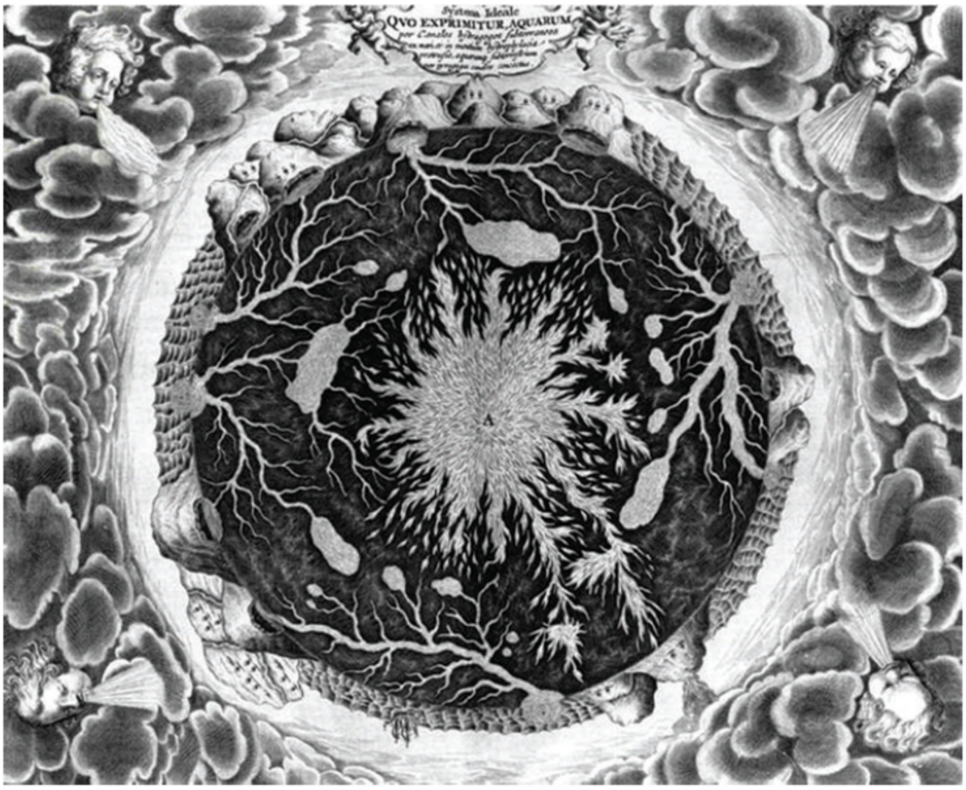
MEDRC

# TRANSBOUNDARY WATERS

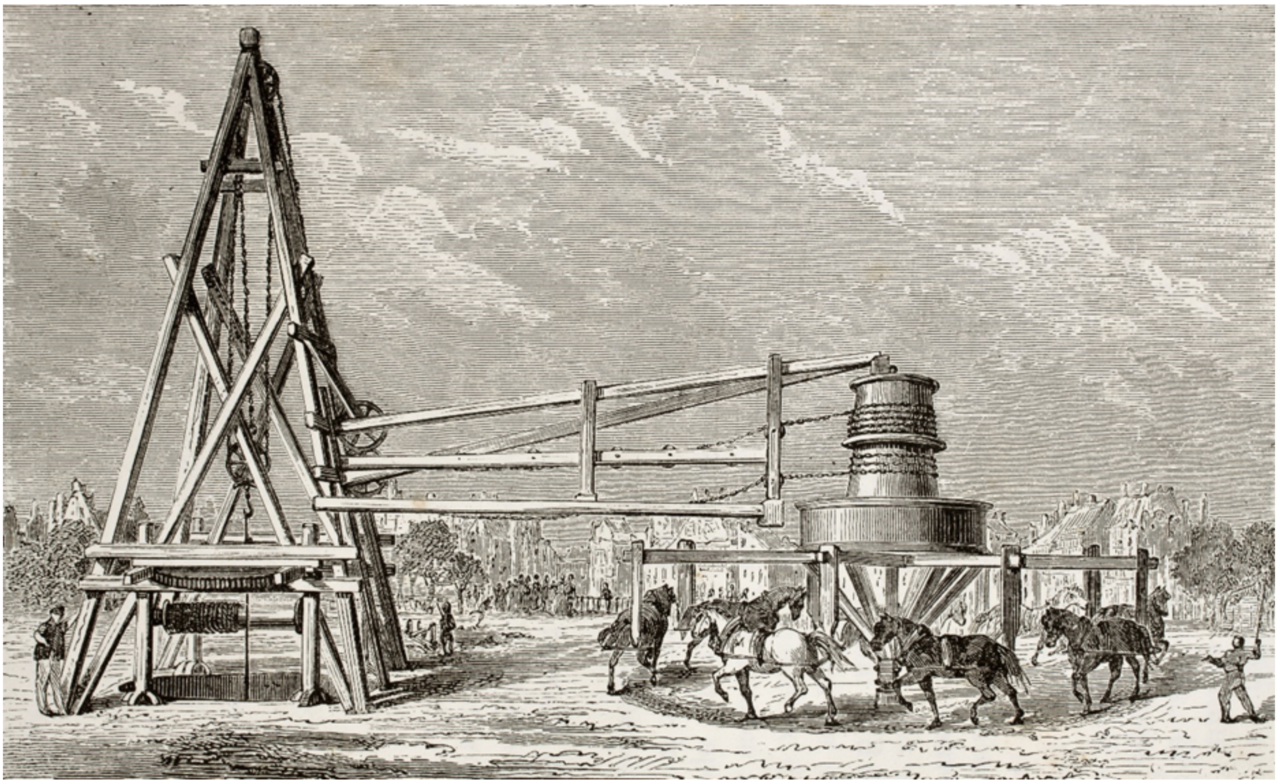
PRACTITIONER BRIEFING SERIES

*Issue 12*

## Groundwater




*17th century depiction of groundwater. Earth Interior – Mundus Subterraneus–Athanasius Kircher (1665). Source: Shutterstock*



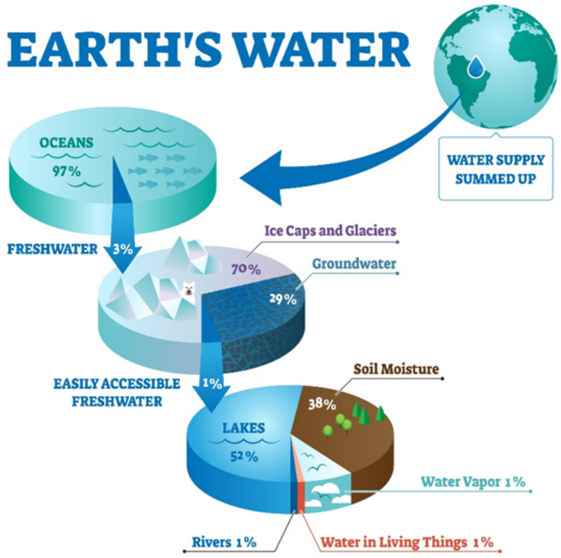
*Antique illustration of drilling artesian well at Grenelle, Paris. Original, created by Lapiante and Javandier, was published on L'Eau, by G. Tissandier, Hachette, Paris, 1873. Source: Shutterstock*

# Groundwater

## Introduction

Groundwater is a key component of the water cycle that is often overlooked as we stand above ground. Making the invisible visible is the theme of World Water Day for 2022, also tapped as the Year of Groundwater.

With 99% of all liquid freshwater on earth being in the form of groundwater, we are unable see 99% of the picture when it comes to our global water resources. Groundwater's role in human development is critical, particularly as a changing climate shifts surface water resources around the globe. The sustainable management of groundwater is therefore a core component to a sustainable future. First, let's clarify what separates groundwater in the water cycle.

