BGS blogs

Sustainable groundwater management underpins food security in South Asia

The most intensively cultivated areas of South Asia are crucial for regional food security and have become global hotspots of groundwater exploitation.

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A paddy field being irrigated by a tube-well tapping the underlying aquifer. Source: nxmaps / iStockphoto

Agriculture is crucial for the livelihoods of many in South Asia, with more than 1 billion people engaged in food production. The importance of agriculture to many Indian people was starkly illustrated by the recent protests opposing changes to India's farming laws.

The Green Revolution

Agricultural practice in South Asia, as in many other parts of the world, was transformed in the 1950s and 1960s during the Green Revolution[1]. The transformation was driven by four fundamental developments:

- the advent of new high yielding varieties of cereals, especially rice and wheat
- the adoption of chemical fertilisers
- increased mechanisation
- increased access to irrigation

The fourth development, increased access to irrigation, is arguably the most important and was made large-scale exploitation of groundwater and policies providing free electricity for groundwater pumping.

After the harvest — Northern India. Image courtesy of D J MacAllister © BGS.

Prior to the Green Revolution, water for irrigation in South Asia was primarily drawn from the region's great rivers and distributed via a large network of canals. However, in India in the early 1970s, the area irrigated by groundwater surpassed that irrigated by surface water for the first time. The number of irrigation tube-wells and, as a consequence, agricultural reliance on groundwater has increased ever since (Mukherji, 2020).

The world's most exploited aquifer

North-west India and central Pakistan are the most intensively cultivated areas in South Asia and are crucial for regional food security. Both areas have a long history of major surface and, more recently, groundwater development. Combined, the areas are regional breadbaskets, representing the largest contiguous tract of irrigated land (Bashaar et al., 2013) and the most intensively irrigated (Siebert et al., 2010) in the world. As a consequence, north-west India and central Pakistan have become global hotspots of groundwater exploitation (Ahmed et al., 2019; Treyath et al., 2016; Watto et al., 2018) and the long-term viability of the transboundary aquifer that underpins the region's agriculture is threatened.

The problem is so severe it can be observed from space. The Gravity Recovery and Climate Experiment (GRACE) satellites, launched in 2002 by NASA and the German Aerospace Centre, showed that groundwater depletion was leading to changes in the Earth's gravity field (Rodell et al., 2009; Tiwari et al., 2009; Chen et al., 2014; Bhanja and Mukherjee, 2019; Tang et al., 2017; Ahmed et al., 2019).

BGS work in South Asia

Since 2012, BGS has worked with partners in South Asia, including the National Institute of Hydrology in India and the International Waterlogging and Salinity Research Institute in Pakistan, to examine in more detail the sustainability of groundwater abstraction in the region. Our work was the first to develop a 3D picture of the regional aquifers (Bonsor et al., 2017) and to map transboundary groundwater depletion and water quality using in situ data (Macdonald et al., 2016).

Wheat field — Northern India. Image courtesy of D J MacAllister © BGS.

The large floodplains of the rivers Ganges, Indus and Brahmaputra form a huge aquifer made up of sands and gravels, which are washed down from the Himalayas by the rivers and their tributaries. The sediments are deposited as the rivers slow down when they enter the plains, forming a vast regional aquifer many hundreds of metres thick. The properties of the aquifer change along the course of the rivers and with depth, leading to a complex variation in water availability and water quality.

BGS work has shown that groundwater depletion is nuanced, regionally heterogenous and influenced by a combination of human and climatic factors. For example, BGS recently illustrated the importance of recharge from the vast canal network (MacDonald et al., 2016) as playing an important role in controlling groundwater levels in the region, while other studies highlight the impact of changes in monsoon precipitation (Asoka et al., 2017).

Climate change

While the human influence on groundwater in the highly cultivated areas of north-west India and central Pakistan is clear, the climatic influence is harder to unravel. However, there is evidence that climate change will impact the region's groundwater resources and, by extension, agriculture and food security. For example, changes in the intensity of rainfall may lied to less groundwater recharge (Asoka et al., 2018) and increased melting of glaciers in the Himalayas could lead (particularly in the Indus) to short-term increases in groundwater recharge via rivers and canals, but ultimately a long-term decline (Immerzeel et al., 2010). Other studies suggest that groundwater pumping itself is influencing the monsoon cycle and changing the timing and location of monsoon rain (Devanand et al., 2019).

Farmers transport their goods to market — Northern India. Image courtesy of D J MacAllister © BGS.

While there is still a need to better understand the climatic mechanisms that control groundwater recharge in the region, it appears clear that climate change has an indirect effect on groundwater levels. Increasingly unreliable rainfall influences changes in farmer behaviour, which in turn affect groundwater development. Since short- to medium-term climate change is forecast to lead to increased availability of surface water, mainly as a result of melting glaciers in the Himalayas, conjunctive use of both surface and groundwater resources may help increase food security while managing groundwater decline.

Managing groundwater

At present, one of the most significant challenges to halting the decline of groundwater levels in the region is ongoing electricity subsidies for irrigation (Mukherji, 2020). For many years, farmers have been able to pump groundwater for little or no cost. These subsidies have become a political hot potato and creative thinking is needed to address the impact they have on groundwater levels in the region. For example, there is evidence that relatively modest decreases in groundwater abstraction of around 20 per cent have the potential to decrease rates of groundwater depletion in India by between 36 and 67 per cent (Shekhar et al., 2020). The largest impacts are likely to be in the most heavily exploited areas. Evidence for the impacts of modest decreases in abstraction has also been demonstrated in the High Plains Aquifer of the USA (Butler et al., 2020). In some areas of north-west India, groundwater levels have risen in the last decade (2010–2019) (Shekhar et al., 2020). This has been attributed to restrictions on paddy crops put in place by state governments.

A paddy field being irrigated by a tube-well tapping the underlying aquifer — Northern India. Image from iStock.

Looking to the future, water management must account for the strong linkages between rivers, canals and groundwater and should recognise that, ultimately, they are all one interlinked water resource. By changing one part of the water cycle, for example lining canals, another part of the cycle (groundwater recharge) can suffer. Therefore, managing all the different water resources conjunctively is likely to have the best overall outcome.

Conclusion

Given the importance of groundwater in north-west India and Pakistan for agricultural livelihoods and South Asian food security, halting recent groundwater depletion is vital to ensure the region's water and food security under a changing climate. The vast aquifer is complex and groundwater depletion and water quality are highly variable, both spatially and with depth. Rainfall, irrigation returns, canals and rivers actively replenish much of the aquifer, and change in any one of these will directly or indirectly affect groundwater. Small decreases in groundwater abstraction, conjunctive use of surface water and groundwater and appropriate electricity and agricultural policy have the potential to reverse groundwater depletion in the breadbasket regions of South Asia and offering a beacon of hope for the region's future food security in a changing climate.

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