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The United Nations World Water Development Report 2022

# GROUNDWATER
## Making the invisible visible

Executive Summary

The purpose of this edition of the *United Nations World Water Development Report* (WWDR 2022) is to shine a spotlight on groundwater, calling attention to its specific roles, challenges and opportunities in the context of water resources development, management and governance across the world.

Groundwater – accounting for approximately 99% of all liquid freshwater on Earth and distributed over the entire globe, albeit unequally – has the potential to provide societies with tremendous social, economic and environmental benefits, including climate change adaptation. Groundwater already provides half of the volume of water withdrawn for domestic use by the global population, and around 25% of all water withdrawn for irrigation, serving 38% of the world's irrigated land. Yet, despite its enormous importance, this natural resource is often poorly understood, and consequently undervalued, mismanaged and even abused. In the context of growing water scarcity in many parts of the world, the vast potential of groundwater and the need to manage it carefully can no longer be overlooked.

## The multiple services offered by groundwater

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The capacity of groundwater systems to offer various services depends on their geographically varying properties and is dynamically influenced by ongoing natural and human processes.

These services include:

- *provisioning services*, which allow groundwater to be withdrawn for (human) water use purposes;
- *regulatory services*, which reflect the buffer capacity of aquifers to regulate the groundwater systems' quantity and quality regimes;
- *supporting services* on which groundwater-dependent ecosystems (GDEs) and other groundwater-related environmental features rely; and
- *cultural services* linked to leisure activities, tradition, religion or spiritual values, which are associated with particular sites rather than with aquifers.

Groundwater offers a number of additional opportunities, such as expanding geothermal energy generation, enhancing storage for improved water security, and adapting to the impacts of climate change.

## The challenges

Groundwater storage depletion occurs when discharge exceeds recharge. Although climate variability and climate change can play a role, most cases of long-term groundwater storage depletion result from intensive abstraction. The rate of global aggregated groundwater storage depletion is considerable: for the beginning of the present century, the estimates are mostly between 100 and 200 $km^3$/year (accounting for roughly 15 to 25% of total groundwater withdrawals).

Groundwater pollution reduces the suitability of abstracted groundwater for drinking purposes and also affects groundwater-dependent ecosystems.

There are many sources of anthropogenic groundwater pollution: most of them are located at or near the land surface, but several other sources inject pollutants into the subsurface at greater depth below the surface. Agricultural pollution is widespread, it is a diffuse source that often includes large quantities of nitrate, pesticides and other agrochemicals. Groundwater pollution is a virtually irreversible process: once polluted, aquifer zones tend to remain with polluted water.

## Groundwater governance

Groundwater *governance* processes enable groundwater management, planning and policy implementation. It takes place at multiple scales and geographic levels, including regional and transboundary scales. Groundwater *management* is action-oriented, focusing on practical implementation activities and day-to-day operations. It occurs more often at the micro- and meso-level.

Because groundwater is often perceived as a private resource (that is, closely connected to land ownership, and in some jurisdictions treated as privately owned), regulation and top–down governance and management are difficult. Governments need to fully assume their role as resource custodians in view of the common-good aspects of groundwater.

*In Sub-Saharan Africa, where the opportunities offered by the vast shallow aquifers remain largely underexploited, only 5% of the area equipped for irrigation uses groundwater*

Domestic laws and regulations regulate access to groundwater as well as human activities that impact the quality of groundwater. Additional relevant legal instruments include those that: provide access to water for basic needs as a matter of human rights; afford access to groundwater for livelihoods and small-scale productive uses; regulate land uses inimical to the natural groundwater recharge and discharge processes; and regulate the formation and functioning of associations of groundwater users for allocation, monitoring and policing responsibilities. Legal frameworks also need to include protection of discharge and recharge zones and of the area surrounding water supply wells, as well as sustainable yield norms and abstraction controls, and conjunctive use regulations.