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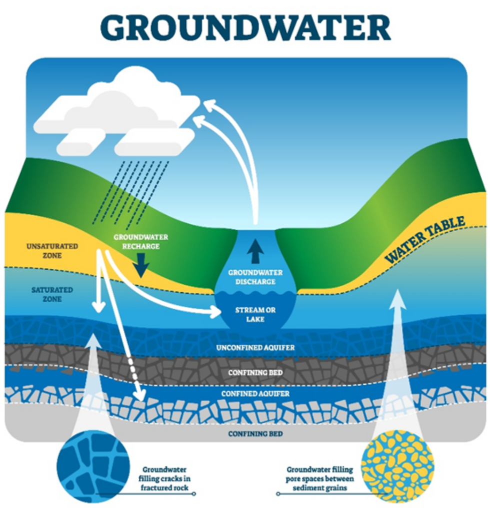
Groundwater are the sub-terranean water resources that feed into wells and wetlands and is the resource nearly half of people worldwide rely on for their drinking water, particularly in areas prone to drought or with unreliable surface waters. Groundwater is the water that collects and flows beneath the surface of the Earth, by filling in the gaps in sediment, rocks, and soil, also called an aquifer. Sand, clay, or shale are permeable materials that allows water to flow through it, as gravity pulls it down from higher to lower elevations and from the surface to underground. If surface water is the water you see, groundwater is the water you don't see.

## Shared Soil:

*Groundwater flows are a critical unseen part of the water cycle. Making the invisible visible is the theme of World Water Day 2022, the year of Groundwater.*

The space where groundwater and surface water ultimately meet is referred to as the water table, between the saturated zone and unsaturated zone. Beneath our feet are complex layers of materials with varying features that affect how water moves through them.[1]

As we know from the water cycle, all water resources are inherently linked and deeply interconnected, as groundwater is to surface water—but the attention paid to the water resources we can't see has been far more limited. Including their damage and depletion, which has occurred alongside economic development, increased water demands, as well as pollution. Groundwater is the primary water source for agriculture and irrigation, and in rural and arid climates this is the water that supports life. However, when extraction outpaces the recharge of an aquifer system, the level can fall hundreds of meters deeper. From the water table down to confined aquifers and fossil aquifers, the age of groundwater can be days to 10's or 100's of thousands of years old. The deeper the source, the more ancient and likely nonrenewable it is.




*Source: Shutterstock*

## Practical Summary

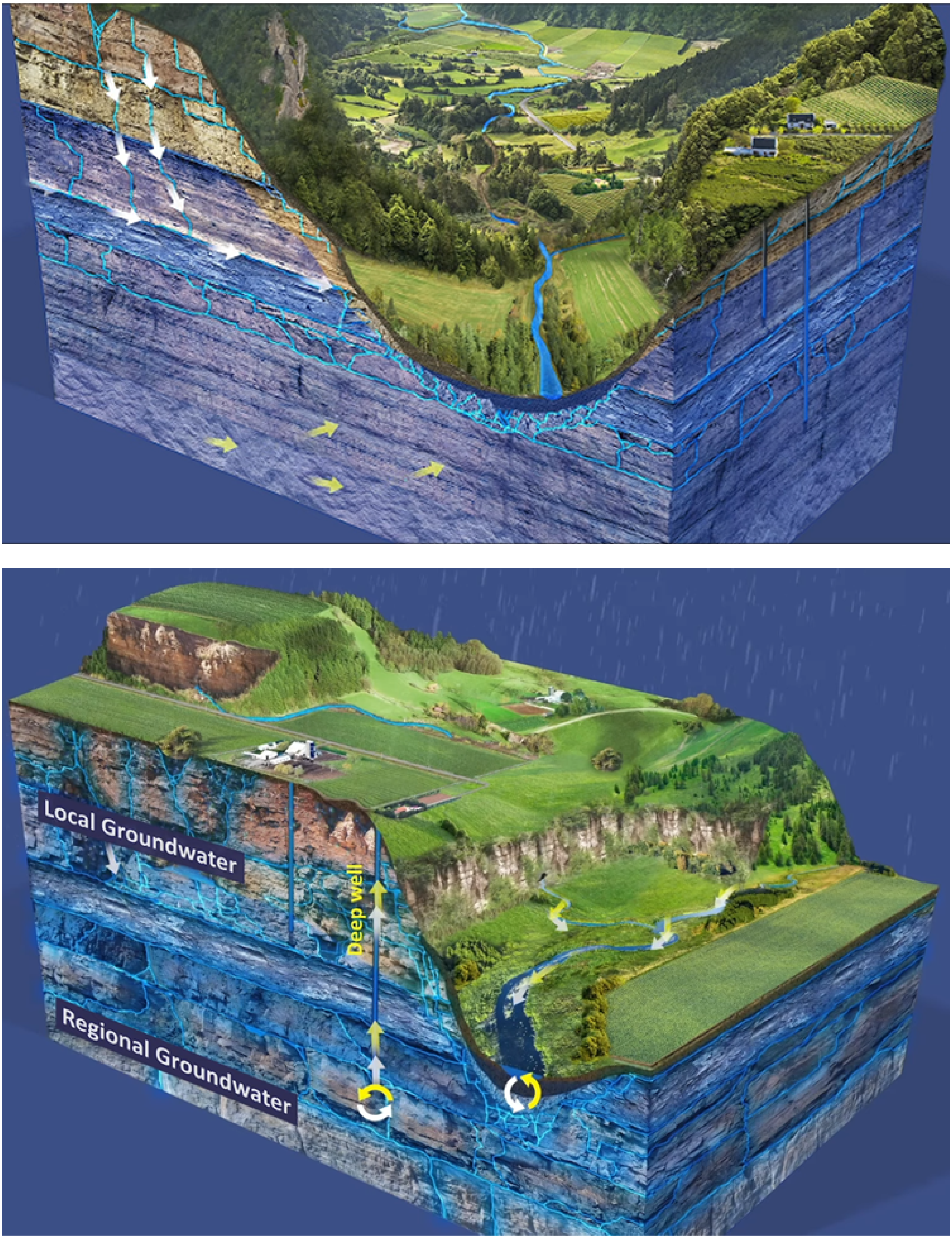
- Groundwater is 99% of all liquid freshwater on earth and is understood much less than easily accessible freshwater in lakes and rivers. Groundwater is the primary potable water source for 40% of people, and up to 100% for many rural communities.
- Groundwater is inherently transboundary and is affected by geography and extraction that shifts the water table, with impacts over very large areas. Climate change is changing surface waters and groundwater recharge, making groundwater monitoring ever more important.
- Overuse and pumping of groundwater are shifting water tables, affecting wetlands, causing saltwater intrusion, and sinking lands. Small drops in groundwater levels can impact stream flows to critical levels. Transboundary agreements are often surface water focused and do not align with the groundwater systems that support them.
- Nonrenewable groundwater resources from confined aquifers in arid climates are being depleted rapidly for short term use and cannot be recharged. The recharge timeline for groundwater can vary from weeks to decades, or even millions of years for fossil water.
- Irrigation plays a critical role in the economy of the Maghreb countries and is essential to sustain the rural population. Groundwater exploitation has grown explosively in the region due to economic incentives and technological innovations.
- Groundwater use in the Maghreb region is dominated by private use and unauthorized pumping is common. Excessive, unsustainable pumping has led to a drop in groundwater levels in many places, affecting the natural environment and creating disparities between farmers who can afford to invest in drilling deeper wells, and those who cannot.
- The sustainable management of groundwater is critical to food production and rural economies everywhere, requiring engagement with farmers, governments, and local communities.

*"Groundwater is a vital resource that provides almost half of all drinking water worldwide, about 40% of water for irrigated agriculture and about 1/3 of water required for industry. It sustains ecosystems, maintains the baseflow of rivers and prevents land subsidence and seawater intrusion."[2]*

Groundwater is often poorly understood. We may think of groundwater as being like subterranean rivers, or the water found flowing in caves and sink holes formed from karst. While this is water that is underground and thus not surface water, it is also not the same as saturated porous material that makes up an aquifer, and thus distinct. Aquifers in general though are rather loosely defined, as primarily a geological formation that holds and transfers enough water, and which varies with the geography. The imprecise definition of aquifers and their physical characteristics has also made their management more difficult from the prospective of international law and a transboundary context.

