International Association of Hydrogeologists

Strategic Overview Series

IRRIGATED AGRICULTURE & GROUNDWATER

KEY MESSAGES

- irrigated agriculture has brought enormous socioeconomic benefits to many of the more arid areas of the world, but simultaneously impacted underlying groundwater
- surface-water irrigation schemes widely augment groundwater recharge and result in rising water-table, which sometimes cause soil waterlogging and salinity that require expensive drainage measures
- uncontrolled waterwell irrigation widely results in groundwater resource over-exploitation often accompanied by a range of negative impacts for ground-water users and the environment
- most types of intensive irrigated agriculture result in the leaching of excess nutrients and pesticides to groundwater, and in some settings progressive aquifer salinization and/or microplastic pollution are emerging problems
- few governments have made adequate parallel investments in water resource management institutions and monitoring infrastructure, and groundwater irrigation use in particular is often completely unregulated
- a paradigm shift is needed on the approach to groundwater use in irrigation with greater emphasis on farmer education about sustainable use, clear incentives for water-resource saving and the establishment of agri-cultural land-use planning to conserve groundwater

What is the socioeconomic context of irrigation ?

The introduction of agricultural irrigation has delivered enormous socioeconomic benefits to many areas of the world with a more arid climate and/or extended dry seasons. The wealth generated by large numbers of irrigated fields under direct farmer control has been remarkable and transformed many previously very poor regions.

National governments have been able to provide finance to support the construction of irrigation canals and water-wells, but have only rarely accompanied this by investments in management institutions and monitoring infrastructure. Thus the development of irrigated agriculture has produced great economic benefits but simultaneously presented challenges for water resource management.

GROUNDWATER DRIP IRRIGATION OF BANANA PLANTATION IN BRAZIL

This Series is designed both to inform professionals in other sectors of key interactions with groundwater resources and hydrogeological science, and to guide IAH members in their outreach to related sectors.

What are the potential impacts of irrigated agriculture on groundwater ?

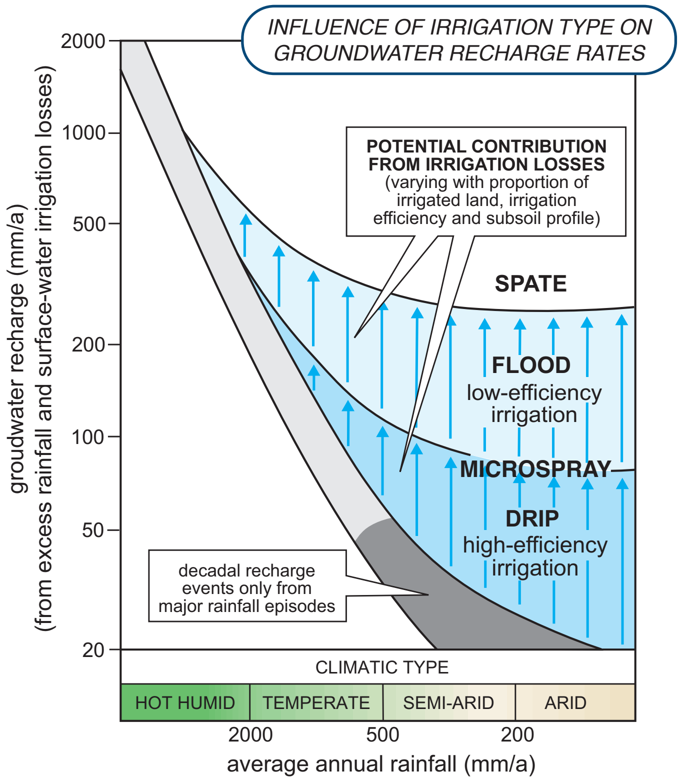
Irrigated agriculture can have a range of potentially-important impacts on underlying groundwater systems, some of which are widely overlooked by the agricultural sector and poorly accounted-for in water resource management :

- irrigation with surface water invariably increases groundwater recharge rates, and can result in rising water-tables and land drainage problems that severely impede crop production and require major infrastructure investment
- irrigation with groundwater widely results in resource overexploitation with declining water-well yields, increased energy costs for pumping, interference with domestic waterwells, and in some cases negative environmental side-effects
- continuous irrigation with groundwater can also lead to progressive aquifer salinization due to salt concentrations in irrigated soils and irrigation-return flows
- all types of irrigated agriculture run the risk of nutrient and pesticide leaching causing potentially serious diffuse groundwater pollution.

