TREND OBSERVATORY ON WATER

TREND SHEET

Managing the invisible – Trends in sustainable groundwater development

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#6

Groundwater provides critical water supply for human use, agriculture and industry. However, managing the “invisible” resource is challenging, leading to unsustainable use and pollution of groundwater worldwide.

Read this Trend Sheet to learn about latest insights, scientific advancements and innovative approaches with regard to trending topics in groundwater management: managed aquifer recharge, resilient urban groundwater management, and groundwater biodiversity.

Content

Why this Trend Sheet?

What trend do we observe?

Over the past 50 years an enormous boom in in groundwater withdrawal has been observed: excessive water abstraction leads to sinking groundwater tables and land subsidence, and groundwater pollution increasingly threatens groundwater as a source of safe water supply.

Why is this trend important for water practitioners in development cooperation?

Groundwater can play an important role in achieving the SDGs, for example in providing access to safe drinking water, including in emergency situations, supporting food production, or as part of water-related ecosystems. Still, in some parts of the world groundwater potential for climate resilient economic development is not yet exploited. There is a lack of groundwater monitoring and general understanding of the resource as well as inadequate groundwater governance frameworks in place. This hampers sustainable groundwater management and use for achieving SDGs, especially in the Global South.

What is new?

New approaches have been developed for sustainable groundwater management, including managed aquifer recharge and innovative urban design allowing for increased water infiltration in urban areas. Digitalisation, smart sensors and remote sensing allow for better assessment, monitoring and modelling of groundwater and therefore enable new tools to support its sustainable use.

Definition of terms

Aquifer: Water saturated geological strata (rocks or sediments) of sufficient permeability to allow significant quantities of groundwater abstraction. (Ravenscroft & Lytton 2022)

Groundwater: All water below the surface of the Earth. (Ravenscroft & Lytton 2022)

Groundwater depletion or 'overexploitation': Prolonged (multi-annual) withdrawal of groundwater from an aquifer in quantities exceeding average annual replenishment, leading to a persistent decline in groundwater levels and reduction of groundwater volumes. (Bierkens et al. 2019)

Fossil groundwater: Groundwater that has recharged before 12000 BP. Relates to the absolute age of groundwater. (Bierkens et al. 2019)

Non-renewable groundwater: Groundwater with mean renewal times surpassing human time-scales (>100 years). (Bierkens et al. 2019)

Introduction

Groundwater resources provide great potential for supporting human well-being and economic development – but groundwater resources are still not well studied and understood, and therefore often undervalued. Groundwater makes up 99 percent of all freshwater that is not frozen on Earth. It provides 50% of global domestic water supply, around 25% of water withdrawn for irrigation. Industry accounts for approx. 19% of total global groundwater withdrawals. For some 2.5 billion people in the world, groundwater is their one and only source of freshwater.

A general lack of groundwater monitoring data limits the assessment and prediction of its quantity, quality and flows. In general, more is known about the quantitative than about the qualitative state. And even less is known about groundwater ecosystems and biodiversity. As a result, groundwater resources are often not managed sustainably.

Over the past decades, pressure on groundwater has increased: excessive water abstraction in some parts of the world has led to sinking groundwater tables, land subsidence and even depletion of aquifers. Large agricultural areas facing groundwater table decline of 2-8 cm/year, and even more can be found for example in India, China, the U.S., and the Arab Peninsula. Read more about groundwater extraction induced land subsidence below.

Governance frameworks for groundwater abstraction are inadequate in many countries. In irrigation, it is often mainly the cost for pumping that regulates groundwater use. Established with the aim to foster agricultural development, energy subsidies may thus sustain unsustainable groundwater use for irrigation, such as e.g. in western India, the Islamic Republic of Iran, Jordan, Mexico, Morocco, Pakistan, and China.

In addition to over-abstraction, increasing pollution from agriculture, municipalities and industry threatens groundwater as a usable resource. Moreover, salination is an increasing challenge, mainly in coastal areas due to seawater intrusion, but also in low-lying arid plains as a consequence of unsustainable irrigation practices. Once polluted, aquifers are very difficult to decontaminate, and contamination can compromise groundwater use even for decades after the original source of pollution has been stopped. Therefore, a preventive approach to protect groundwater quality is crucial.

Past experience highlights the need for improved monitoring and adequate groundwater governance to sustainably manage the resource and to protect it from over-use and pollution. The example of Guantao County in the North China Plain below demonstrates an integrated approach to groundwater management. Other measures for groundwater management involve increasing groundwater recharge, innovative approaches have been developed for example in managed aquifer recharge and water-wise urban planning.

Potential of groundwater development

Over the past 50 years, global groundwater withdrawal has increased significantly, especially for agricultural irrigation in South and East Asia, but also for urban water supply and industrial purposes. Shallow wells have been used for water supply for thousands of years. Rural electrification and technological development over the past century allowed deep boreholes to be drilled relatively quickly and to extract large volumes. These developments have thus pushed groundwater abstraction worldwide.