*Source: Shutterstock*

Groundwater is inherently transboundary. While many rivers and lakes form somewhat natural borders between nation-states, we don’t create political borders by the trends of gaps in rock or sediment. Water flows down, laterally, and up, moving through, below, and over the surface of the earth.




*Groundwater movements in aquifers – down, laterally, and up. Source: Minnesota Department of Agriculture*

The water found as surface water in a spring may flow from an aquifer that is recharged many miles away. It may flow overland as surface water, disappear into groundwater, and then reemerge as surface water again. As shown in the images on the previous page from the Minnesota Department of Agriculture, a cutaway view of the earth's surface can illustrate the various vagaries of how water moves throughout the earth.

Moving from the surface, though the layers of rock and sediment, you first encounter the water table, the saturated zone, and an unconfined aquifer, which most shallow wells will draw from—perhaps 70ft to 200ft deep. Beneath this layer are more layers, which may also hold water, further below layers that do not (confinement bed), and would be called a confined aquifer, having an impermeable layer both above and below. Groundwater moves laterally in these layers towards the water table, or to the surface with elevation changes. Each of these layers may be recharged in different ways or from different sources, and under varying levels of pressure. A deep well into a confined aquifer will drive water up to higher levels, shifting the balance of flows or creating a cone of depression. A river may receive water from groundwater flows or lose water to it.

In many regions around the world, many deep and ancient aquifers are being depleted at a rapid pace and ultimately at unsustainable levels, with resources that may have developed over hundreds, or even thousands of years, being used up in only decades. In regions ranging from Yemen to central California, the stress placed on groundwater resources is a critical challenge that governments are sleepwalking into, as the environmental limits of groundwater pumping are reached. Such 'fossil water' aquifers for example will not be replaced by precipitation and are thus non-renewable sources. In places like Saudi Arabia and North Africa, these have been used to grow crops and produce food, which is setting up a food system reliance on a finite water resource.

With rapid urban development across the globe, more and more people are living in cities, with accompanying increases in demand for water that must come from elsewhere. Urban infrastructure also often creates water runoffs that are less than optimal for recharging groundwater aquifers, further impacting water tables and can lead to seawater intrusion in coastal regions as well.

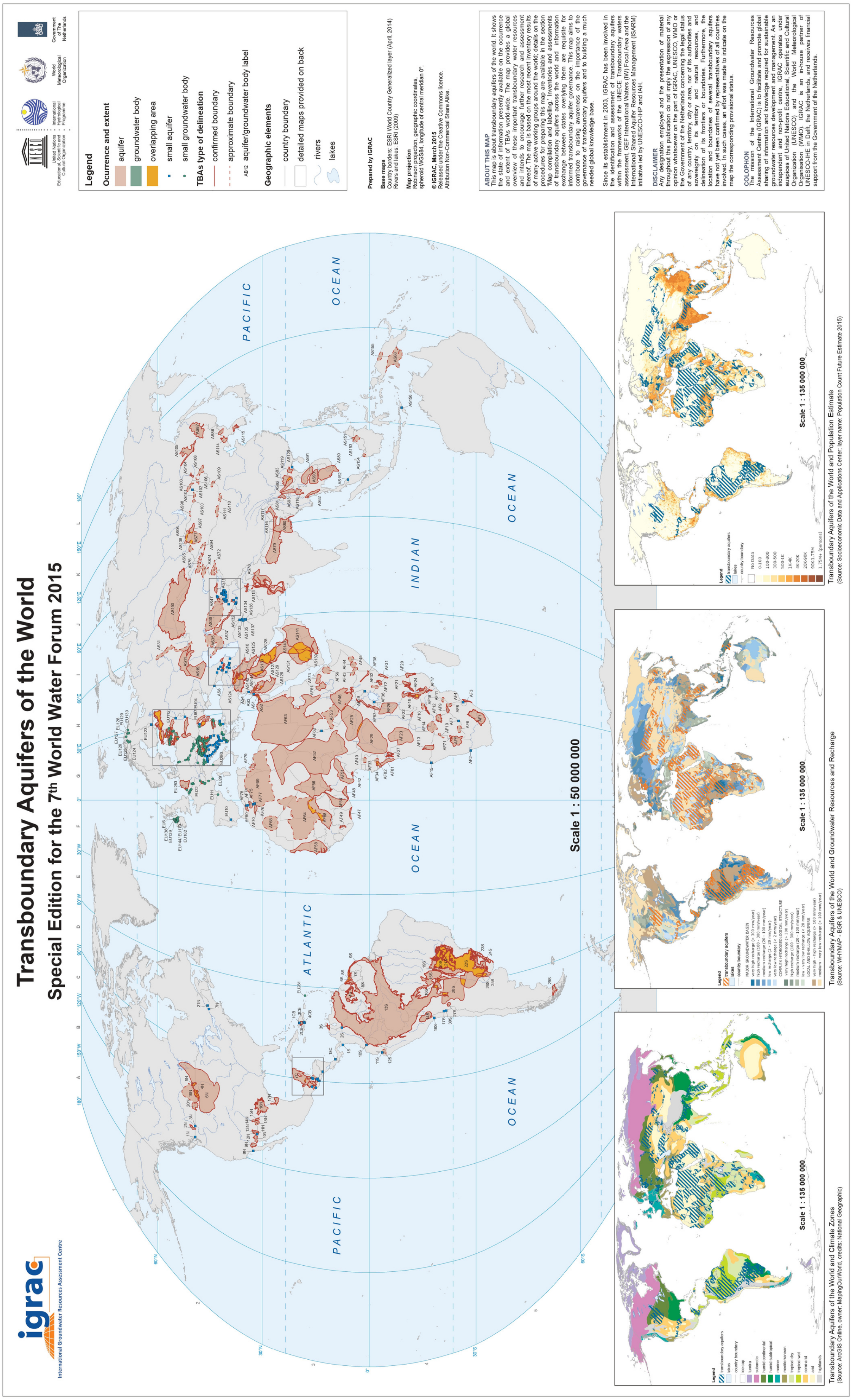
Much of urban development is happening along the coasts globally. In the US, nearly half of the population live in coastal counties, and 40% of the global population live within 100km of the coast.[3]

> *"Urban areas often have impervious surfaces, such as parking lots, for instance. Impervious surfaces prevent water from seeping into the ground below. Instead of entering the area's zone of saturation, water becomes runoff. The water table dips."[4]*

If we think in finance terms, surface waters are the checking account and groundwater is the savings account, and fossil water are inheritance. Aquifer depletion is draining the groundwater saving accounts of many regions, primarily due to a lack of integrated water resource management and nature-based solutions. It is also a question of priorities, taking the measures to account for these resources properly, and preserve them from pollution and degradation, in addition to overuse. Properly exploring and protecting these resources is also an opportunity to potentially unlock even further unknown resources beneath our feet.

In this issue on Groundwater, two chapters are given to provide a look into the limits of groundwater pumping around the world, and its impact on the environment, as well as a case study on groundwater resource use in North Africa, which is facing particularly difficult challenges between increasing economic development and preserving these critical groundwater resources.

Dr. Inge de Graaf is our guest author for this issue, she is Assistant Professor of the Water Systems and Global Change Group, at Wageningen University in the Netherlands.




*Source: igrac*


Source: Shutterstock

# Environmental Limit of Groundwater Pumping

*By: Dr. Eng. Inge de Graaf*
*Assistant Professor - Water Systems and Global Change Group, Wageningen University, Netherlands*

## Our Thirsty World

Groundwater is the largest accessible freshwater resource on earth and is vital for humanity and the environment. Groundwater is, in general, more widely accessible and less vulnerable to quality degradation and droughts than surface water. Worldwide, 2.5 billion people depend solely on groundwater for their drinking water and basic daily needs. Irrigation agriculture is by far the largest user of groundwater worldwide. Currently, approximately 40% of the irrigated area depends on groundwater. Groundwater flows into rivers and lakes help to maintain flow even during times of drought.