The intensive use of groundwater for agricultural irrigation can also have incidental institutional complications, since it tends to concentrate groundwater use rights in the hands of a few more affluent land and waterwell owners (for example producing high-value crops for the European export market). This can destroy indigenous farming and displace traditional farming communities from their land.

How does irrigated agriculture increase groundwater resource availability ?

Historically the level of irrigation-canal lining was very low and the application of surface water to irrigated land was by periodic land flooding (or even 'spate irrigation') techniques. This accidentally resulted in applications greatly in excess of plant requirements and a major



• *vertical arrows indicate the potential increase in groundwater recharge in scenarios of varying water-use efficiency, assuming that irrigation losses freely infiltrate to an unconfined aquifer*

increase in groundwater recharge rates. In the long run this tended to cause rising water-tables, which in some settings led to associated land drainage problems. This can be managed by promoting groundwater use for irrigation conjunctively.

In other forms of irrigation, water applications will be smaller, but farmers often deliberately over-irrigate at certain times of the year to 'clean the soil'. On the North China Plain, for example, even with modern improvements in canal lining and field application, the current average irrigation efficiency with surface water is only about 60%. In Pakistan large lenses of fresh groundwater have accumulated from losses along major surface-water canals.

Why does groundwater irrigation often lead to serious resource overexploitation ?

Groundwater irrigation now accounts for about 40% of the total global irrigated area, with notably high levels in North America (59%), South Asia (58%), West Asia (45%) and Western Europe (41%), although there is still a very low level in Sub-Saharan Africa (5%) as a result of a complex interaction of factors including limited rural electrification and lack of investment funds. It has often been developed without adequate groundwater evaluation. The marked increases in productivity in areas under groundwater irrigation tends to motivate farmers to expand their areas of irrigated cultivation, regardless of long-term groundwater availability. Groundwater use in horticultural irrigation, in particular, is highly profitable for the farmers involved.

In most climatic settings where groundwater irrigation is practiced the annual required irrigation application and the land area available for irrigated cultivation considerably outweigh groundwater resource availability. Serious groundwater resource overexploitation widely results, often accompanied by reductions in stream baseflow, degradation of wetlands, upconing of saline water and land subsidence.

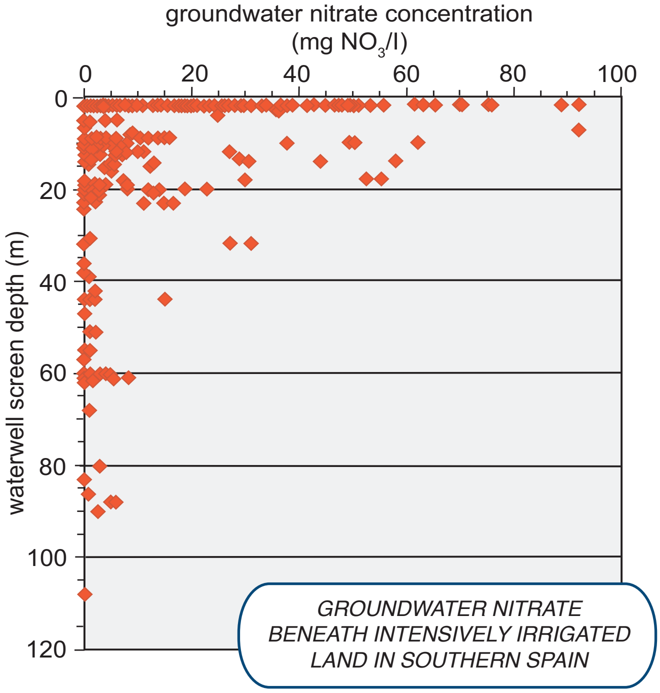
The utilization of groundwater for irrigation is all too frequently completely unregulated. Waterwells under direct farmer control are widely over-pumped in attempts to maximize crop production, regardless of the abstraction rates authorized by regulatory agencies. Moreover, current investments in groundwater monitoring are almost everywhere far from adequate. The quantification of volumes abstracted requires metering of individual waterwells and aquifer water-levels need continuous monitoring, which is often beyond the capacity of regulatory agencies.

