., Macdonald, A. & Dochartaigh, B. *Proglacial groundwater storage dynamics under climate change and glacier retreat*
- Mahmood, H., Caucci, S., Mahjoub, O., Kalwa, F., el Nasri, A. J. & Liedl, R. *Managed Aquifer Recharge as a source of emerging pollutant in groundwater*
- López Acosta, N. A. & Martínez Salvador, C. *Vulnerability indexes in groundwater assessment*
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- Meinzen-Dick, R., Falk, T., Priyadarshini, P., Singh, S. & Mittal, R. *Gaming the system stimulating rules and behaviour change for governance of groundwater and conjunctive use in India*
- Mohan, C. & Western, A. *Uncertainties in groundwater recharge projections using CMIP5 data a global study*
- Munyai. B, Pietersen. K, Sauramba. J, Kanyerere, T. *Towards a road map for groundwater management capacity development for the SADC region*
- Musacchio, A., Mas Pla, J., Re, V., Soana, E. & Sacchi, E. *Governance and groundwater modelling: Addressing governance gaps on nitrate pollution through numerical flow and transport simulations*
- Nyathi, M., Stigter, T., Gettel, G. & Franca, M. J. *Comparative assessment of small water storage structures in semi-arid regions considering hydro-climatic, geological and socio-economic contexts*
- Ortmeyer, F., Mas-Pla, J., Banning, A. *Projection of groundwater nitrate evolution under different climate scenarios in NW Germany*
- Patel, P. M. *Community's response to revive depleting groundwater in arid region of Kachchh*

- Pham Van, T. & Koontanakulvong, S. *The impact assessment of climate change on groundwater resource development in the Vietnamese Mekong Delta. Case study: Tra Vinh Province*
- Pavelic, P., Faiz Alam, M., Sikka, A., Mishra, V. K., Verma, C. L., Jha, S. K., Ratna, R. V. & Govindan, M. *Co-managing floods and droughts on the Gangetic Plain through a novel MAR approach*
- Petersen, A. *Contesting water injustice farmworker activism, climate change, and groundwater governance in California*
- Rankgomo, G. *Assessing the potential of artificial groundwater recharge: case study of Palla road wellfields, Botswana*
- Reinecke, R. *Changes of groundwater recharge at different global warming levels: A global-scale multi-model ensemble approach*
- Singh, S., Priyadarshini, P., Meinzen Dick, R., Mohanty, R. & Falk, T. *Commoning water – co-creating knowledge and institutions for conjunctive use of water*
- Sixt, G., McCarthy, A. C., Portney, K. E. & Griffin, T. S. *Water diplomacy at the macro scale groundwater governance in the high plains aquifer region of the United States*
- Songa, P. *The WASH basins toolkit and WASH connect IWRM app: Tools for integrated groundwater management through WASH projects*
- Sterckx, A. & Ruz Vargas, C. *Groundwater data sharing: The challenge of spatio-temporal data*
- Szabó, Z., Ridavits, T., Csiszár, E. & Szőnyi, J. M. *Preliminary results of rooftop rainwater harvesting and shallow well infiltration pilot project in the Danube-Tisza interfluve, Hungary*
- Taylor, R. *Groundwater recharge and the amplification of rainfall extremes under climate change*
- Thanh Tran, L., Koontanakulvong, S. & Suthidhummajit, C. *The impact of climate change towards groundwater use and mitigation in the Upper Central Plain Basin of Thailand*
- Thuy, L. *The gender perspective of groundwater governance*
- Tuqan, N. *Agricultural water use impact on the eastern aquifer basin sustainability under climate change uncertainty*
- Wang, L., Kinzelbach, W., Yao, H., Steiner, J. & Wang, H. *Monitoring groundwater abstraction using electric energy as proxy in an area of intensive agricultural pumping*
- Yang, Y., Yu, L., Chen, F. & Ding, Y. *Groundwater pricing policies in the practice of groundwater over-pumping control in North China Plain*

