United Nations
Educational, Scientific and
Cultural Organization

International
Hydrological
Programme

GRAPHIC

GRAPHIC

GROUNDWATER AND CLIMATE CHANGE

Mitigating the Global Groundwater Crisis and Adapting to Climate Change

POSITION PAPER AND CALL TO ACTION

INTERNATIONAL HYDROLOGICAL PROGRAMME
Division of Water Sciences

GRAPHIC
GLOBAL COMMITMENT TO GROUNDWATER AND CLIMATE CHANGE

The United Nations Educational, Scientific, and Cultural Organisation (UNESCO) International Hydrological Programme (IHP) initiated the Groundwater Resources Assessment under the Pressures of Humanity and Climate Change (GRAPHIC) project in 2004[1] to better understand the effects of climate change on global groundwater resources.

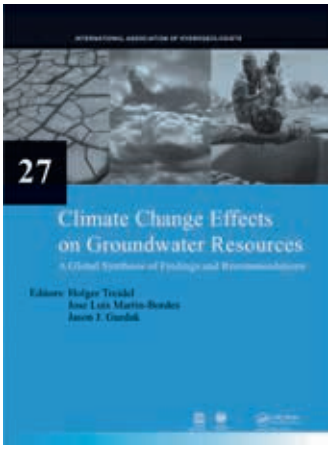
Vision of GRAPHIC:

- advance sustainable groundwater management considering projected climate change and linked human effects.

Mission of GRAPHIC:

- provide a platform for exchange of information through case studies, thematic working groups, scientific research, and communication.
- serve the global community through providing scientifically based and policy-relevant recommendations.
- use regional and global networks to improve the capacity to manage groundwater resources.

GRAPHIC improves understanding of how groundwater interacts within the global water cycle, supports ecosystems and humankind and, in turn, responds to complex and coupled pressures of human activities and climate change. To achieve these objectives within a global context, GRAPHIC is a collaborative effort and umbrella for international research, education, and outreach. GRAPHIC has international investigations covering major geographical regions, groundwater resource topics, and methods to help advance the combined knowledge needed to address scientific and social aspects of the global groundwater crisis in the context of climate change.



Climate Effects on Groundwater – A Global Synthesis of Findings and Recommendations[2] is a compilation from 20 studies in more than 30 countries under GRAPHIC network.

GRAPHIC uses a multidisciplinary scientific approach that extends beyond physical, chemical, and biological investigations to include human systems of resource management and governmental policies. GRAPHIC has been divided into subjects, methods, and regions. The subjects encompass (i) groundwater quantity (recharge, discharge, and storage), (ii) quality, and (iii) management aspects. GRAPHIC uses many scientific methods, including analysis of field data, geophysics, geochemistry, paleohydrology, remote sensing, and modelling. GRAPHIC has regional studies in Africa, Asia and Oceania, Europe, Latin America, and the Caribbean and North America.

Additional information about GRAPHIC is available at **www.graphicnetwork.net**.

INTERNATIONAL CLIMATE NEGOTIATIONS – NEED FOR MORE EXPLICIT DISCUSSIONS REGARDING GROUNDWATER

2015 is a momentous year for climate change mitigation. Three key global summits – on finance (Third International Conference on Financing for Development), on the adoption of the post-2015 development agenda, including the Sustainable Development Goals - SDGs (United Nations Sustainable Development Summit), and on climate (21st Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change - COP21) – will define the ambition and direction of economic advance, social inclusion and environmental sustainability; to which climate change is the greatest threat.

The 2030 Agenda for Sustainable Development includes dedicated goals on climate change (SDG13) and water and sanitation (SDG 6). COP20 resulted in the Lima Call for Climate Action which was a critical step toward reaching a legally binding and universal agreement on climate at COP21 in Paris. Groundwater is critical for mitigating climate change impacts because many efforts to reduce greenhouse gas emissions depend on reliable access to sustainable water resources. Strategic management for climate resilient groundwater resources is the foundation for long-term adaptation and mitigation plans, and should therefore be incorporated in future global climate negotiations. Moreover, as water related hazards exacerbate inequalities, which are disproportionally felt by developing and vulnerable communities, climate resilient groundwater infrastructure is a key for development and poverty reduction.