India has an estimated 20 million waterwells and 92% of its annual groundwater abstraction is used for irrigation (213 billion m^3), which poses a tremendous challenge for sustainable groundwater management.

In what ways does irrigated agriculture degrade groundwater quality ?

Nutrient Leaching

The large-scale and/or ill-timed application of nitrogen fertilisers to agricultural crops in search of increased yields has widely led to their leaching to groundwater, and has been especially marked in areas under horticultural multi-cropping. The WHO drinking-water guideline concentration of 50 mg NO_3/l has frequently been exceeded in areas of irrigated agriculture. For example, a recent study of the piedmont area of the North China Plain, with an average water-table depth of 45m, revealed that 6,600 kgN/ha were held in the unsaturated zone and being slowly transported down to the water-table at about 0.6 m/a to impact groundwater quality in future decades. In Spain the ecological functioning of the Mar Menor (a shoreline lagoon on the Mediterranean coast) has been radically modified as a result of the input of nutrient leaching from intensive agriculture that has caused three severe eutrophication episodes with dramatic fish mortality.



GROUNDWATER NITRATE BENEATH INTENSIVELY IRRIGATED LAND IN SOUTHERN SPAIN

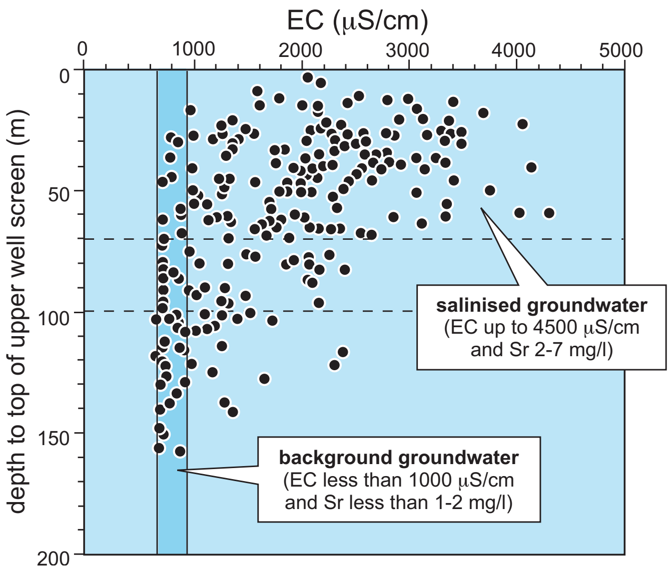
Pesticide Leaching

Globally the application of pesticides to agricultural crops has been increasing rapidly in recent years.

Many of these compounds are relatively mobile in soil solution and subject to leaching to groundwater, and while they have relatively short half-lives in fertile soil are extremely persistent in groundwater. These compounds and their partial breakdown products (metabolites) present a major complication to the use of groundwater for potable water-supply. For example, in the North China Plain various organophosphorus pesticides (OPPs), notably dimethoate, dichlorvos and malathion, have been detected in groundwater.

Progressive Salinisation

Extensive groundwater irrigation runs the risk of accumulating salts in the soil zone and farmers usually apply an excess irrigation layer to leach this to greater depths, eventually reaching groundwater. This has widely impacted shallow groundwater quality to depths of about 100m, and has been researched in detail in Mendoza (Argentina) and Almeria (Spain). Uncontrolled groundwater pumping for agricultural irrigation in coastal zones often results in depleting groundwater to below sea-level with consequent large-scale encroachment of saline water, and have been monitored in detail, for example in China. Moreover, in areas of surface-water irrigation excessive applications can lead to rising water-table and phreatic evaporation, with soil salinisation as a consequence.



SALINISATION OF UPPER PART OF CARRIZAL AQUIFER OF MENDOZA, ARGENTINA, DUE TO MANY DECADES OF GROUNDWATER IRRIGATION

Microplastic Pollution

In and around intensively-used agricultural land the soil is often found to be polluted by microplastics (MPs). These compounds can enter groundwater recharge, although knowledge of their occurrence is still limited. High MP concentrations have been detected in cultivated soils as a result of the use of plastic mulching film.

What can be done to reduce the impact of intensive groundwater resource exploitation for irrigated agriculture ?

The integrated use of groundwater and surface-water resources should give much greater flexibility to farmers to cover the water demand of their crops, and ease the pressure to further increase waterwell abstraction.