Existing groundwater resources can provide safe water supply for human survival as well as support livelihoods and economic development. This **groundwater has some advantages over surface water use,** including:

- Its widespread distribution provides potential direct access through wells in many locations.
- Groundwater is generally of high quality, less prone to anthropogenic pollution and requiring less treatment than surface water.
- It provides relatively stable supply, less dependent on rainfall variability than surface water sources.

Groundwater has played a major role in increasing food production since the 1970s, especially in Asia. In other parts of the world, groundwater potential to support food production and human supply has not yet been exploited: in Sub-Saharan Africa, only 2% of the internally renewable groundwater resources are currently used, a great potential if used sustainably, in particular for semi-arid and arid areas with low precipitation and limited surface water availability. Read more about groundwater extraction induced land subsidence below.

However, any groundwater development needs to be preceded by proper hydrogeological investigation to prevent overdevelopment, e.g. to meet the concentrated demand of urban areas or large commercial farms. The diverse characteristics of aquifers need to be carefully considered, notably their groundwater recharge potential, depending on the structure, geometry and hydraulic properties of the aquifer system. In order to prevent depletion, groundwater extraction over the years should be in balance with recharge rates. Non-renewable aquifers, i.e. those that are recharged only at a negligible rate on the human timescale, must be managed with a view to the fact that they are a finite resource.

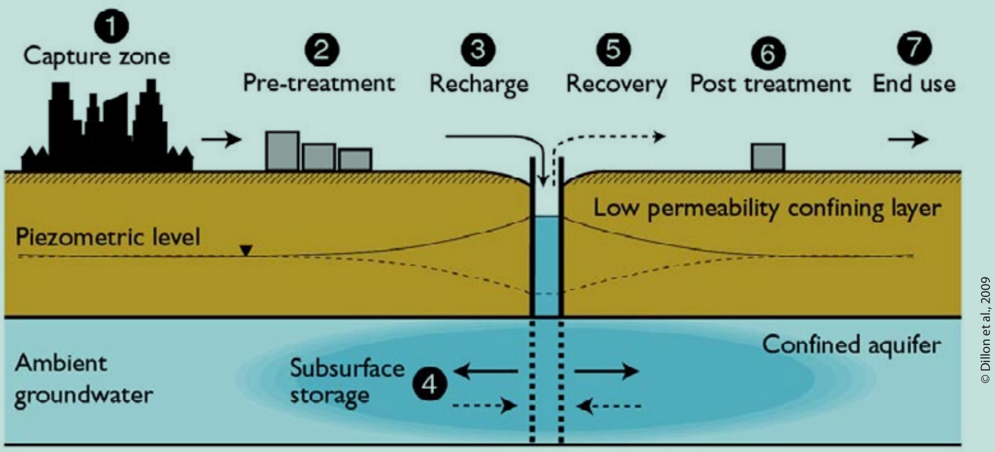
Groundwater also has significant potential for emergency supply, as for example for refugee camps. Deep groundwater is often considered a favourable emergency resource, as it can be made available quickly, without requiring larger infrastructure construction: Deep aquifers often supply high quality water and tend to be more extensive, allowing wells to be located closer to the point of consumption, thus saving costs and time for construction of distribution networks and water treatment.

Still, in emergency situations, it is crucial to rapidly identify areas, where deep wells are most likely to provide high yields. For this purpose, the Rapid Groundwater Potential Mapping (RGWPM) concept was developed with funding from SDC, as a practical tool to support decision making in humanitarian assistance.

Digitalisation and new sensors increase potential of managed aquifer recharge

Managed aquifer recharge (MAR) involves the controlled infiltration of water into the ground in order to replenish aquifers, to store water underground, to manage floods, to improve water quality or to supply groundwater-dependent ecosystems with the water they need. See the case studies below for some examples.

An assessment of the costs and benefits of 24 MAR case studies from 18 countries estimates that in average the MAR schemes delivered 50% reduction in costs compared with conventional alternatives. Nevertheless, the potential has not yet been adequately put into use. One of the reasons that has so far hampered MAR development are the remaining risks of contaminating aquifers as well as difficulties in controlling groundwater quality and quantity in the recharge system. This has also affected trust and acceptance of aquifer recharge.



Recent developments in analytics, sensor development and digitalisation allow better monitoring and management of MAR schemes. Such innovations help ensuring reliability of the recovered water in terms of quantity and quality, and therefore increase the MAR application potential in the future.

Recent developments in MAR

MAR can take various shapes depending on the hydrogeological context and objectives to be achieved. The sources of water to be infiltrated can be multiple, including rainwater, treated wastewater, agricultural effluents or surface water. Infiltration can take place with or without integrating technical infrastructure. The INOWAS platform provides an overview of different concepts and techniques used for recharge.