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ANNEX 2. POSTERS

THEME I: *Groundwater Natural Resources Assessment under Climate Change*

- Imaz-Lamadrid, M.A., Wurl, J & Gutiérrez-González, M.V.G. *Groundwater availability and evolution of seawater intrusion in overexploited aquifers in arid zones under climate change scenarios*
- Macallister, D. J., Macdonald, A., Kebed, S., Bell, R., Azagegn, T. & Calow, R. *Resilience of rural groundwater supplies during drought in Ethiopia*
- Trásy-Havril, T., Tóth, A., Molson, J. W., Galsa, A. & Mádl-Szőnyi, J. *How might groundwater flow systems be modified by climate change?*
- Schuler, P., Hunter Williams, N., Doherty, D., Campanyà i Llovet, J., Kabza, M., Naughton, O. & McCormack, T. *A framework for assessing the potential impact of climate change on groundwater resources in Ireland*
- Wannous, M., Troeger, U., Tügel, F. & Theilen-Willige, B. *Managing the surplus runoff in areas with different groundwater ages under climate change weather conditions Eastern Desert of Egypt*
- Rauniyar, A. *Impact of water source depletion on livelihood: Linkage with Chure–Kang River Basin*
- Ben-Salem, N., Reinecke, R., Wachholz, A., Rode, M., Borchardt, D. & Jomaa, S. *Combination of regional modelling and in-situ data analysis for groundwater assessment in the Mediterranean region*

THEME II: *Climate Change Effects on Groundwater Resilience - Pollution and Remediation*

- Rezvani, F. & Sarrafzadeh, M. H. *A brief description of drinking water contaminants with a focus on nitrate and its current removal approaches*
- El Gohary, R. *Environmental assessment of using shallow hand pump systems as a drinking water source in development communities: a case study*

THEME III: *Contribution of Technology to Groundwater Resilience*

- Ibrahim, I. A. *Big data impact on transboundary water agreements*
- Meisina, C., Zucca, F., Bonì, R., Bordoni, M., Teatini, P., Ferronato, M., Zoccarato, C., Guardiola, Albert C., Herrera García, G., Béjar-Pizarro, M., Ezquerro, P., Tomás, R., Valdes-Abellan, J., López Sánchez, J. M., Cano, M., Riquelme, A., Pastor, J.L., Pla, C., Elçi, A., Ören, H., Shatanawi, K., Mohammad, A.H., Letterio, T., Genovesi, R., Anconelli, S., Khreisha, H. &, Smadi, M. *Sustainable groundwater resources management by integrating Earth Observation derived monitoring and flow modeling results*

THEME IV: *Groundwater Governance, Management & Policy*

- Notini Moreira Bahia, A. *The human right to water and the law of transboundary aquifers in Latin America: synergies of the Guarani aquifer agreement and the jurisprudence of the inter-american court of human right*
- Chorfi, K. & Abdmalek, B. *Stakeholder participation in water resources problem: legislative and practice (case study Laghouat state Algeria)*
- Yu, I. & Sun, F. *Dual control management of groundwater table and groundwater exploitation in China*
- Logan, W. S. & Komlos, S. B. *Managed aquifer recharge for resilient water management at the US army corps of engineers*
- de la Hera-Portillo, A. & López-Gutiérrez, J. *Resilience of great sedimentary basin aquifers: Water security and SPAs*
- de la Hera-Portillo, A. & López-Gutiérrez, J., Henriksen, H.J., López-Gunn, E, Gejl, R. N., Mayor, B., Zorrillas Miras, P. & Martínez Santos, P. *Resilience of groundwater ecosystems to pumping*
- UPGro Partners. *Unlocking Africa's Groundwater Potential*

THEME V: *Groundwater Education & Capacity Building*

- Deshmukh, R., Aslekar, U. & Joshi D. *Community resource person: A catalyst in bringing the transformations in practices around groundwater, experiences from Maharashtra, India*

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