In some jurisdictions, groundwater is regulated in conjunction with surface water, including rivers. In instances where there are conflicts between groundwater rights and surface water rights (for instance in the case of a stream that is drying up due to intense groundwater pumping nearby, and vice versa), a conjunctive management approach is warranted.

Point sources of pollution can be regulated through permits as well as through general effluent and/or ambient water quality standards. Non-point source pollution from diffuse or indistinct sources requires prevention measures: regulation of land uses and/or imposition of best agricultural and environmental practices.

## Agriculture

Groundwater is a critical resource for irrigated agriculture, livestock farming and other agricultural activities, including food processing. In order to meet global water and agricultural demands by 2050, including an estimated 50% increase in food, feed and biofuel demand relative to 2012 levels, it is of critical importance to increase agricultural productivity through the sustainable intensification of groundwater abstraction, while decreasing the water and environmental footprints of agricultural production.

Where a perennial and reliable source of shallow groundwater exists, groundwater can be an important source for smallholder farmers. Regions heavily reliant on groundwater for irrigation include North America and South Asia, where 59% and 57% of the areas equipped for irrigation use groundwater, respectively. In Sub-Saharan Africa, where the opportunities offered by the vast shallow aquifers remain largely underexploited, only 5% of the area equipped for irrigation uses groundwater.

It is estimated that agricultural pollution has overtaken contamination from settlements and industries as the major factor in the degradation of inland and coastal waters. Nitrate, from chemical and organic fertilizers, is the most prevalent anthropogenic contaminant in groundwater globally. Insecticides, herbicides and fungicides, when improperly applied or disposed of, can pollute groundwater with carcinogens and other toxic substances.

Evidence suggests that laws and regulations to prevent or limit diffuse groundwater pollution from agriculture, and especially their enforcement, are generally weak. Policies addressing water pollution in agriculture should be part of an overarching agriculture and water policy framework at the national, river basin and aquifer scale.

Rural electrification has been a principal driver for groundwater development, especially where rural power grids have been extended into areas that would otherwise have relied on diesel fuel or wind energy. Advances in solar technology have witnessed the development of Solar-Powered Irrigation Systems (SPIS), adopted at scale to service farming operations. However, there is a risk of unsustainable water use if SPIS implementation is not adequately managed and regulated.

## Human settlements

The groundwater dependence of innumerable cities appears to be intensifying, such that nearly 50% of the global urban population today is estimated to be supplied from groundwater sources. However, many urban poor live in peri-urban settlements, which are unplanned and lack legal status, and where public water infrastructure and services are not provided.

*Groundwater provides the only feasible and affordable way to extend basic water access to unserved rural populations in much of the world*

In developing economies, the use of private waterwells for urban self-supply has proliferated in recent years. The practice usually commences as a coping strategy in the face of irregular or inadequate piped water supply, and then continues in perpetuity as a cost reduction strategy to avoid paying higher water tariffs.

The impact of inadequate or inappropriate sanitation on groundwater is observed in urban areas where main-sewer coverage is low and most domestic faecal waste is discharged into pit latrines. Water utilities need to put a much more consistent emphasis on protecting their critical waterwell/springhead sources through restricting agricultural cropping and housing development in their groundwater capture zones, in the interest of safeguarding public health and reducing the cost of water supply.

Groundwater provides the only feasible and affordable way to extend basic water access to unserved rural populations in much of the world. This is especially the case in Sub-Saharan Africa and South Asia where the rural population is large but dispersed.

The coexistence of on-site sanitation and groundwater supply is a serious concern for shallow sources. Persistent contamination of rural groundwater supplies with pathogens is estimated to affect about 30% of the total installations. It will usually impact the marginalized the most (women and girls are often disproportionately more at risk of disease due to pathogens and toxins as a result of their exposure to wastewater).

The settlements, both temporary and permanent, of displaced people require special mention. These settlements often have a high population density but fall between the urban and rural categories. The construction of well-designed waterwells, in conjunction with appropriately cited and well-maintained sanitation systems, is vital in these cases.