MAR is not a new concept, the Global MAR Portal includes over 1200 examples of MAR schemes from over 60 countries, demonstrating the important contributions of MAR to agriculture, drinking water supply, ecology and also industrial applications. Nevertheless, the 2022 World Water Development Report concludes that there is still ample scope for further expansion, from the current 10 km^3/year to probably around 100 km^3/year.

The greatest potential for MAR today is seen in the infiltration of reclaimed water and its reuse after sub-surface passage into the aquifer. This option is also adopted in the world's largest MAR scheme, located in Israel. The MAR scheme infiltrates 135 million cubic meters of secondary effluent from the Shafdan Wastewater Treatment Plant every year through 6 recharge sites and 60 recharge basins, in a total recharge area of 110 hectares. After natural treatment through ground passage, the reclaimed water meets high quality standards. It is recovered through 150 recovery wells and reused for irrigation of fruits and vegetables.

Recent research aiming to increase the application potential of MAR focuses on ensuring high quality of water recovered from MAR systems:

- Within the SMART-Control project, for example, the Research Group INOWAS at Technical University Dresden together with its international partners developed a cloud-based monitoring and modelling framework for real-time, web-based groundwater management where time series data collected from sensor networks installed at six selected MAR sites (pilot to full scale) in Germany, France, Cyprus and Brazil were remotely transferred and automatically fed into real-time simulation algorithms. The new smart modelling framework for MAR serves to improve the management and operation of MAR facilities by allowing real-time control and risk assessment.
- Using the recently developed automated flow-through cytometer BactoSense for online monitoring of microbial cell numbers in water, researchers of the Kompetenzzentrum Wasser Berlin carried out bacteriological measurements directly in the groundwater at a MAR scheme in Berlin. This allowed to quantify the pathogen occurrence and to gain insights on microbial dynamics along the flow path of the aquifer recharge and recovery system. Together with a web-based tool for quantitative microbial risk assessment this could in future support real-time evidence-based assessments to minimize the risks from pathogens and water-related infectious diseases.

Resilient urban groundwater management

Globally, groundwater is the source for nearly 50% of urban water supplies. The rapid shift of populations to urban areas is causing ever-greater concentrated demands, particularly in the Global South, leading to over-abstraction of groundwater resources within the limits of larger cities. In addition, increasing impervious surface areas (streets, buildings, parking lots, etc.) limit recharge of the aquifer underneath.

Over-abstraction of groundwater not only risks sustainable supply of drinking water - **it can also cause cities to sink** due to land subsidence.

Groundwater resources underlying urban areas are further threatened by contamination from inadequate urban infrastructure, such as sewer and sanitation systems, as well as seepage from solid waste dumps, leakage from fuel tanks, or unmanaged discharge of industrial effluents. Read more about common groundwater challenges in fast-growing African cities below.

Innovative water-wise urban development that allows aquifers to be recharged from the surface can help address sinking groundwater tables in urban areas. Some of the main principles include:

- Making the city ground more permeable to absorb and store rainwater and mitigate stormwater run-off contaminating surface waters
- Developing green infrastructure to restore, purify and reuse stormwater

There are a number of different technical and nature-based solutions to increase aquifer recharge, ranging from permeable pavements, parking lots and roads, to infiltration ponds in parks, swales, trenches and recharge pits. Integrated water-wise urban planning needs to identify areas where infiltration-based elements would be effective, depending on the underlying geological structure.