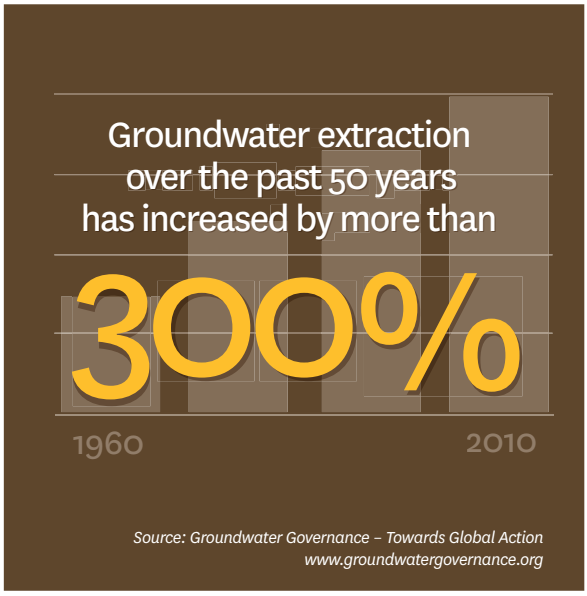
Explicit consideration of the global groundwater crisis and the role of groundwater resources in climate change adaptation and mitigation are therefore essential in climate change negotiations and mitigation solutions.

GROUNDWATER AND CLIMATE CHANGE

Groundwater is an essential part of the hydrological cycle and is a valuable natural resource providing a primary source of water for agriculture, domestic, and industrial uses throughout the world. Nearly half of all drinking water in the world[3] and about 43% of all water effectively consumed in irrigation[4] is sourced from groundwater. Groundwater is vital for sustaining many streams, lakes, wetlands, and other dependent ecosystems[5].

Global groundwater resources are in a state of crisis[6] because of over-abstraction in many semiarid and arid regions and the uncertain consequences of climate change[7]. Climate change is expected to significantly modify the global hydrological cycle and there is a broad consensus that climate change effects will be felt by humans mainly through its impacts on water resources globally, including groundwater resources[8,9], and water-related disasters such as floods and droughts. Direct impacts of climate change on natural processes (groundwater discharge, recharge storage and quality) may be exacerbated by the human response to these impacts, such as increased groundwater abstraction due to extended and more frequent droughts. The effects of climate change on groundwater resources are therefore closely linked to sustainable development goals and to global change drivers, including population growth, land use changes, and urbanization[10].

The **purpose of this paper** is to highlight the important role groundwater has in meeting the demands for drinking water, agricultural and industrial activities, and sustaining ecosystems, particularly in the context of adaptation to and mitigation of the impacts of climate change. This paper outlines several key recommendations that are particularly relevant for future international climate negotiations.



Source: Groundwater Governance – Towards Global Action
www.groundwatergovernance.org

ROLE OF GROUNDWATER IN ADAPTATION TO CLIMATE CHANGE

GROUNDWATER IS CRUCIAL FOR SOCIETY'S ADAPTATION TO CLIMATE CHANGE

In many regions, groundwater provides a secure, sufficient, and cost-effective water supply. Use of groundwater is particularly

relevant to sustaining access to potable-water supplies because groundwater resources are resilient to drought and the impacts of increased freshwater demand during these periods. During droughts, use of groundwater for irrigation can increase, including the use of non-renewable groundwater resources, which may impact the sustainability of groundwater resources.

SUPPORT ADAPTATION IN DEVELOPING COUNTRIES

Information from intensively studied groundwater systems can help inform groundwater monitoring in areas where monitoring infrastructure and resources are limited. Mapping analogues from other parts of the globe in terms of climate change impact studies and adaptation approaches is a promising first-order approach. Using global analogues of adaptation can lead to policy and best-practices to water resource managers and groundwater governance in similar climatic and socio-economic settings. International support for adaptation programs should take precedence in developing countries, providing incentives for capacity strengthening in groundwater management, planning, and conceptualization of adaptation programs.