## Industry

Industries that withdraw groundwater include manufacturing, mining, oil and gas, power generation, engineering, and construction. Industries with a high groundwater dependency via supply chains include the apparel and food and beverage sectors. Various industrial processes make use of groundwater resources, in locations where surface water availability is limited in quantity, but also in situations where quality is important.

The discharge and infiltration into the ground of untreated or only partly treated industrial effluents can pollute groundwater. Human health and the environment can also be put at significant risk as a result of soil contamination and leaching from non-engineered and old industrial dumpsites and legacy mines.

Many production processes need a large amount of water for washing and cleaning their products at the end of production, to separate residues of processing chemicals. The use of groundwater for cooling purposes is very dependent on the location and type of industry and will therefore vary widely from country to country. Underground construction, such as tunnels, frequently require either temporary or permanent dewatering.

*The oil, gas and mining industries, through their various activities, may have ample in-house data on the location and extent of aquifers and their properties*

Mines in many cases require frequent or continuous dewatering in order to operate, and there is the risk of contaminating a local aquifer, which may be a source of drinking water. The disposal of the water also presents challenges for treatment if it is contaminated by the mining activities. However, the oil, gas and mining industries, through their various activities, may have ample in-house data on the location and extent of aquifers and their properties. Such data could be very useful to hydrogeologists, governments and water supply utilities.

The energy sector can also have profound effects on groundwater quality. Coal used in the generation of thermal electricity can significantly impact groundwater quality as a result of leaching through coal ash waste dumps. Fracking for natural gas, particularly in shallow aquifers, can also present considerable risks of groundwater contamination. Pollution sources include wastewater from formation water, flow-back water, and drilling and fracturing liquids.

The financial sector is now exerting its considerable influence over sustainable investing and this will have a knock-on effect, favouring clients in industry and energy who use groundwater sustainably, and encouraging others to do so.

## Ecosystems

Groundwater-dependent ecosystems (GDEs) can be found across a variety of landscapes, ranging from high mountain valleys to the bottom of the ocean and even deserts.

Groundwater discharge supports the baseflows of streams and rivers, a crucial water source that determines their risk of falling dry during periods of drought. Terrestrial ecosystems depend on groundwater in all biomes around the world where it is accessible to plants. Water holes in arid environments are often purely groundwater-fed, and thus groundwater is crucial to sustaining the complex food webs of arid landscapes, such as savannahs. Riparian zones, wetlands and other surface water bodies often depend on groundwater.

GDEs also support critical ecosystem services. Aquatic and terrestrial GDEs provide habitat, support biodiversity, buffer floods and droughts, provide food, and offer cultural services. GDEs play critical roles in protecting aquifers from contamination by ensuring physical separation, by enabling biophysical processes like filtration, biodegradation and sorption of contaminants, and by facilitating and protecting natural recharge.

The shared well-being of groundwater, ecosystems and humans may be enhanced by groundwater management, conjunctive water and land management, nature-based solutions, and improved ecosystem protection. While groundwater management often focuses on groundwater or aquifers themselves, groundwater and ecosystems need to be managed together in order to ensure the continued provision of critical ecosystem services.

## Climate change

Climate change directly impacts the natural recharge of groundwater through its influence on precipitation and on leakage from surface waters, including ephemeral streams, wetlands and lakes. Substantial uncertainty persists, however, in global projections of the magnitude of the impacts of climate change on groundwater recharge.

One observed and widespread impact of climate change influencing groundwater replenishment is the intensification of precipitation. In areas with inadequate sanitation provision, heavy rainfall events can flush faecal microbial pathogens and chemicals through shallow soils to the water table.

*Developing water supplies that are resilient to climate change will, in many parts of world, involve the use of groundwater conjunctively with rivers, lakes and other surface water reservoirs*

Global sea level rise (SLR) has induced seawater intrusion into coastal aquifers around the world. However, the impact of SLR alone on seawater intrusion is often small relative to that of groundwater abstraction. The impacts of climate change on groundwater may be greatest through its indirect effects on irrigation water demand via increased evapotranspiration.