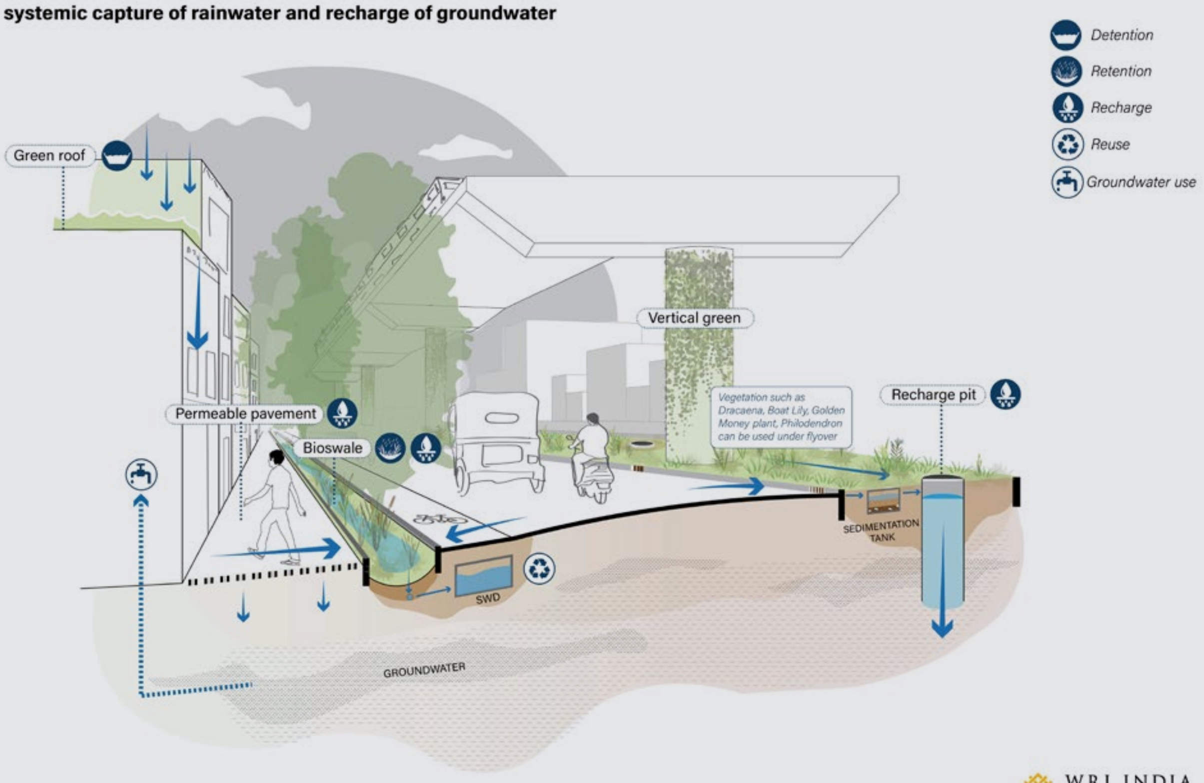
The major risk associated with urban infiltration is that groundwater may become contaminated if the infiltrating water is polluted. Although aquifers have the ability to attenuate many pollutants, infiltration may have to be restricted to clean water sources such as roofs, parks and residential streets, and should not include major roads and industrial areas where the risks of pollution and chemical spills is high. The illustration by the World Resources Institute (WRI) below shows how impermeable urban spaces can be strategically transformed into permeable blue-green spaces. The case study of the La Quebradora Waterpark below is a good practice example.

Groundwater challenges in fast-growing African cities

The International Groundwater Resources Assessment Centre (IGRAC) has recently analysed groundwater challenges in 15 fast-growing West-African cities. Groundwater quality issues related to fecal bacteria, nitrates or other anthropogenic contaminants threaten safe water supply in almost all cities analysed. The analysis shows that urban water security issues arise from the lack of investments in safe water supply and sanitation, as well as the lack of appropriate groundwater management measures.

Uncontrolled self-supply through private water wells, a "booming phenomenon" in numerous cities in Sub-Saharan Africa further complicates sustainable and safe water supply from groundwater. Shallow hand-dug wells, a common practice in low-income parts of e.g. Lagos, Cotonou, Lomé, or Abidjan, are particularly vulnerable to contamination providing risks for human health. In higher income areas, where people can afford deep boreholes, such uncontrolled wells can provide safe private supply but challenge planned groundwater management. Also boreholes introduce risks of contamination of deeper aquifers.

Interlinking transit corridors, building roofs, and neighbouring unused urban spaces for systemic capture of rainwater and recharge of groundwater



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Source: WRI India. Illustration created by Sindhuja Janakiraman

Groundwater abstraction makes land sink

When groundwater is abstracted excessively from the ground, the soil above the aquifers may compact and depress, causing the gradual sinking of land, or land-subsidence. Subsidence due to groundwater over-abstraction is a slow and gradual process that develops over months or years, typically over very large areas (tens to thousands of square kilometers). Recent research estimates that almost 20 percent of the world's population will be affected by land subsidence by 2040. Researchers have published a world map showing subsidence risk due to groundwater abstraction. Worldwide, especially urban areas are affected - the city of Jakarta, for example has sunk by more than 2.5 metres in the past 10 years - but also agricultural areas are hit by land-subsidence.

In cities, the effects of groundwater extraction on land-subsidence are further aggravated by the weight of heavy construction. While a number of large cities is affected, subsidence rates are highly variable within cities and from city to city. Land subsidence damages infrastructure and can therefore cause contamination of water supplies, e.g. from damaged sewer lines, and thus in turn contaminate groundwater resources already under pressure.

Coastal cities are particularly affected by land subsidence, here the phenomenon comes along with increasing risks of coastal flooding and saltwater intrusion into aquifers. Satellite data indicates that land is subsiding faster than sea level is rising in many coastal cities throughout the world. Coastal cities prone to disappearing include Jakarta, Lagos, Houston, Dhaka, Venice, Bangkok, Rotterdam, or Alexandria.

But also continental cities are affected, such as Delhi, Beijing, Teheran, or Bogota. A prominent example is Mexico City, which supplies 70% of its drinking water from groundwater. Recent research has shown that Mexico City continues to sink, in some parts at a rate of up to 50 centimetres a year. See the case study of the La Quebradora Waterpark below for an innovative approach to address this issue.