GROUNDWATER FOR HUMAN DEVELOPMENT

GROUNDWATER IS A KEY RESOURCE FOR HUMAN DEVELOPMENT

Despite the importance of groundwater resources for domestic uses, irrigated agriculture, and other industry, groundwater has often been neglected in development strategies and projects. Groundwater can play an important role in many sustainable development goals, including improving access to drinking water, sanitation, and hygiene.

GROUNDWATER AND CLIMATE POLICIES ACCOUNT FOR IMPORTANT DIFFERENCES BETWEEN THE DEVELOPED AND DEVELOPING WORLD:

While groundwater resources in nearly all regions of the world are stressed by overuse, population growth, and climate change, there are important differences in policy and management to minimize stressors on groundwater resources between the developed and developing world. In the developed world, water management can be complicated by a number of institutional, political and socioeconomic barriers, which include the lack of sufficiently dense monitoring well networks, disparate sampling, data reporting and archiving strategies, inadequate data sharing policies, and in many regions, the lack of groundwater use reporting requirements. In the developing world, such management strategies are in their infancy. Policy efforts to implement adaptive management must recognize these important differences and address limitations appropriately.

POLICY RECOMMENDATIONS: A CALL TO ACTION

The role of groundwater in human development

- Groundwater is a key resource for human development and has an important role in many sustainable development goals.
- Groundwater provides drinking water to at least 50% of the world's population and 43% of all the water used for irrigation.
- Groundwater sustains the base flow of rivers and important aquatic systems.
- Sustainable groundwater is an issue of national and international security.
- Groundwater systems are highly vulnerable on Small Island Developing States (SIDS).

Groundwater is a critical resource for adaptation to climate variability and climate change

- Groundwater provides a unique buffer during extended dry periods.
- Knowledge is fragmented regarding climate change impacts on groundwater quality.
- Science policy is needed to better quantify groundwater withdrawal and sustainable yield.
- Support for adaptation should take precedence in developing countries.
- Programs that empower women and advance gender equality are needed.

IMPROVED GROUNDWATER GOVERNANCE IS NEEDED FOR SUSTAINABLE GROUNDWATER RESOURCES

- Create an adequate basis for governance through political commitment and leadership.
- Build effective institutions and permanent stakeholder engagement mechanisms.
- Systematically make linkages to other water sources and other sectors (Water-Energy-Food-Climate).
- Groundwater management needs to integrate regional water and agricultural policies.
- Public finances related to groundwater need to be reviewed critically for sustainable groundwater management.
- Policy must account for important differences between the developed and developing world in terms of addressing climate and human stresses on groundwater resources.

PROMOTE GROUNDWATER MANAGEMENT STRATEGIES TO REDUCE VULNERABILITIES

- Integrated water resources management should be adopted.
- Managed Aquifer Recharge (MAR) is a promising adaptation approach.

COLLABORATE WITH PARTNERS OF SPECIALIZED KNOWLEDGE

- Need to collaborate with programs and agencies with specialized knowledge (e.g. NASA's Gravity Recovery And Climate Experiment (GRACE) satellite mission)

WATER-ENERGY-FOOD-CLIMATE NEXUS

GROUNDWATER IS AN INTEGRAL COMPONENT OF THE WATER-ENERGY-FOOD-CLIMATE NEXUS

Climate change and economic development increase pressure on global water, energy, and food resources, amplifying trade-offs and conflicts among these resources and stakeholders[11]. Groundwater is an important component of the global hydrologic cycle and climatic system,including regional climate feedbacks that are important drivers of the Water-Energy-Food-Climate Nexus. Groundwater is necessary for many human and natural systems, and is a substantial economic resource in most developed and developing countries. The management of groundwater resources has policy implications outside of the water sector, including agriculture and food security, energy, human health, and sustainable ecosystems. Thus, policy decisions need to carefully assess their implications for climate-water-society connections and the sustainability of groundwater resources.