Over the past decades, water demands have increased rapidly, mainly driven by global population growth and economic development. Although global water demands can in principle be met by surface water from lakes, rivers, and reservoirs only, the available surface water stocks are not evenly distributed across the globe and throughout the year, leading to water stress in several parts of the world. For example, in monsoon-dominated climates, a substantial portion of the annual runoff occurs during a short period of the year. Or, in irrigated regions in arid to semi-arid climates, surface water availability is limited due to low precipitation.

In regions with frequent water stress and where large aquifer systems are present, groundwater is often used as an additional source of fresh water. However, if more groundwater is pumped than replenished by infiltrating rain or streamflow, overexploitation, and persistent groundwater depletion—which means that groundwater is lost from its storage—can occur. Consequently, groundwater levels will drop, which can have devastating effects on streamflow, groundwater-fed wetlands, and related ecosystems. Also, in deltaic regions, dropping water levels may lead to land subsidence and saltwater intrusion. In the Central Valley in California for example, groundwater levels have dropped up to 120 meters in 100 years in the regions where groundwater pumping is intensive, which have led to land subsidence and reduction of streamflow. Another example is the Jakarta delta in Indonesia, where the risk and frequency of river and coastal flooding have increased significantly due to land subsidence caused by groundwater pumping. Reported regions of excessive groundwater use and groundwater depletion are, for example, the San-Joaquin aquifer in the Central Valley of California, the Ogallala Aquifer in the central United States, North-East China, Iran, Yemen, and the South-East of Spain (Fig.1).

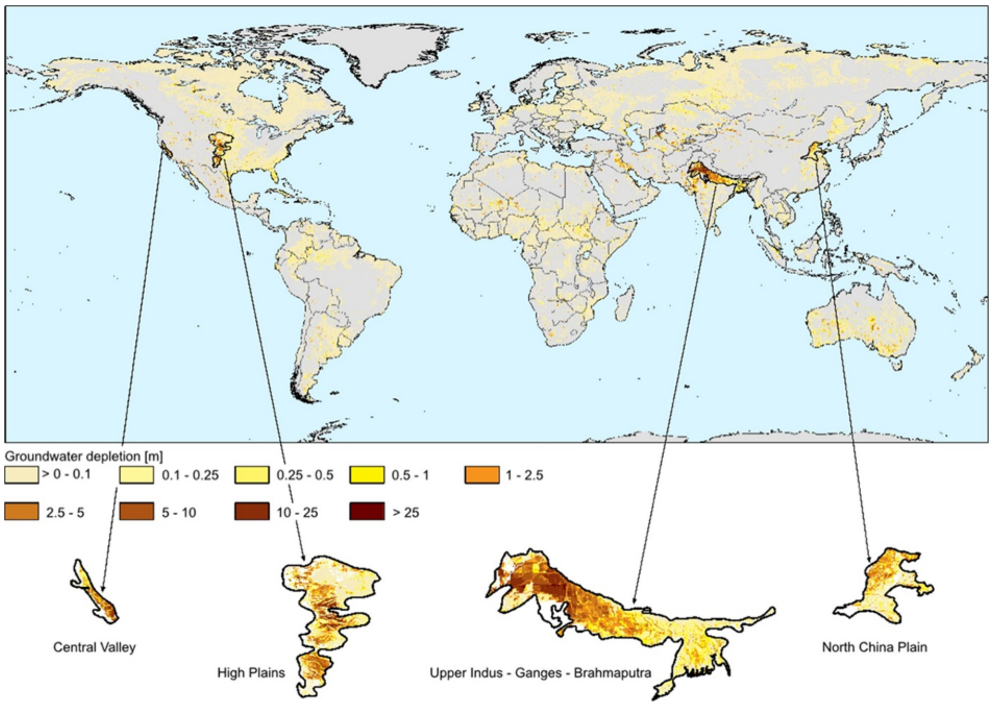



*Figure 1. Gridded estimates of cumulative groundwater depletion (in m3 per m2) period 1960-2010. (Previously published in de Graaf et al 2019)*

Another consequence of dropping groundwater levels is that wells will run dry and pumping costs will increase. As a result, costs for crop production will increase as well as food prices. The increase in costs will affect all users, especially the world's poorest farmers who cannot afford a deeper well and a stronger pump. Without financial support and technical improvements, wells will run dry and agricultural production will likely decrease, threatening regional and global food security.

It is expected that, over the coming decades, water demands will increase further, mainly driven by population growth, economic development, and the expansion of irrigated land. The demand for food will increase as well, especially in the less developed countries due to population growth, but also in the upcoming economies where incomes are rising, and dietary patterns are changing towards a higher meat intake. In addition, climate change will have a growing impact on water resources, as precipitation patterns and soil moisture will change, glaciers will melt, and water-related disasters, such as floods and droughts, will become more frequent and severe.

The expected increase in water demands, climate change impacts, and the negative consequences of groundwater overuse that are already experienced pose for me the urgent question: How much groundwater can be used sustainably and will this be enough to meet future food demands, driving crop water requirements.In this article, I will discuss the results of a recent study1 and provide a look into the future of sustainable groundwater use worldwide.

## Global-scale Groundwater Modeling and the Environmental Impact of Groundwater Pumping

Groundwater and surface water are connected. Every groundwater well creates a cone of depression in the aquifer it draws water from. If the extraction rate is high enough the cone can extend over a great distance, and therewith can impact water tables in neighboring wells, streams, and rivers.

Up to recently global scale knowledge on how groundwater pumping impacts river discharge was still missing. A global-scale model that could simulate groundwater heads and flows and interactions with surface water was not available yet. In my work I developed a global-scale model that dynamically simulates groundwater and surface water storages and fluxes, allowing groundwater and surface water to interact with each other [1]. I used this model to find out where and when streamflow hits or will hit, critical levels needed to maintain healthy ecosystems, for the first time, due to groundwater pumping.

At the level of individual catchment or smaller river basins, hydrological models that simulate the flow of groundwater and its interactions with surface water were available already. However, using a global-scale model provides insights for every region worldwide, which is something that cannot be achieved with catchment models only, and evaluation of the results can be used as a road map for identifying regions that need higher resolution modeling and more observations.

In the global model, I included water uses of four sectors, namely industry, domestic use, livestock, and irrigation, and water consumption from both surface water and groundwater resources were estimated. The model was run over the period 1960-2100. For the historic period (1960-2010) historical climate and water demand data were used. After 2010, it was assumed water demands would remain constant, except for irrigation demands that increased as a result of climate change. Climate inputs were used from three Global Climate Models using the Representative Concentration Pathway 8.5. (This is a greenhouse gas concentration trajectory, used by the Intergovernmental Panel on Climate Change).

To determine when streamflow hits critical levels I defined a standard that assumes that, to maintain healthy ecosystems, groundwater pumping should not lower the natural groundwater contribution to low streamflow (averaged over 5 years) by more than 10%. This standard is loosely based on a previous publication [2]. If the groundwater contribution to low streamflow dropped by 10% or more for more than 3 months in a row and two consecutive years, the critical level of streamflow was reached. However, streamflow and groundwater levels can also be affected by more than pumping. Climate change, for example, will have an impact as well. To exclude the impacts of climate change I compared results of model runs including human activities (human-run) and without human activities (naturalized run).