Developing water supplies that are resilient to climate change will, in many parts of the world, involve the use of groundwater conjunctively with rivers, lakes and other surface water reservoirs. Groundwater-based adaptations to climate change exploit distributed groundwater storage and the capacity of aquifer systems to store seasonal or episodic water surpluses. They incur substantially lower evaporative losses than conventional infrastructure, such as surface dams.

The development of geothermal energy, a sustainable energy source, plays an important role in reducing $CO_2$ emissions. Deep aquifers can also be used for carbon capture and sequestration, the process of storing carbon to curb accumulation of carbon dioxide in the atmosphere.

## Regional perspectives

### Sub-Saharan Africa

Africa possesses large groundwater resources. While not all of this groundwater storage is available for abstraction, the volume is estimated to be more than 100 times that of the annual renewal of the region’s freshwater resources. The development of groundwater has great potential to satisfy the need for rapidly increasing water supply across Sub-Saharan Africa, both for human survival as well as to promote economic development. About 400 million people in Sub-Saharan Africa still do not have access to even basic water services.

Most countries in Western and Central Africa have little groundwater storage but high annual rainfall and therefore regular recharge. Conversely, many countries in Eastern and Southern Africa have considerable groundwater storage despite very low levels of recharge. This storage provides a significant buffer before abstraction will impact the regional groundwater system. However, current groundwater pumping will ultimately be at the expense of future generations.

Only 3% of the total cultivated land in Sub-Saharan Africa is under irrigation, and only 5% of that is irrigated with groundwater. The development of groundwater could act as a catalyst for economic growth by increasing the extent of irrigated areas and therefore improving agricultural yields and crop diversity. The further development of groundwater in Sub-Saharan Africa is not currently limited by a lack of groundwater, but rather by a lack of investment, most notably in infrastructure, institutions, trained professionals and knowledge of the resource.

## Europe and North America

The characteristics of groundwater resources and their availability vary between and within pan-Europe and North America, reflecting the differences in geology and hydrology. The share that groundwater makes up of the total withdrawal of freshwater also varies greatly from one country to another.

In many countries of Europe, groundwater is principally used for drinking water, which underscores the need to control water quality, given the potential health risks. The pollutants that most commonly cause poor chemical status in the European Union are nitrates as well as pesticides. While pollutants from agriculture dominate, industrial chemicals and substances related to mining also lead to chemical groundwater pollution in several river basin districts. More information is needed concerning such 'new' (or 'emerging') pollutants.

In addition to the need for collaboration among different water users within a given country, there is an increasing awareness of the transboundary nature of many groundwater resources, and, therefore, of the need for interjurisdictional cooperation.

Groundwater monitoring and expertise is commonly held by specialized institutions, while the implementation of water policy instruments calls for cooperation between institutions. Indeed, many pressures and drivers are the same for ground- and surface water. Integrated policies and efforts to ensure coherence are being developed.

*Most groundwater resources in the Arab region are non-renewable, and must be managed with a view to the fact that they are a finite resource*

## Latin America and the Caribbean

Due to the relative abundance of surface water and the limited level of groundwater use, less than 30% of the freshwater abstracted in Latin America and the Caribbean comes from groundwater sources. In the countries that do rely on groundwater, approximately half of the extraction is used for irrigation, a third is for domestic use and the rest is for industrial use.

Throughout the region, there are shortcomings in the protection and monitoring of groundwater, giving way to its intensive exploitation and/or contamination, ultimately endangering its sustainability as well as its accessibility to the most vulnerable populations, who depend on these groundwater sources for their drinking water supply.

Groundwater plays an important role in the water supply systems of most Latin American cities, even though not always as the main source of supply. It also represents 50% of the water used by the industrial sector. In the Caribbean, where surface water tends to be relatively scarce, groundwater represents about 50% of the water abstracted.