IMPROVED GROUNDWATER GOVERNANCE

IMPROVED GOVERNANCE IS NEEDED FOR SUSTAINABLE GROUNDWATER RESOURCES

Many groundwater resources are vulnerable to climate change and coupled human activities because of 1) inadequate legislation, regulations, and national water policies that provide no clear priorities or directions to responsible government agencies, and 2) limited financial means and personnel to sustainably manage groundwater resources and water supply systems.

Political commitment and leadership are essential to create an adequate basis for governance. Building effective institutions, comprising the legal and regulatory framework, organisation (both governmental and non-governmental) and permanent stakeholder engagement mechanisms are at the core of groundwater governance[12]. Likewise, the implementation and adoption of laws and regulations by all stakeholders are essential to enable effective management (Fig.1).

ADAPTIVE GROUNDWATER MANAGEMENT NEEDS TO INTEGRATE REGIONAL WATER AND AGRICULTURAL POLICIES

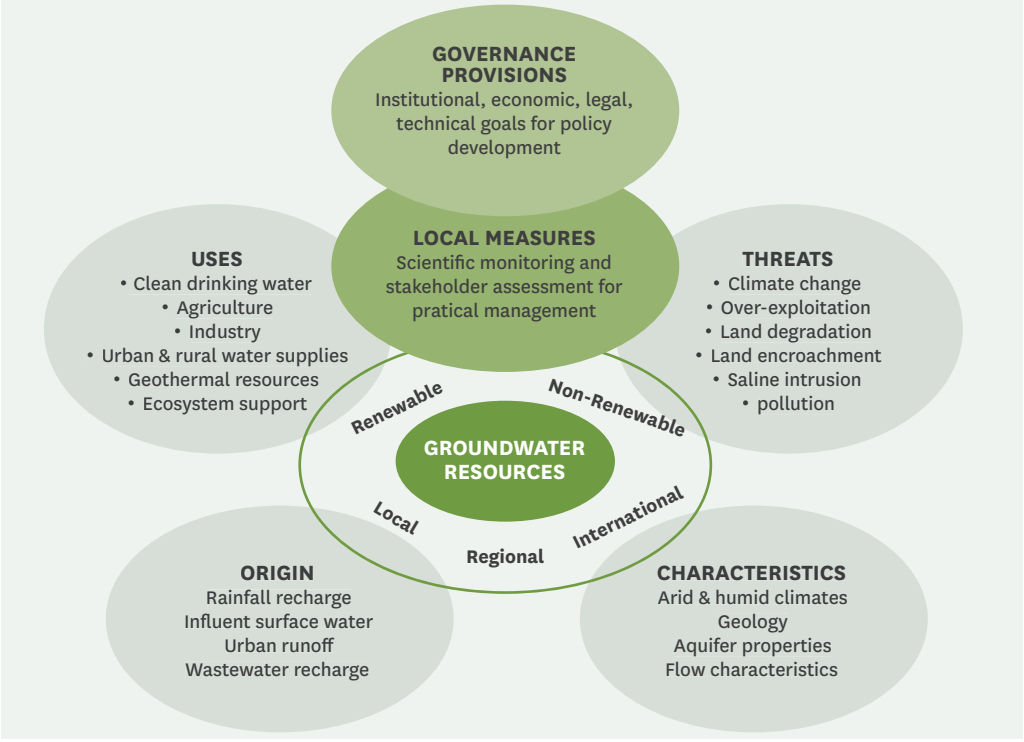
Water-stressed regions may achieve sustainable groundwater resources by effectively integrating regional water and agricultural policies. Such policies can control illegal groundwater abstraction, create water banking infrastructure and policy, diversify crops and implement best practices for water-efficient irrigation. Such management approaches need to strike a balance between ecological protection, human development, and acceptable socio-economic costs.