Irrigation water-use efficiency is also an important issue that requires greater efforts to optimise, distinguishing irrecoverable irrigation water losses from those that simply return to groundwater systems. Moreover, there is scope for irrigation-water saving by using drought-resistant crop strains, improved crop planting routines and introducing crops of lower irrigation water demand. In some cases it may also be necessary to subsidise farmers to reduce their irrigated areas leaving more land fallow during years of low rainfall, and to provide land for managed aquifer recharge with excess rainfall, and to replace groundwater by appropriately-treated wastewater where feasible.

Improving farmer education on the need to modify cropping patterns and to improve irrigation-water scheduling in areas of groundwater resource stress is a high priority.

In some areas progress on groundwater resource conservation has been made through :

- more realistic power pricing, such that farmers

bear the full cost of their energy use which serves as a powerful incentive for water saving
- in some cases over-pumping has been incidentally stimulated by government energy subsidies to promote agricultural production, and such 'perverse subsidies' must be eliminated
- improved measurement and charging for waterwell abstraction by metering rural power consumption as an indirect indication of pumping, and then combined invoicing of power consumption and groundwater use
- the introduction of solar-powered waterwell pumps, if appropriately planned, can aid the regulation of groundwater abstraction, if farmers are provided with attractive incentives to sell-back power to rural electricity grids rather than using it to over-pump groundwater.

In recent years China has put a major effort into groundwater monitoring, but measuring irrigation -water consumption is not easy and relies upon estimates from electricity use, irrigation quotas and cultivated areas. At pilot scale waterwell irrigation use has been controlled by restrictions on electricity distribution.

Glasshouse cultivation results in significantly lower evapotranspiration rates and thus reduces the demand for irrigation water. Moreover, encouraging farmers to abandon cultivation of the lowest-value crop in the annual multi-cropping cycle can save significant groundwater.

The special case of using essentially non-renewable groundwater for agricultural irrigation (now occurring at large-scale in parts of the deserts of North Africa and the Middle East) requires much more careful management including such additional measures as :
- using groundwater only to cultivate high-value and/or low water-demand crops, avoiding irrigated cropping in the summer months
- employing pressurized irrigation systems (such as drip or micro-sprinkler) which are more efficient and allow close control of water application.

INTENSIVE IRRIGATED STRAWBERRY PRODUCTION UNDER GLASSHOUSE CULTIVATION IN SOUTHERN SPAIN

What techniques can assist irrigated agriculture to manage groundwater resources sustainably ?

The water sector should actively promote conjunctive use of surface-water and groundwater resources, and the artificial recharge of shallow aquifers in areas on groundwater stress.

The agricultural sector can greatly assist the task of groundwater resources management through :
- preparing agricultural land-use management plans that identify groundwater resource sustainability as an issue and target funding to reduce agricultural water demand through precision irrigation technologies
- implementation of best land-use management practices with farmers that aim to conserve groundwater resources and protect groundwater quality.

Farmer use of mobile phone apps for weather forecasting can much improve irrigation scheduling and reduce leaching losses. Other types of useful guidance on agricultural cultivation are also available by this route.

The application of satellite imagery can aid the quantification of crop water-demand and track

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consumptive crop water-use, which in turn can enable the development of efficient seasonal irrigation schedules. Geophysical techniques can also help identify areas suitable for managed aquifer recharge with excess surface water on permanent crops.

PRIORITY ACTIONS

- **greater emphasis needs to be given to the regulation of groundwater abstraction in areas of waterwell irrigation, with improved irrigation technology, measurement of pumping rates, and groundwater level monitoring.**
- **conjunctive use of groundwater and surface-water resources will give greater flexibility to farmers to cover crop water-demand and ease the pressure for further waterwell abstraction**
- **farmers should bear the full cost of energy use as an incentive for water saving, with metering power consumption as an indirect indicator of pumped volumes to allow combined invoicing of power consumption and groundwater use to individual farmers**
- **both the capital and operational costs of irrigation waterwells have often been subsidized by governments to stimulate agricultural production and this perverse subsidy must be progressively eliminated**
- **the introduction of solar-powered waterwell pumps requires parallel action on attractive grid buy-back arrangements rather than using all the power generated for pumping**
- **introducing glasshouse cultivation lowers evapotranspiration rates and reduces irrigation water-demand, and abandoning cultivation of low-value summer crops in the annual multi-cropping cycle can save significant groundwater**

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