As the importance of aquifers for the region´s ecosystems, social development and economic activities will only further increase in the near future, the region needs to move towards political processes that harmonize decision-making, monitoring and groundwater management both nationally and internationally.

## Asia and the Pacific

The Asia-Pacific region is the largest groundwater abstractor in the world, containing seven out of the ten countries that extract most groundwater (Bangladesh, China, India, Indonesia, Iran, Pakistan and Turkey). These countries alone account for roughly 60% of the world's total groundwater withdrawal.

These socio-economic benefits of groundwater use are particularly crucial for the agricultural sector. The industrial and municipal sectors are also important users. While groundwater is abundant across most of the region, its depletion has led to concerns over the sustainability of groundwater usage in different areas across Central Asia, China, South Asia and certain urban centres in Southeast Asia.

Groundwater contamination from both anthropogenic and geogenic processes is an additional concern. The impacts of climate change on precipitation variability further exacerbate pressure on groundwater resources, particularly in areas with semi-arid to arid climates and on Small Island Developing States.

While management practices and institutional, legal and regulatory systems to address groundwater issues exist throughout the region, groundwater governance is challenging due to the unrestricted access regime in place in many countries. Improved groundwater governance, with popular support and enforcement capacity, is critically needed.

### The Arab region

The Arab region is one of the most water-scarce in the world and groundwater is the most relied-upon water source in at least 11 of the 22 Arab states. Over-extraction of groundwater in many parts of the region has led to groundwater table declines, especially in highly populated and agricultural areas. This is particularly alarming as groundwater is the primary source of water for vulnerable groups that are not formally connected or do not have access to public sources. Unsustainable agricultural practices, as well as industries and urbanization, are significantly impacting groundwater quality.

Most groundwater resources in the Arab region are non-renewable, and must be managed with a view to the fact that they are a finite resource. However, monitoring groundwater extraction remains difficult, despite the emergence of new technologies. This complicates the management of groundwater, particularly in a transboundary context. Unfortunately, only very few cases of groundwater cooperation exist in the region.

The importance of groundwater for the region's water security under a changing climate demands improved governance through policies and legislations, innovative management approaches, enhanced use of technologies, dedicated funding for better understanding of the resource, and heightened regional cooperation.

## Building and updating the knowledge base

*Groundwater data collected with public funds should be freely accessible*

The UN *Summary Progress Update 2021 on SDG 6* raises the issue of the lack of groundwater data and groundwater monitoring initiatives, emphasizing that groundwater monitoring is a 'neglected area'.

Groundwater needs to be monitored over time in terms of quantity and quality, in order to learn about the behaviour and state of aquifers, and to identify possible negative changes such as over-abstraction, reduced recharge (including climate change effects) and pollution. Groundwater recharge is usually estimated rather than directly measured. Highly vulnerable aquifers that provide services to people and the environment need to be monitored more frequently.

Scientific knowledge in hydrogeology and the methods and tools available are sufficient to address most groundwater management issues. The challenge lies more with the scarcity of reliable data for area-specific groundwater assessments and scenario analyses. Since all aquifers and their boundary conditions are unique, it is crucial to have groundwater assessments at field level to enable informed policies and management of groundwater resources.

Although often relatively expensive, monitoring is a wise investment: identifying problems at an early stage can be highly cost-effective, allowing mitigation measures to be introduced before serious deterioration of the resource takes place. Conventional monitoring programmes can be augmented by citizen science initiatives, which can also promote the integration of local knowledge into hydrogeological characterization and groundwater system assessments. Remote sensing techniques have also been used by the scientific community to improve monitoring and estimation of groundwater resources.

The sharing of data and information is often deficient, especially in low-income countries. Groundwater data collected with public funds should be freely accessible. Private companies should disclose relevant data and information concerning subsurface water-related parameters that would improve the assessment and management of groundwater. For example, geophysical and borehole data acquired during oil and gas exploration could improve knowledge of aquifer extent and parameters.