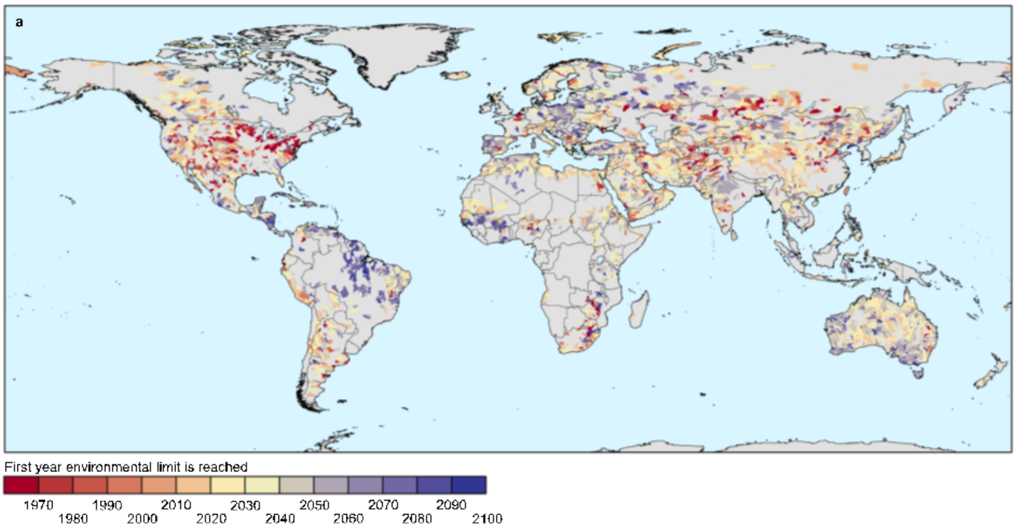



*Figure 2: Estimated first-time environmental flows have been or will be reached, by year, averaged per sub-watersheds (previously published in de Graaf et al 2019).*

Our calculations showed that almost 20% of the watersheds where groundwater is pumped currently suffer from a reduction of streamflow, putting aquatic ecosystems at risk. We estimated that by 2050 more than half of the watersheds where groundwater is pumped will not be able to maintain healthy ecosystems. Our estimate of where and when critical streamflow is reached for the first time is presented in Figure 2. The peak of sub-watersheds reaching their environmental limit is estimated around 2030-2040 [1].

The most striking insight is that only a small drop in groundwater level will already cause river flow to drop below the critical level (Fig 3). This means that river flow is very sensitive to fluctuations in groundwater levels and happens before significant losses in groundwater storage are experienced (i.e. groundwater depletion). Groundwater flow is slow; it can take months, years, or even decades for groundwater to reach the river or stream and the impact of current groundwater pumping will often become noticeable only after years of decades. This means that we cannot detect the future impact of groundwater pumping on rivers from the current levels of groundwater decline.

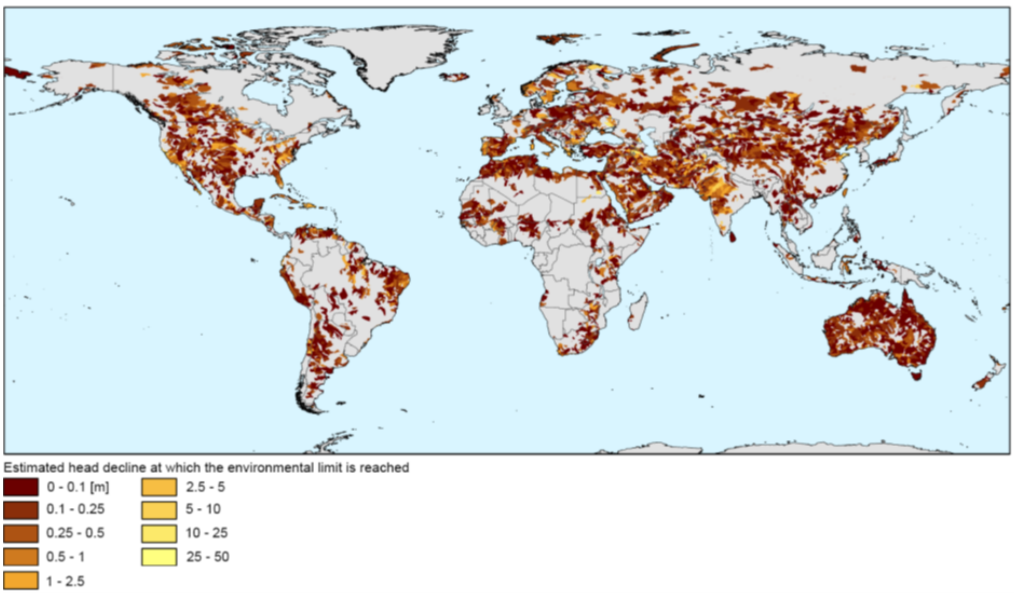



*Figure 3: Estimated head decline, caused by groundwater pumping, associated with reaching the environmental limit. The estimated head decline is shown in meters (previously published in de Graaf et al 2019)*

We already see negative impacts of groundwater pumping on river flows in, for example, central and western United States and the Indus River basin in India. If groundwater pumping continues as it is now, we expect the negative impact to occur in southern and eastern Europe, North Africa, and Australia in the coming decades, and climate change will accelerate this process.

## The High Plains Aquifer Case

One well-known example of an excessively abstracted aquifer, and one of the case studies I am fascinated with, is the High Plains aquifer (also called the Ogallala aquifer) in the central United States. The High Plains aquifer is a shallow water table aquifer surrounded by sand, silt, clay, and gravel. It is one of the world's largest aquifers and underlies an area of approximately 450,000 km2 in portions of eight states (South Dakota, Nebraska, Wyoming, Colorado, Kansan, Oklahoma, New Mexico, and Texas). Large-scale pumping operations largely started from this aquifer. Not surprisingly this is where the first negative impacts of excessive groundwater pumping are experienced. Groundwater abstractions from the High Plains aquifer exceed those of any other aquifer in the United States. Today about 27% of the irrigated land in the entire United States lies over the aquifer and is heavily dependent on the High Plains groundwater. Since 1970 groundwater levels have steadily declined over a large part of the aquifer. In 2014, the U.S. Geological Service (USGS) estimated that withdrawals from the High Plains aquifer since pumping began have totaled (370 cubic kilometers)), roughly the equivalent of two-thirds of Lake Erie. In many cases, the groundwater pumped from the aquifer is gone forever. Most of the water stored in the High Plains Aquifer is fossil, which recharged the aquifer millions of years ago. In the current climate conditions, precipitation in the overlying area is so little that most parts of the aquifer recharge extremely slowly.

However, the negative effects are not experienced to the same extent for all parts of the High Plains. The northern part of the aquifer has seen little to no groundwater depletion and even a small recovery of dropping groundwater levels. For this region, precipitation is more than adequate to recharge the aquifer. In contrast, large parts of the central and southern High Plains experience head declines between 15 to over 30 meters (Fig 4).

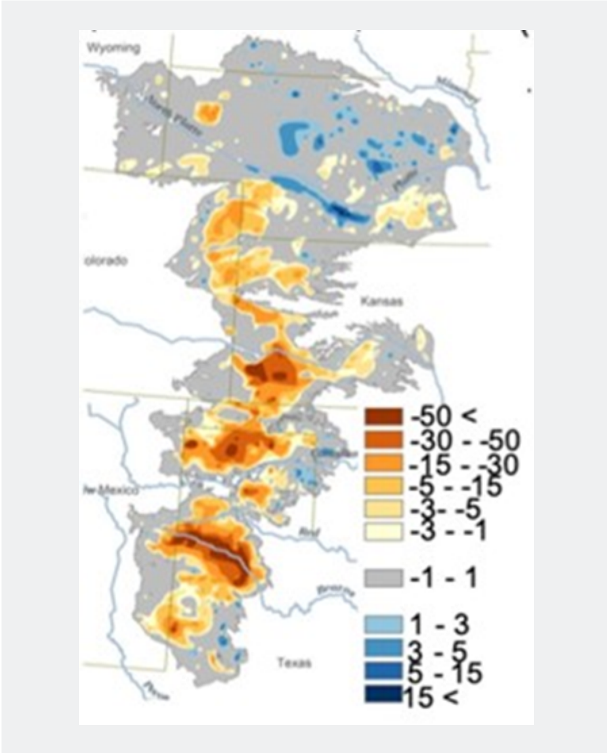



*Figure 4: USGS reported head changes in meters for the High Plains aquifer over 1950-2007 (modified after McGuire, 2009). [5]*

For parts of these regions, groundwater levels have dropped to such an extent that pumping is no longer economically feasible. Also, many smaller rivers and streams have fallen dry as larger rivers have seen their streamflow decline significantly. If pumping continues at current rates, it is estimated that 35% of the Southern High Plains will be unable to support irrigation within thirty years.[3]