Groundwater biodiversity – the known unknown

Some experts say we know more about the surface of the moon than we know about groundwater ecosystems. Groundwater ecosystems have so far received little attention. The same refers to the Stygofauna, i.e. the animals living in groundwater systems and pores and fissures of aquifers. Researchers estimate that there are between 50,000 and 100,000 species living in underground in aquifers and caves, dominated by microorganisms and millimeter-sized invertebrates. However, still very few species of the stygofauna are known. What is known, is that **groundwater animals are vital for the quality of groundwater and also affect water flow:** stygofauna removes organic pollutants remaining in groundwater after the soil passage and eliminates pathogenic microorganisms and viruses.


© David Ashley, U.S. Fish and Wildlife Service

As there are no plants to feed on and little space to move, some stygofauna species feed on so-called biofilms that contain bacteria and carbon carried into the aquifers by inflowing surface water. By preventing fine pore spaces from clogging with organic material, stygofauna also enhance water flow in the aquifer.

Groundwater animals are perfectly adjusted to their habitat. For example, the amphipod of the genus Niphargus is colourless, has no eyes and lives in total darkness. They are also adapted to the low temperatures in the aquifer. The functioning of groundwater ecosystems are therefore sensitive to changes in their habitat conditions and highly vulnerable towards effects of climate change and pollution. This is expressed by the stygofauna's low thermal tolerance as well as the limited dispersal potential of their surroundings.

Further research is needed in order to sustain groundwater not only as source for human utilization but also as living environment. To do so, the Swiss project AmphiWell records and documents groundwater animals in spring wells. The more diverse the stygofauna, the better the water quality. This dependent relationship can be used as an indicator to assess the condition of groundwater ecosystems. An important step towards the development of an index for groundwater health was made by a research project from New Zealand. Based on traditional and genetic information, researchers found a correlation between the stygofaunal community composition and the following factors related to the examined wells: conductivity, dissolved oxygen, well diameter, latitude and several attributes of the associated up-stream river catchment. It needs further research to reliably relate changes in the stygofauna to land-use effects.

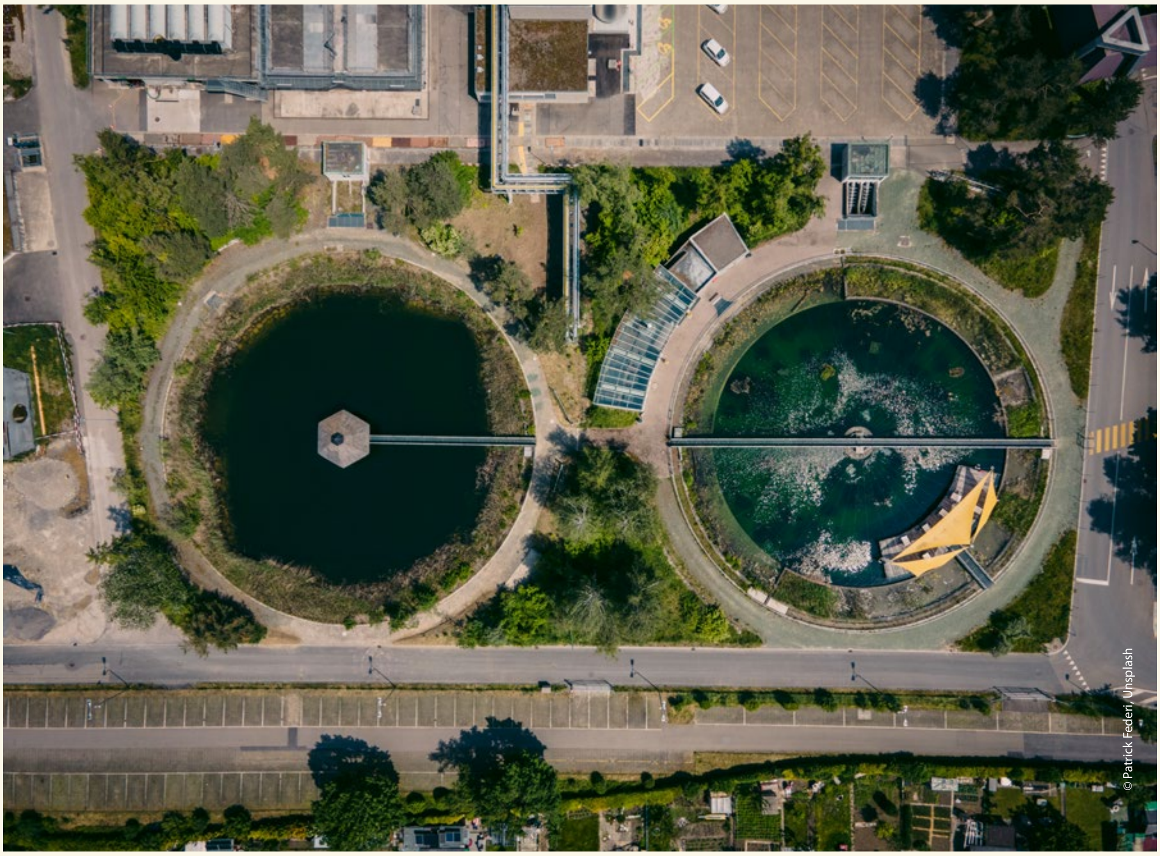
Coastal aquifer storage and recovery in the Netherlands