In many low- and middle-income countries, hydrogeological capacity is missing, even when groundwater makes up the largest part of their managed water resources. This often comprises both technical and institutional capacity.

## Policy and planning

All too often, the adoption of a groundwater policy is primarily focused on the utilization of groundwater after abstraction. This is far removed from sound management of *the aquifer*, which requires attention to land use, replenishment, protection, and implementation of measures that aim at preserving groundwater system services and functions.

***Deployment of several groundwater management tools is contingent upon first having the legal and institutional structures in place that grant authority for their use and enforcement***

Any national 'groundwater management vision' needs to be embedded within a national vision for water resources, in dialogue with actors ranging from local groundwater users and technicians to scientists, policy-makers and investors. Groundwater policy should be contingent on the legal status and nature of ownership of groundwater (public or private), as well as on factors like the water users, the interrelated surface water features, and the land uses in aquifer recharge areas. It also should provide for integrated decision-making for groundwater resources and aquifer systems, and connect to other sectors and domains of society beyond the water sector – such as socio-economic development, gender equality and poverty alleviation, food and energy, ecosystems, climate change, and human health.

Policies, strategies and plans should be tailored to the local context, based on the priorities and aspirations of the local population, and informed by sound scientific evidence. Plans can be prepared as a cooperative effort between national ministries, provincial and local agencies, and other relevant stakeholders, based on dialogue and inclusive technical support (e.g. participatory mapping) to enable co-ownership of the process and the outcome. The process produces a formal document that can be validated, with time-bound actions and indicators that can be monitored, and outputs and impacts/outcomes that can be evaluated.

## Groundwater management

Groundwater management aims to control groundwater abstraction and quality as well as to address the effects of groundwater abstraction on ecosystems, surface waters, land subsidence and more. Perhaps one of the most critical components of groundwater management is control of the location and quantity of water withdrawals from the aquifer.

Deployment of several groundwater management tools is contingent upon first having the legal and institutional structures in place that grant authority for their use and enforcement. However, not all management occurs through government. Communities and/or groundwater users themselves may independently choose to manage well siting and groundwater abstractions.

The most sustainable and cost-effective approach to managing groundwater quality is to ensure its adequate protection, thus avoiding contamination. This can be achieved through vulnerability mapping, development of groundwater protection zones and land use planning.

Particular attention should be given to the conjunctive management of surface water and groundwater resources and to the potential for 'nature-based' solutions. Integration with environmental management, land use management, and management of space and resources of the subsurface are all important issues within the purview of integrated management.

Managed aquifer recharge (MAR) is an integrated approach that allows replenishment of aquifers to complement storage dams and provides a cost-effective alternative that minimizes evaporation and environmental impacts. MAR can also be used to retain unharvested urban stormwater and recycled water, to be made available for productive use when needed. At the watershed scale, MAR can be used to maintain environmental water flows and their availability, creating lags in water discharges to a stream. The application of MAR has increased by a factor of 10 over the last 60 years, but there is still ample scope for further expansion, from the current 10 km³/year to probably around 100 km³/year.

## Transboundary aquifers

Transboundary aquifers include a natural subsurface path of groundwater flow crossing an international boundary. Actions on the aquifer in one country, such as heavy abstraction or contamination, can have a significant impact on the other side of the border.

*Frequently, transboundary aquifers are made part of broader water cooperation agreements developed for transboundary river basins*

Transboundary aquifer management often suffers from a lack of institutional will and insufficient resources to collect the necessary information, especially at the local level. Coordinating, harmonizing and sharing data represents the first step in cooperation between neighbouring countries. These actions are essential to reaching an agreement about a reliable conceptual model of the aquifer, which in turn is a prerequisite for the formulation of management plans. The integration of gender considerations into transboundary cooperation generates opportunities for more socially equitable groundwater management.

International water law was initially developed for surface waters, but ever more frequently, transboundary aquifers are made part of broader water cooperation agreements developed for transboundary river basins. This illustrates the growing awareness of the importance of transboundary aquifers.