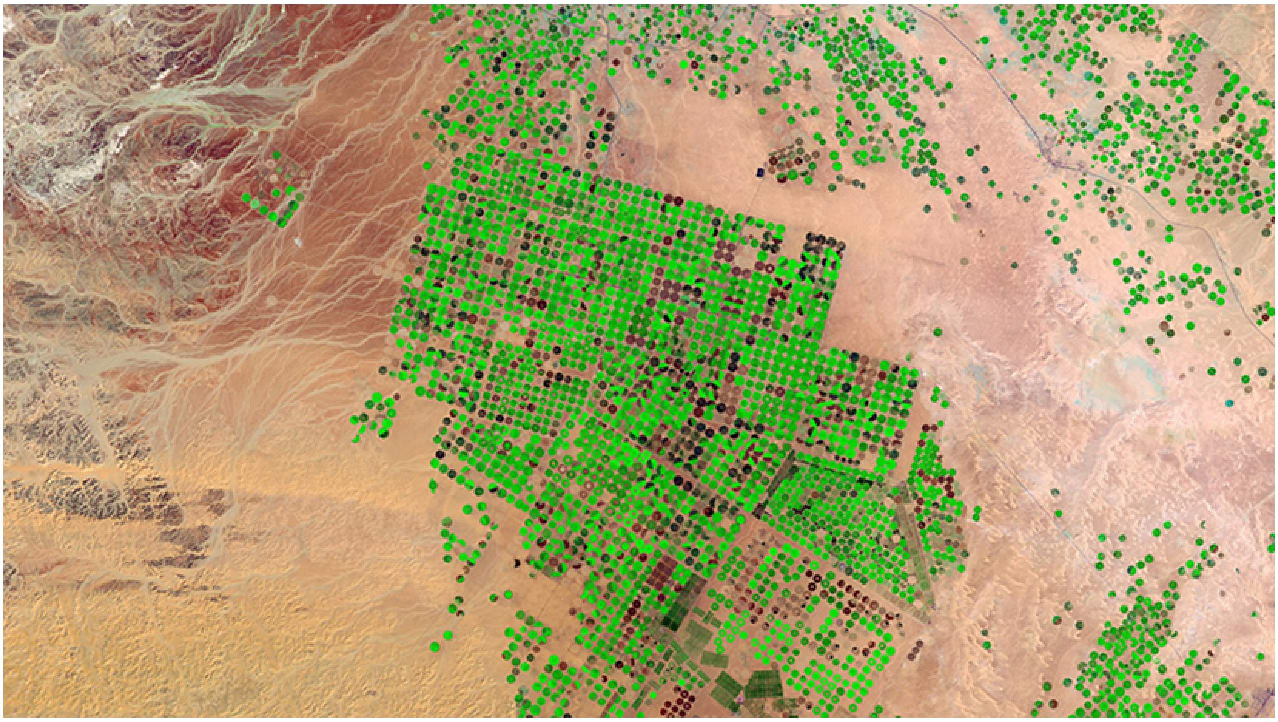
A recent study [4] concluded that the vast majority of farmers in the regions want to save groundwater. But groundwater depletion is a structural problem embedded in agricultural practices. To support the farmers in this region in using groundwater more sustainably, help from policymakers is needed.

## Challenges and Opportunties

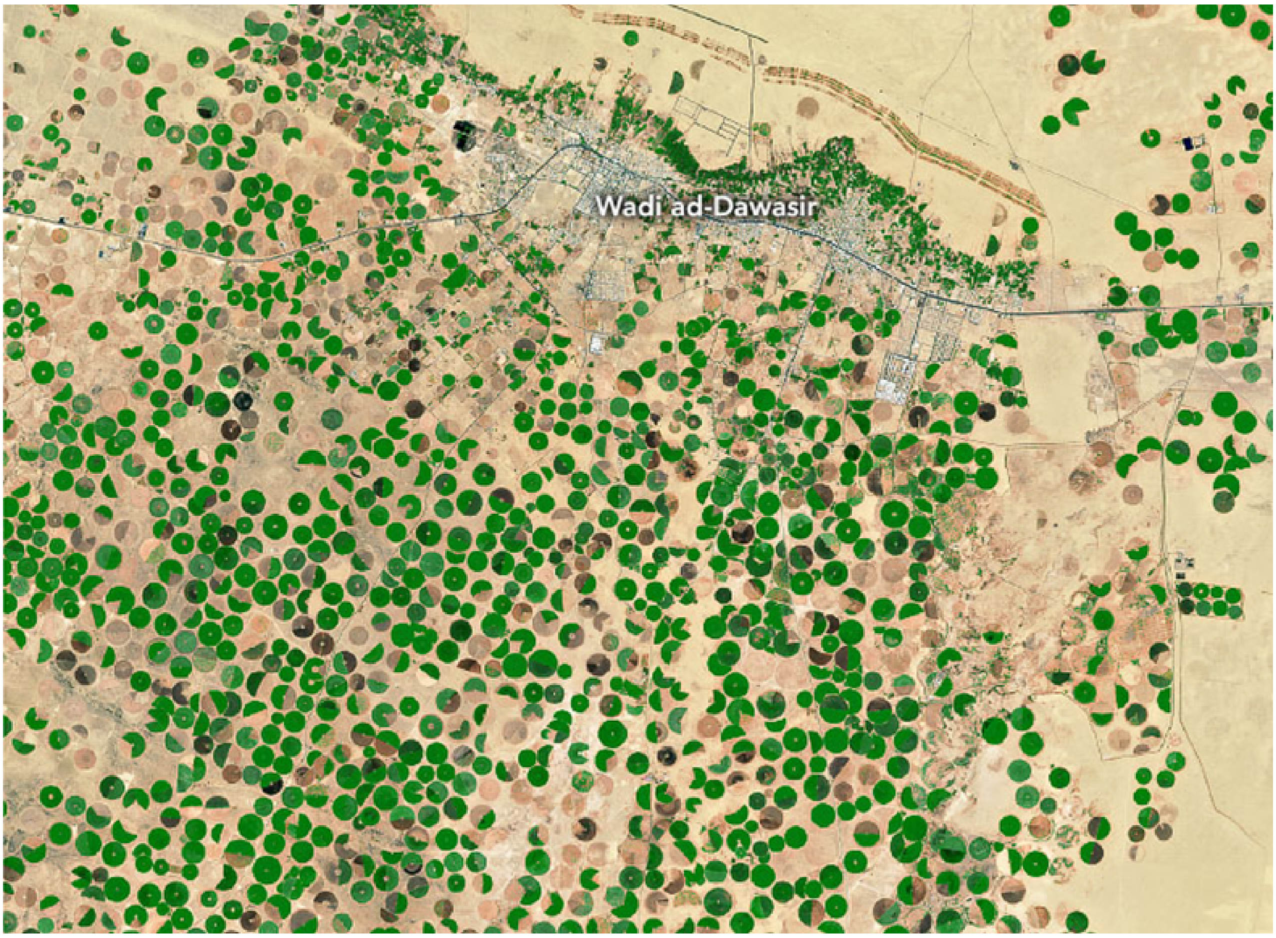
With my research, I hope to raise awareness of a slowly evolving crisis. The only way to reduce and prevent negative impacts of groundwater overuse is the use less groundwater, while at the same time, sufficient crop production to support food security needs to be maintained and enhanced. It is important to know how much groundwater can be used sustainably, now and in the future, to inform the development of sustainable adaptation strategies for future water use and food production. Adaptation measures can focus on increasing water availability, for example through the use of desalination, reuse, or managed artificial recharge; decreasing water demands, for example by increasing water productivity, or increasing irrigation efficiency; decreasing food demands, for example by a change of diet, or decreasing food loss.

I think it is important the realize that these adaptation strategies differ from region to region as no one approach can be applied everywhere. I recently got awarded a European Research Council Starting Grant (ERC-StG) on the topic of groundwater sustainability and crop production. With a small research team, I will study if and how groundwater can be used sustainably to support the crop production needed to meet current and future food demands. We will evaluate to what extent current and future crop production is compatible with sustainable groundwater use and reveal current and future trade-offs between groundwater withdrawals used for crop production and the aquatic environment.