The village of Dinteloord – located in the Netherlands – is well-known for its agricultural and industrial productivity. The main actors within this scene are a sugar factory and the Nieuw Prinsenland greenhouse area. Both depend on high-quality water for their production but neither the surface water nor the groundwater can satisfy their requested water supply. The former because of seasonal changing rainfall patterns expressed in drought periods during summer. And the latter because of the areas coastal vicinity which leads to brackish water quality. As a result, the businesses of both parties are at risk.

An innovative high-tech solution exists in the Aquifer Storage and Recovery (ASR) system. As a form of MAR, it not only provides a green-grey alternative to exploitive groundwater abstraction but also presents a way to suppress saltwater intrusion along the coast. In the case of Dinteloord, a full-scale ASR reuse system with 8 wells has been set up between 2015 and 2018 with a total storage capacity of 300,000 m^3. Following the approach of Circular Economy, treated wastewater of the sugar factory is reused for freshwater provision at the greenhouse. The time gap between wastewater generation in winter and the need for additional water for the greenhouses in summer is closed by storing water in the subsurface. Building on the buoyancy effect of freshwater in more saline water, the treated wastewater is injected at the base of the aquifer, and later on recovered at the top. A high frequency, automated **real time monitoring of electrical conductivity enables optimised management of the 8 wells used for water injection and recovery.** This allows to maintain a floating freshwater bubble and to prevent mixing with the surrounding saline water. At the end of the process, the recovered high-quality water is distributed between the greenhouse, the sugar factory and adjacent food industries.

By doing so, the ASR system provides a sustainable and innovative solution for water reuse, groundwater recharge and improving groundwater quality. At the same time, wastewater from agricultural production is reused and guarantees a year-round availability of recovered freshwater.

For more information on ASR in Dinteloord check out GRIPP and Allied Waters.



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Underground transfer of floods for irrigation in India

The Gangetic Plain in India represents an arena of divergent water-related risks. Especially Jiwai Jadid, a village located in the upper part in the district of Rampur in Uttar Pradesh, was at the mercy of monsoonal floods and droughts over the last years. Within this scenario, groundwater is overexploited mainly by farmers using privately owned wells to cultivate rice and wheat. According to statistics, annual water abstraction equals 81% of the total groundwater recharge in the aquifer supplying Jiwai Jadid village. As a result, **the aquifer water level is declining and signs of depletion arise.**

The MAR concept offers practical and sustainable solutions to counteract this alarming development. While MAR is well-established in the Indian context to address droughts, a new form came to the fore: **Underground Transfer of Floods for Irrigation (UTFI). The combination of groundwater recharge, storage for year-round water availability and flood management** gives UTFI its innovative character. The UTFI approach aims to feed excess wet season flow into the aquifer through recharge wells. In the case of Jiwai Jadid, wet season flows of a tributary of the Ramganga river are channeled into a rehabilitated pond. There, the water is pre-treated by sedimentation and gravel-based filters around the heads of the recharge wells. Following gravity, the water then infiltrates into the recharge wells where it is further treated by a coordinated inner and outer pipe filtration system. Finally, the former river water reaches the aquifer.

Close monitoring shows that the groundwater level recovers. It is estimated that after one monsoon a volume of 26,000 to 62,000 m³ is added to the aquifer. While these numbers are already considerable, they still bear great potential for upscaling at basin level.

Innovative urban design for groundwater recharge: Parque Quebradora in Mexico City