GENDER, CLIMATE CHANGE, AND GROUNDWATER

CONTINUED NEED FOR PROGRAMS THAT EMPOWER WOMEN AND ADVANCE GENDER EQUALITY

Women represent at least half of the workforce in agriculture and food production, and often bear the daily burden of carrying water to their families. Although women play such a pivotal role in water resource management, sanitation and hygiene (especially in rural areas), gendered water data are among the least available of national-level indicators, and 45% of countries do not produce any gender statistics related to water[13]. Climate change, inadequate access to water, and poor water quality negatively affect women's and girls' health, education, employment, income, and empowerment in ways that are distinct from their male counterparts[14-16] There are corresponding risks to both local and global food production and the care of livestock[17]. Additionally, in academia, women are under-represented in hydrogeology studies mainly because of the structure of academia and historically low numbers of women entering the field[18].

Figure 1: Interlinkages in Groundwater Governance



ASSESSMENT OF GROUNDWATER AVAILABILITY AND SUSTAINABILITY

STRONGER LINKS BETWEEN SCIENCE AND POLICY ARE NEEDED TO BETTER QUANTIFY GROUNDWATER WITHDRAWAL AND SUSTAINABLE YIELD

Freshwater withdrawals for agriculture, households, and industry have major effects on most groundwater resources representing one of the few components of the groundwater budget that society can most directly influence by adaptive management practices and policy decisions. Because there is a temporal lag (months to years) in many aquifers before the trending effects of groundwater withdrawals become evident, there is a tendency to neglect studies that are needed to properly support groundwater management until water-resource crises materialize. This reactionary stance can be improved if there is policy that supports scientific efforts to better monitor, quantify, and regulate groundwater withdrawals. Improved estimates of withdrawals will complement efforts to quantify recharge, and lead to improved estimates of current and future groundwater storage. Adaptive management planning will require best estimates of sustainable groundwater yield, which is not currently available for aquifer systems in many regions of the world.

KNOWLEDGE IS FRAGMENTED REGARDING CLIMATE CHANGE IMPACTS ON GROUNDWATER QUALITY

Climate change impacts and threats to groundwater quality are multiple and significant. However, our knowledge of regional scale groundwater quality processes under the pressures of climate change remains fragmented.

Examples of factors and their expected effects on groundwater quality

FACTOR	EXPECTED EFFECT
Hydroclimatic Systems	
Reduced rainfall and prolonged drought periods	Reduced transport of surface contaminants to groundwater, but increased contaminant concentrations in residual waters[19]
Increased groundwater temperatures	Increased reaction rates of biogeochemical processes
Reduced permafrost; and increased frequency of high intensity rainfall events	Accelerated mobilisation of pollutants to groundwater[20]
Declining groundwater levels due to increased pumping	Mobilisation of some oxidation-sensitive contaminants in groundwater
Agricultural Systems	
Smart water saving techniques reducing the quantities of surface waters used for irrigation practices	Decreased recharge and reduced transport of agricultural chemicals to the water table
Increased fertilizer application to crops, due to increased nutrient leaching from soils	Increased risk of groundwater in rural areas
Increased pesticide applications to crops due to augmented weeds and insects with rising temperatures	Increased risk of groundwater in rural areas
Increased recharge due to changing climate or agricultural practices	Mobilize naturally occurring salts in the soil and negatively affect groundwater quality
Socio-economic Systems	
Predicted migration of populations away from high risk areas[21]	Increased risk of contamination in urban areas
Coastal Systems	
Sea-level rise	Sea-water intrusion and degradation of coastal groundwater[22]

GROUNDWATER SYSTEMS ARE HIGHLY VULNERABLE ON SMALL ISLAND DEVELOPING STATES (SIDS)

Although all islands are vulnerable to saltwater intrusion, SIDS rely on small coastal aquifers that are at higher risk of saltwater contamination from sea level rise, pumping, and wave over wash events. In the absence of coordinated and sustained national and international action, low-lyig islands in the Pacific that are highly dependent on scarce, polluted and increasingly saline groundwater resources, and impacted by climatic variability and change, are facing dramatic choices. In many other islands around the world, degradation of groundwater quality and growing water demands are posing short-medium term threats to human health and impairing ecosystem services[23].