Acknowledgment: I like to thank my colleagues of the Water Systems and Global Change Group (Wageningen University) for proofreading this article.



*Source: USGS/NASA Landsat Program*




*Source: NASA Earth Observatory images by Joshua Stevens*

## Case Study: Groundwater in North Africa

Like other countries in the MENA region, Morocco, Algeria and Tunisia are facing increasing water scarcity due to population growth, inefficient water use and overexploitation of water resources, which is further exacerbated by the effects of climate change. Agriculture plays a significant role in the economy, generating 10-20% of GDP and exports in the region. Irrigated farming provides employment to 20-33% of the labour force in both Tunisia and Morocco. Groundwater resources have become particularly fragile, due to the intensification of irrigated agriculture, that is accompanied by withdrawal rates that in many cases exceed the natural recharge capacity of aquifers. An 'elusive' resource, groundwater is hidden from view and seemingly eternally present. As in many countries, the characteristics of aquifers in the Maghreb have not yet been fully mapped out, however it is clear that groundwater overexploitation has led to a drop in the water table, which pushes farmers to pump up water from deeper levels. This trend has dire consequences for the region's aquifers, but has also prompted a race for water, in which small farmers are losing out to large investors. In a bid to manage groundwater resources sustainably, while also protecting the rural economy, the Maghreb countries have developed a combination of strategies. For these to be successful, it is crucial to engage at the local level with farmers. [1]

### Silent Revolution

Groundwater has played an increasing role in irrigated agriculture in North-Africa in recent decades, despite the existence of large-scale public surface irrigation schemes. Technological innovation helped spur the development of groundwater for irrigation, which led to a silent agricultural revolution. The process started about 70 years ago, when the dissemination of borehole drilling and pumping methods, as well as the introduction of modern machines that made drilling of boreholes easier and more affordable, led to a sharp increase in the use of groundwater in agriculture. The exploitation of groundwater was further encouraged by subsidies and favorable bank loans. In Algeria, such bank loans for equipment and machinery brought about groundwater abstraction peaks in the 1970s and 1980s. Improved pumping and farming methods helped increase the irrigated surface by 650,000 new hectares between 1981 and 1985. This growth was also seen in the number of surface wells, which grew explosively in the region. For example, in Tunisia alone the number of surface wells doubled in 20 years, from 60,000 in 1980 to 120,000 in 2000. According to recent estimates, groundwater supplies more than 500,000 farms in Morocco, Algeria and Tunisia today, and pumping wells are being used for the irrigation of more than 1.75 million ha. Irrigation thus plays a critical role in the economy of the Maghreb countries and is essential to sustain the rural population. [2] [3] [4]

Unsurprisingly, excessive pumping of groundwater has also influenced the natural environment. In coastal areas, overexploitation of aquifers has led to the infiltration of seawater. Declining groundwater also affects surface water, such as oases and wetlands. For example, in North East Algeria where the Ramsar wetland of Beni-Belaid is threatened by excessive groundwater pumping. [5]

The economic cost of overexploitation is felt on a local as well as national scale. The African Development Bank describes in a report in 2011 how a local agricultural crisis developed in coastal Chaouia, Morocco, due to groundwater overexploitation. Since the 1970s, the region was known for citrus fruit production, then tomatoes and potatoes, and livestock fodder. Seawater infiltration, as well as a drop in water levels more inland, forced farmers to deepen boreholes, fetch water from wells further afield or rent land elsewhere. The saline-sensitive citrus fruits were replaced by more saline resistant, but less profitable crops. Farmers then turned to rain fed crops. Ultimately, many farmers were forced to leave the area for opportunities in urban centers. This exodus affected the whole production chain connected to agriculture in the area. According to the report, the number of cooperatives involved in market gardening exports fell from 120 in the 1980s to 3 in 2011. If such trends continue, it will eventually have repercussions for the food security of the Maghreb countries. [2]

*Source: Shutterstock*

## Farmers' Strategies

Farmers across the region have resorted to a variety of strategies to address the impacts of declining groundwater. The AfDB distinguishes 2 groups of strategies, the first being 'chasing strategies'. Chasing strategies vary, depending on whether the aquifer is deep or shallow. When the aquifer is deep, farmers tend to invest in new drilling equipment in order to obtain sufficient quantities of water, to maintain production levels. Often, legal control mechanisms are bypassed in order to use a borehole more extensively. For example, in Tunisia, farmers would sometimes obtain an electricity connection for boreholes for domestic or non-farm use to then change it to 'agricultural use', which comes with a lower tariff. When the aquifer is shallow, and boreholes extend to the substratum, farmers often opt to pump the water from another location and pump it back to their land.

The second group of strategies are adaptive strategies. In some cases, farmers may switch to more localized irrigation systems or in other cases, water quantity or quality has degraded to the point that farmers are forced to return to rain-fed crops, which makes them more vulnerable during dry periods, especially as weather patterns become more erratic.

The current situation is creating a 'race to the bottom', that causes a widening gap between those who, with the right connections and adequate financial resources, manage to circumvent the rules and make ever-larger investments, and those who are forced to adapt. The consequences particularly affect small farmers in traditional agriculture. [2]

## Private Use

Groundwater use in the Maghreb region is dominated by private use, which is an important factor for the rapid increase of groundwater wells in the Maghreb countries. Well-density is high in many places, often with several wells per m2 and wells are dug, deepened and subsequently abandoned at a high pace. A significant proportion of these private wells is not registered, making it difficult for authorities to monitor abstraction, estimate abstraction rates, or levy fees from users. Administrations may find it easier to control mechanically drilled wells, for which drilling machines are needed and electricity is used, which makes them easier to track- than manually dug wells. There have also been attempts at levying water fees, that can subsequently be used to maintain infrastructure. Although multiple programs have been initiated in the region in this regard, the collection rate for such fees is often low.

For instance, in Morocco, fees were made compulsory by law in 1995 and farmers have pay for the development, operation and maintenance of wells, but in practice, implementation is not effective. Other factors that inhibit the implementation of policies for the sustainable use of water resources are the countries' inadequate institutional mechanisms, the lack of coordination between the different levels of government and between authorities from the agricultural and water sectors, and the limited involvement of water users in general. [3]

Different institutional mechanisms and frameworks for cooperation have been developed throughout the region to enhance coordination between national and local authorities, and to engage users in water resource management and the protection of aquifers. Examples from Morocco and Tunisia are highlighted below.

## Aquifer Management Contract

Morocco announced the expansion of the 'Contrat de Nappe' aquifer management system in 2014, after successes in the Souss region, where farmers, the river basin agency, local authorities and other stakeholders collaborated since 2007 to improve local agriculture and reduce groundwater withdrawals. The discussions that would form the basis of the Souss aquifer agreement started after protests from agricultural unions against the closure of two wells by the Souss Massa River Basin Agency. The well closures were carried out alongside an awareness campaign aimed at farmers, to promote the new water law. In an attempt to solve the issue, the wali (local governor) brought the different parties together to address the overexploitation of the aquifer, while safeguarding local agricultural development. The commission that was established comprised of 20 stakeholders, including the river basin agency, local authorities, agricultural unions, research institutes, water suppliers, and users (farmers). Measures and actions negotiated by the stakeholders included control on the expansion of orchards and irrigated areas, control on the digging of wells and boreholes, implementing water-saving technologies (drip irrigation, irrigation scheduling), the provision of additional surface water (from new to build dams), and establishing improved mechanisms for levying user fees (for the maintenance of water infrastructure and investments).