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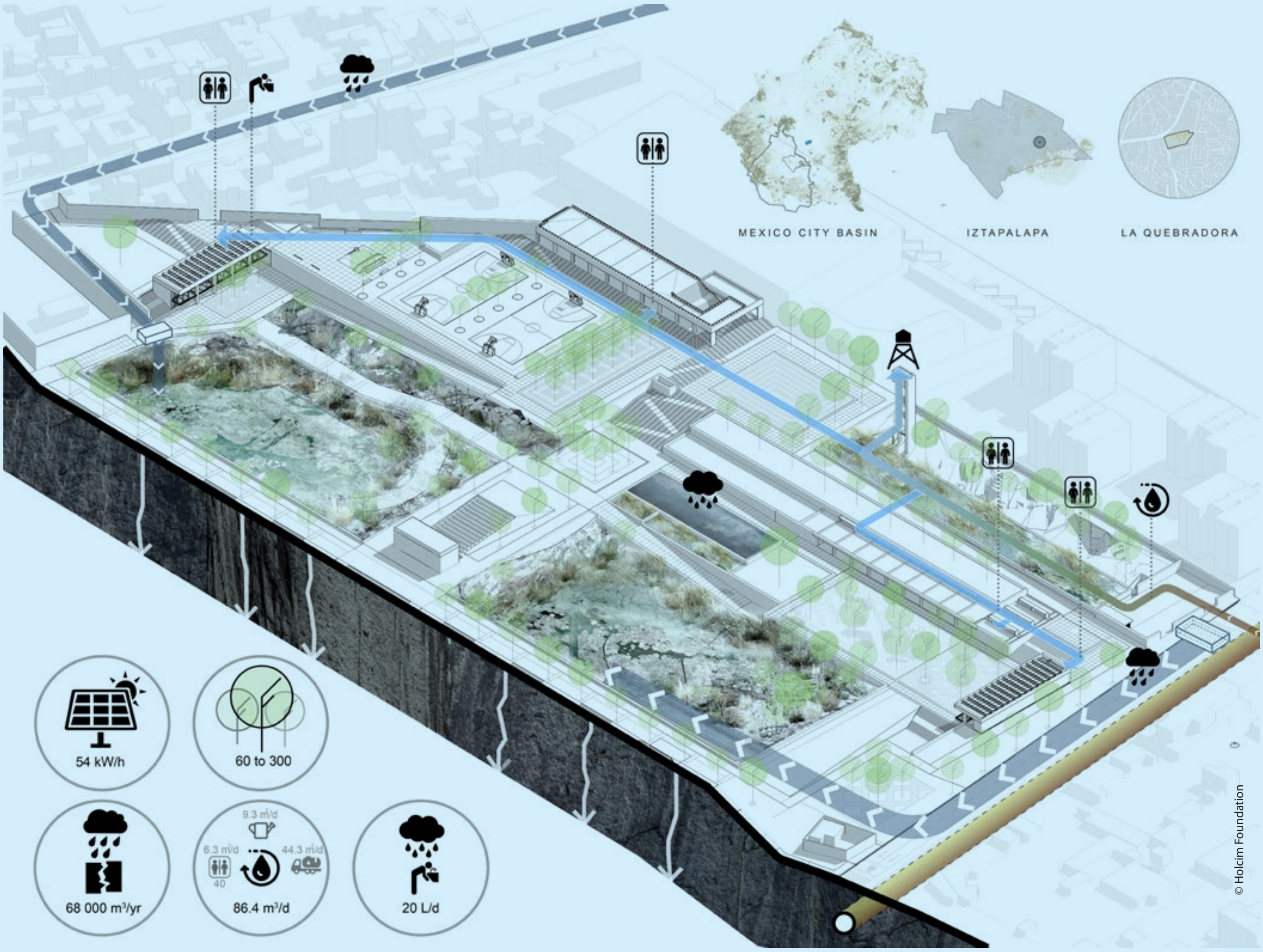


The metropolis of Mexico City, home to more than 22 million people, is sinking. A combination of longtime groundwater drainage – mainly for drinking water supply - and soil compaction due to heavy construction have led to alarming ground subsidence. Researchers detect a partial lowering of 10 meters over 100 years and expect subsidence to continue. Around 70% of the city's drinking water is covered by groundwater extraction and still, Mexico City's demand for drinking water is not met yet. In addition, the city faces risks of flooding from heavy rain events. To adapt to current and to prevent future problems, a paradigm shift in Mexico's urban water management is needed.