Scientific cooperation initiatives, in the framework of technical projects on transboundary aquifers, exist around the world. Such initiatives can have various scopes, some of them aiming at joint scientific assessment, while some others tackle the management of specific issues. In these cases, the role of regional and international organizations and donors can be critical, particularly when the countries concerned are not on a par as regards to capacity, knowledge and information, or when confidence is lacking.

## Financing

In contrast with surface water, where capital costs tend to be covered by the public sector, groundwater development infrastructure is usually financed by the end user, be it an industry, a household, a farmer, or a community. Users access the resource directly and in a decentralized way. The end users invest their private capital for the cost of accessing groundwater, which usually consists of a fixed cost for a well and a variable cost for pumping. In some countries, there may be an abstraction fee or a groundwater tariff, but these fees and tariffs rarely reflect the true costs and value of the resource.

Governments need to assess and accept their potential role in promoting the sustainability of groundwater resources in accordance with the local conditions, and use the limited financial resources more efficiently through tailored initiatives. Government budgets should, at minimum, fund groundwater monitoring – quality and quantity, and related operating and maintenance costs – and leverage private investment by funding initial exploratory and management initiatives.

There is an opportunity to better integrate sustainable groundwater development and management as part of other water sector projects and initiatives. For example, groundwater storage and abstraction can be included as part of urban water supply in order to add security and flexibility in case of seasonal resource variation. This would allow to further leverage existing funding from official development assistance, from water supply and sanitation tariffs, and even from public–private partnerships. Fees and taxes in other sectors, such as in agriculture, can also help finance groundwater initiatives and reduce potential negative externalities.

In many countries, publicly funded activities in other sectors contribute to the depletion or pollution of groundwater resources. For example, subsidies in the energy sector that incentivize the over-extraction of groundwater by reducing electricity charges, or farm subsidies that encourage crops with high water demands, can become perverse incentives. Reforming harmful subsidies and aligning them with groundwater policies should be part of the water financing agenda.

## Moving forward

*It is essential that countries commit themselves to developing an adequate and effective framework for groundwater governance*

The General Assembly of the United Nations (UN), as well as the Human Rights Council, recognize that equitable access to safe and clean drinking water and sanitation are distinct human rights. UN Member States are expected to realize the human rights to safe drinking water and sanitation through action plans or strategies, and – since groundwater is an essential component of water supply and sanitation – to groundwater protection and aquifer recharge.

It is essential that countries commit themselves to developing an adequate and effective framework for groundwater governance. This requires that governments take the lead and assume responsibility to set up and maintain a fully operational governance structure, including: the knowledge base; institutional capacity; laws, regulations and their enforcement; policy and planning; stakeholder participation; and appropriate financing. It is also incumbent upon countries to ensure that their policies and plans are fully implemented (groundwater management). It is imperative that governments assume their role as resource custodians in view of the common-good aspects of groundwater and ensure that access to (and profit from) groundwater is distributed equitably and that the resource remains available for future generations.

## Coda

The Earth's total groundwater resources represent an enormous supply of freshwater. In a world of ever-growing water demand, where surface water resources are often scarce and increasingly stressed, the value of groundwater is poised to become progressively recognized by everyone, as a resource that has allowed human societies to flourish since millennia.

However, in spite of its overall abundance, groundwater remains vulnerable to overexploitation and pollution, both of which can have devastating effects on the resource and its availability. Unlocking the full potential of groundwater will require strong and concerted efforts to manage and use it sustainably. And it all starts by making the invisible visible.

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This publication is produced by WWAP on behalf of UN-Water.

Cover illustration by Davide Bonazzi

Graphic design and layout by Marco Tonsini



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unesco
World Water
Assessment Programme

This publication is financed by
the Government of Italy and Regione Umbria.

Regione Umbria

Climate neutral
Production
ClimatePartner.com/12066-2002-1001

SC-2022/WS/3