The Sous aquifer management agreement was signed in 2007 but has so far not been replicated on a wider scale, despite the governments' ambitions to do so for all major aquifers by 2016. [3] [1]

## Groups of Agricultural Development

A completely different approach can be seen in Tunisia where from 1987, at the instigation of the World Bank and the IMF, the country established a new approach to groundwater governance. A shift from state controlled to community water management was part of the envisaged reforms, aimed to increase the role of users and enhance water demand management. Local associations were set up to collect revenue through member subscription fees, subsidies obtained from regional agriculture development commissions, as well as the sale of water to users. These associations were also given administrative control of the national hydraulic infrastructure, and later became in charge of maintenance and management of these networks. After several decades and name changes, these associations transformed into what are now called Groups of Agricultural Development (the French acronym being GDA). Effectively, these function as user organisations in which farmers take on the role of water resource managers. GDA's can be part of public irrigation schemes or function independently, run by farmers. The number of GDA's in irrigation in 2014 was 1253. The total number of GDA's was 2,703 at the end of 2018. In areas of public irrigation where groundwater is used, management and operation are almost completely in the hands of GDA's. That GDA's can be instrumental in implementing local strategies for the protection of aquifers is shown by the Bsissi-Oued El Akarit Aquifer, where the GDA was a partner in the establishment of an association for the development and monitoring of the aquifer. It has played an important role in preventing the drilling of new boreholes and the control of pumping capacity. [3] [1]


Source: Shutterstock

## Legal Frameworks and Institutional Mechanisms for Groundwater Management

Provisions for groundwater management are included in the national water laws of the Maghreb countries. The 1975 Water Code of Tunisia, the 1995 Water Act of Morocco and the 2005 Water Act of Algeria, all contain clauses for the authorization of groundwater exploitation. They also stipulate quantitative and qualitative protection through the establishment of protection zones where the drilling of new boreholes and wells is subject to authorization or banned entirely.

Currently, the making of a new water code is in its final phase in Tunisia. It forms the basis for a shift from supply management to demand management. It includes provisions for more sophisticated water governance, progression towards sustainable groundwater management, improved development of irrigated perimeters while controlling water savings, and bringing decision-making closer to the local level.

A new Water Act was also adopted in Morocco in 2016, with reforms regarding a more decentralized, participatory management of water resources, enhancing consultation and coordination structures, as well as improved mechanisms for the protection and conservation of water resources.

For the implementation of regulations, authorization of groundwater exploitation, and 'water policing', the Maghreb countries have established institutional mechanisms that are very different from each other. In Morocco, the establishment of a 'water police' was included in a decree of 1925. The task now rests with the river basin agencies (as well as the police), who also play a major role in data collection, research, and implementation of water resource development policy, and as such, are the main protectors of the aquifers. The State Secretariat for Water and Environment oversees their activities.

In Algeria, the Ministry of Water Resources is the central authority for water management, while at the local level, water resources are controlled by the hydrological department of the wilaya (governorate), with an advisory role for the National Hydraulic Resources Agency and the river basin agencies, the latter of which is also tasked with the registration of water users.

In Tunisia, the Ministry of Agriculture is responsible for monitoring and control of groundwater exploitation, with tasks delegated to the Regional Commissions for Agricultural Development. Groups of Agricultural Development (GDA's), in which local farmers are represented, are responsible for maintenance and management of water networks and the collection of user fees, and serve as intermediaries for the implementation of public policies.

To meet the needs of ailing agricultural areas suffering from degraded land and water resources,
Morocco, Algeria and Tunisia have each developed their own strategies to ensure adequate supply while also bringing down water demand. On the supply-side, the countries focused on mobilizing surface water for irrigation, groundwater recharge initiatives, and unconventional water resources.

In some cases, large distances are bridged to transport surface water for irrigation purposes, such as between the Souss basin and Guerdane irrigated area (90 km) or in Tunisia, where areas in northern Cap Bon receive water from the Medjera valley, which also supplies the capital with drinking water. Additionally, water from the Medjerda valley has been injected in old quarries or wells to recharge the underlying aquifer of the coastal area of Ras El Jebel. Tunisia's aquifer recharge projects started in the 90's, and the practice was made a national priority in the National Strategy for the Development of Water Resources, with recharge activities in 21 aquifers fifteen years later. Algeria and Morocco developed aquifer recharge practices as well, through recharge basins or by slowing down and diverting flood water in wadis. Water released from storage dams is also commonly used for recharge purposes. The drawbacks of such solutions in support of agriculture are that in most watersheds, much of the surface water has already been mobilized to meet the demand of other sectors. [2]

The agricultural use of desalinated water and treated wastewater has slowly emerged in the region. In Tunisia, treated wastewater has been in use since 1989, after the official publication of treated wastewater quality standards for agriculture. In Algeria, a volume of 12.325.269 m3 of treated water was used for the irrigation of 11,045 hectares of agricultural land in 2019. In Morocco, with 15 desalination installations by 2016, a plant is under construction in Agadir to meet the drinking water and irrigation needs of 800,000 people. Tunisia is in the process of developing desalination for high commercial value crops such as greenhouse and nursery crops. In Algeria, desalination is expected to augment supply to urban areas, with the objective that dam water can subsequently be rechanneled for irrigation. [3] [1]

## Incentives & Control

On the demand side, a combination of financial incentives and control measures have been used to curb groundwater withdrawals. Financial incentives commonly consist of government subsidies that aim to increase water productivity (e.g. crop yield per unit of water consumption), often in the form of subsidies for equipment that enables farms to transition to localized irrigation. The roll-out of such programs depends on mechanization levels, as well local administrative capacity and can therefore be limited in certain areas. Moreover, water saving technology can only make a real difference if farmers are properly trained to work with the new equipment. Furthermore, applicants need to have groundwater abstraction authorization to be eligible to apply for such subsidies, which may discourage farmers. Finally, it has been found that a transition to local irrigation can in some cases lead to increased water withdrawals, as farmers who switch to more effective and productive irrigation methods often expand their land. The rise of localized irrigation has paved the way for more intensive agriculture, sometimes with adverse consequences. [2]

## Restoration?

With new legislation in recent years, the Maghreb countries have adopted policies that clearly focus on water conservation, the reduction of water withdrawals, more efficient and productive farming techniques, augmenting water supply with unconventional water, and enhancing institutional mechanisms for the protection of groundwater resources. On the other hand, the development of agriculture remains an important spearhead of the North African governments. They envision steady growth of the sector, with better access to the international market, increasing job opportunities, solutions for youth unemployment, and providing new impetus for rural development. These plans, such as Morocco's Plan Maroc Vert and The Green Generation plan, offer opportunities for the development of sustainable, environmentally friendly agriculture, but also pose new challenges in preserving groundwater resources. While important steps are being taken in reducing water withdrawals and mitigating over-exploitation, these have not led to the restoration of the resource-use balance. Building coalitions with local stakeholders -as in the above examples- and pursuing a participatory approach in which farmers' interests are taken into account, are pivotal for the next step: the long-term restoration of aquifers.

## Transboundary Aquifers

There are three transboundary aquifer systems shared between Morocco, Algeria and Tunisia:

The **Errachidia Basin** between Algeria and Morocco is a relatively small transboundary basin, spanning 60.000 km2., with rainfall rates between 200 and 80 mm.

The 210.000 km2 **Tindouf Basin** is shared between Algeria and Morocco, and also extends to Mauritania. Located in predominantly dessert areas, with scarce rainfall, active recharge to the aquifer is extremely low. The demographic density in this basin is also low.

Algeria, Tunisia and Libya share the **North Western Sahara Aquifer System** (NWSAS) which is the largest transboundary groundwater reserve in North Africa, extending over 1 million $km^2$.

Its water resources are largely non-renewable and the aquifer can therefore be considered a fossil groundwater resource. Over the last decades the agricultural and industrial development in the basin, as well as the technological advances in well drilling led to steadily growing water abstraction.

The NWSAS is composed of two major water-bearing layers, the Continental Intercalary (CI) and the Terminal Complex (CT). From the 1970 to the 2000s, abstraction by drilling has risen from 0.6 to 2.5 billion m3/year. The rate of withdrawals from the aquifer far exceeds the rate of its replenishment. The water abstraction is currently standing at three times the aquifer's natural recharge rate (1 billion m3 per year).

*Source: Water in agriculture in three Maghreb countries - Acacia Water, The Salt Doctors, 2021*

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