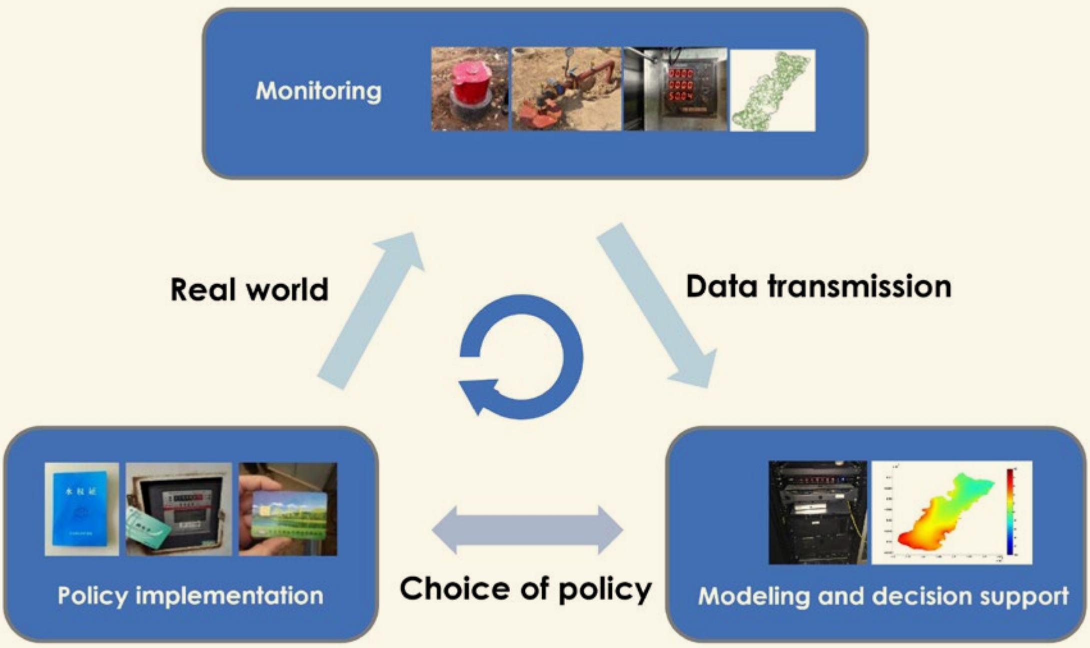
The La Quebradora Waterpark, located Mexico City's district Iztapalapa, finds an innovative solution to the paradox of excess of rain and runoff water versus sinking groundwater tables: public space was transformed into a soft water management landscape. Within an area of 4 hectares, elements of recreation are combined with a water harvesting system. The park's unique **combination of natural infiltration basins, floodable areas, wetland systems, terracing and rain cisterns** makes excess rain and runoff water usable for various purposes. A major achievement is the considerable recharge of Mexico City's aquifer: Data states that the park's annual water infiltration amounts to 68,000 m³. Groundwater recharge mainly takes place through natural infiltration basins, where water percolates through basaltic stone into the aquifer. In addition to the rain water directly harvested in these basins, a rainwater conduction system directs surface runoff into these basins. The collected and treated water also serves for irrigation of the park, the operation of public toilets (6 m³ per day) and further distribution (16,167 m³ per year). Besides its water-related function, the waterpark offers important social benefits: It provides the marginalized and insecure neighbourhood of Iztapalapa with much needed natural and recreational open space. It could thus serve as a role model for future projects around the world.

Strategy for rehabilitation and management of over-pumped aquifers in China

Guantao County – pilot site of the Sino-Swiss cooperation project "Rehabilitation and Management Strategy for Over-Pumped Aquifers" – is located in Hebei Province in the North China Plain (NCP). The region is known for its intensive agricultural patterns as 30% of China's grain is produced here. In winter, double crops of wheat are cultivated and maize in summer. Irrigation of the 300 square kilometers agricultural area highly depends on groundwater. Use of about 8000 pumping wells led to massive over-pumping of the aquifer, with extraction rates 15-20% higher than the average recharge. As a consequence, the groundwater table declined and farmers face growing pumping costs.

In order to support sustainable groundwater management in Guantao County, a cutting-edge management system **including real-time groundwater monitoring and modelling combined with integrated governance approaches** has been set up by the Sino-Swiss cooperation project. The first component – the groundwater monitoring – sticks out through its efficient approach, feasible in rural areas: Groundwater levels are observed through automatic wells, in addition the electricity consumed by operating the wells serves as a proxy for the pumped groundwater volume. This is combined with monitoring of annual cropping patterns through satellite remote sensing data. Second, the user-friendly Guantao model app for groundwater management decision support was launched in 2016 and can be accessed via computer, tablet or even smartphone. The app provides an optimizer for groundwater allocation, an irrigation calculator, a box-model water-balance and a 2D model of the shallow aquifer of Guantao County. The app requires only minimal technical expertise by offering a wide range of comprehensive functions within an interactive web-interface. Based on real time data and the model results, the app supports local water managers in decision making for quota planning, with information on estimated crops water demand and predicted groundwater level. The two technical components of the project are complemented by introduction of new governance approaches which are designed based on the improved groundwater data collected. In the case of Guantao County, governance approaches focus on three measures: (1) Subsidies for fallowing area of the water-consuming winter crops, (2) subsidies for drip irrigation equipment in large greenhouse areas, and (3) fees for pumping rates exceeding defined quotas. In addition, a groundwater online game has been developed to increase public awareness for sustainable water use and has already been tested by famers in the NCP.

For more information on innovative groundwater management check out this webinar lecture series.



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The "**Trend Observatory on Water**" of the Swiss Agency for Development and Cooperation (SDC) aims at informing the RésEAU, SDC's Water Network, and interested parties about relevant emerging trends and innovative approaches for development cooperation in the water sector. Initiated by SDC's Water Section and run by adelphi, it analyses how major global trends can affect water resources and management practices in the future. Through various communication formats and its website https://hazu.swiss/deza/trend-observatory-on-water it aims to raise awareness of opportunities that arise for more sustainable solutions, but also of the risks and challenges that might come along with them.

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