GROUNDWATER MONITORING IS AN IMPORTANT FIRST STEP

Groundwater levels should be monitored regularly to establish baseline conditions and help make best informed management decisions, including how groundwater can be used for climate change adaptation.

GROUNDWATER MANAGEMENT STRATEGIES TO REDUCE VULNERABILITIES

SUSTAINABLE GROUNDWATER IS AN ISSUE OF NATIONAL AND INTERNATIONAL SECURITY

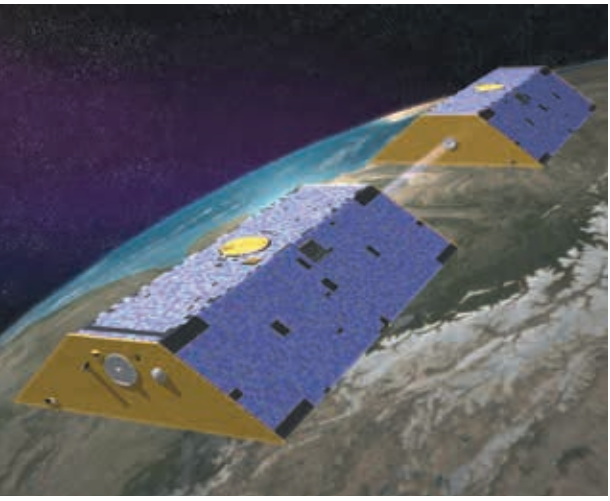
Groundwater is a key component to national and international water security[22]. International climate discussions need to continue to develop a policy infrastructure that shares groundwater resources across political boundaries as an important component of national and international adaptation strategies.

INTEGRATED WATER RESOURCES MANAGEMENT NEEDS TO BE ADOPTED MORE UNIVERSALLY

Integrated Management of Water Resources (IMWR) includes the conjunctive use of surface-water and groundwater for optimal use as one water resource. IMWR should meet strategic local objectives and be flexible over time as projected climate-groundwater interactions become certainties or unexpected realities.

MANAGED AQUIFER RECHARGE (MAR) IS A PROMISING ADAPTATION APPROACH

Support programs and initiatives that assess the suitability of managed aquifer recharge (MAR) and artificial storage and recovery (ASR) projects, particularly in developing countries. Artificial recharge and managed storage and recovery projects will likely become more important strategies of many local water managers to store excess renewable water supplies in aquifers during wet periods, which can be used to off-set limited surface-water supplies during dry periods.



GRACE satellites (source: NASA).

COLLABORATE WITH PARTNERS OF SPECIALIZED KNOWLEDGE

COLLABORATE WITH PROGRAMS AND AGENCIES WITH SPECIALIZED KNOWLEDGE

Local water management agencies looking for assistance with adaptation strategies should contact one of the several international programs and agencies with specialized knowledge about groundwater and climate change[24], including GRAPHIC, International Groundwater Resource Assessment Centre (IGRAC), and the International Association of Hydrogeologists (IAH) Commission on Groundwater and Climate Change.

PROMISING NEW TECHNOLOGIES

NASA's Gravity Recovery And Climate Experiment (GRACE) satellite mission has revolutionized the monitoring of the global water cycle. By monitoring the temporal variations of the Earth's gravity field with an unprecedented temporal and spatial resolution, GRACE has provided new insights into water masses stored at the surface and in the subsurface, including "inaccessible" groundwater systems. GRACE provides sufficient accuracy to track changes in the Earth's gravity associated with water [25]. Major advances encompass the quantification of groundwater overexploitation in major agricultural regions of the world[26] and the evaluation of water policies with regard to sustainability goals[27]. The GRACE mission prepared by the American and German space agencies (NASA and DLR), was launched in 2002 for an initial life of 5 years. After 10 years of reliable service, the success of the mission has encouraged NASA and DLR to launch a follow on mission, planned for 2017.

CONTRIBUTORS

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