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Climate change impacts on the water resources of the Ganges basin

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Headlines

- The South Asian monsoon, which supplies 80% of India's total annual rainfall, shows increasing variability linked to climate and land cover change, and to increased aerosols levels.
- Groundwater (see Figure 4) is an essential resource for food production, drinking water and acts as a buffer to climate variability, yet in many regions, especially in north-west India, this resource is under threat.
- Increased groundwater use since the 1950s in conjunction with more variable monsoons has led to increased strain on water resources, in terms of quality and quantity of water available.
- Guaranteed procurement prices, subsidised energy for groundwater irrigation and farmers' resistance to change contribute collectively to problems in securing future water resources.
- New policies to promote solar pumps, rural electrification and energy subsidies, along with suitable water use and management practices would increase food production in affected regions, reduce the pressure on small and marginal farmers, and promote social and economic welfare.
- There is a need to ration and control energy subsidies and solar pumps to prevent over-exploitation of groundwater resources. The Jyotigram scheme is promising, but local hydrological and socioeconomic conditions need to be considered.
- Careful use of both surface and groundwater, and managed aquifer recharge can help maintain the region's water resources. Promoting the implementation of community-level storage schemes may encourage farmers to manage groundwater as a shared resource, rather than as private property.

Contents

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Introduction

India's green revolution, initiated in the mid-1960s to achieve food security for its growing population, was characterised by the introduction of high-yielding wheat and rice varieties combined with increasing use of fertilisers, pest-control and agricultural machinery[1]. Irrigation, which provides a buffer against intra-seasonal monsoon variability, and allows farmers to grow crops in the dry winter season, has played a central role in the resulting productivity gains (Figure 1). The epicentre of the green revolution was the fertile Indo-Gangetic plains in northern India, particularly the states of Punjab, Haryana and western Uttar Pradesh. The green revolution enabled India to become self-sufficient in food production. It has supported the livelihoods of millions[2], while reducing the incidence of rural poverty[3,4]. Today, more than 60% of India's working population is employed in the agricultural sector. Agriculture contributes around 18% to India's gross domestic product and supplies more than 70% of its exports[4].

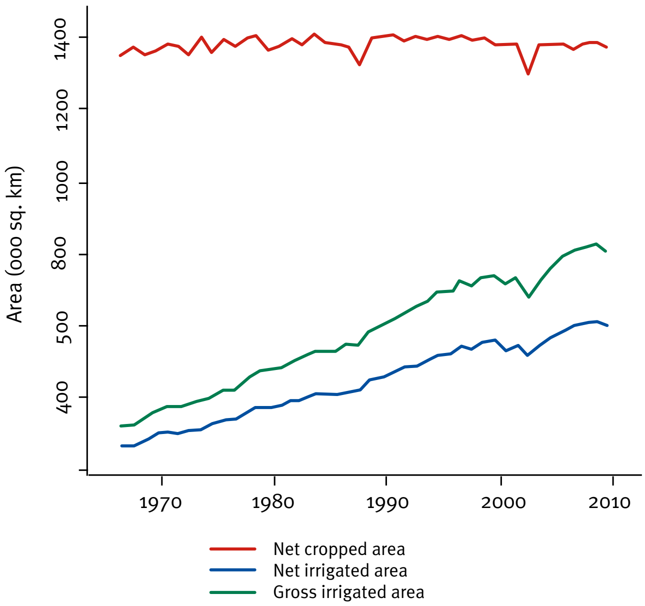

Figure 1: Change in net cropped area, net irrigated area and gross irrigated area over time. The sharp drop in the respective areas around 2002 is a consequence of the July 2002 drought. The most substantial environmental change arising from India's green revolution is the growth in irrigated area rather than the expansion of agricultural land.

Threats to water supply

From the latter half of the nineteenth century and immediately following independence in 1947 there was considerable public expenditure on large hydraulic structures including dams and canals, to convey surface water resources to irrigation command areas. However, the supply-driven canal system was unable to meet the irrigation requirements of farmers growing high-yielding rice and wheat varieties[5]. In addition, farmers outside irrigation command areas did not benefit from canal infrastructure. From 1970 onwards, small, affordable pumps and boring rigs provided a technological breakthrough, enabling groundwater to emerge as the primary source of water for irrigation[6] (Figure 2). Groundwater provides on-demand irrigation throughout the year and is more resilient to drought conditions compared to surface water irrigation schemes.
The number of electric or diesel pumpsets in operation increased from around 150,000 in 1950 to about 19 million in 2000[7].

Figure 2: A tubewell in operation. In this case the pump is diesel-powered.

Groundwater levels in several areas of the Indo-Gangetic plain, particularly in the states of Punjab, Haryana and western Uttar Pradesh, have declined since the 1950s[8,9]. Groundwater depletion increases the cost of pumping because it must be lifted from greater depths, as well as increasing the cost of installing and maintaining wells, and threatening the livelihoods of small and marginal farmers. In addition, it can lead to declining groundwater quality either because of upwelling of saline groundwater, or because of saline groundwater intrusion to fresh groundwater because of changing groundwater dynamics. Moreover, declining groundwater resources deepens inequality because wealthier farmers are able to drill deeper and sell water to smaller farmers who cannot access the resource themselves[2].

The pressure on water resources in India will soon intensify. According to the United Nations Population Division, population growth in India is not expected to stabilise until 2060, when it will have grown from 1.21 billion following the 2011 census to an estimated 1.72 billion, with the highest growth rate occurring in urban areas. Continued economic growth is likely to increase industrial water use. At the same time, land use change arising from urbanisation and industrialisation is reducing the area under agriculture in many parts of country[10]. In addition, groundwater levels beneath many urban areas, notably Delhi, are falling rapidly[11]. Growing demand for biofuels, in part due to policies enacted by the Indian government[12], is placing additional pressure on the agricultural system and may decrease the area of land available for food production[13].

The South Asian monsoon

The South Asian summer monsoon, which supplies up to 80% of India's total annual rainfall, is critically important to the nation's water resources. Changes in the timing, intensity and duration of the monsoon as a result of climate change and other factors represent a major threat to water supply[14]. Since the middle of the twentieth century there has been a decreasing trend in mean monsoon rainfall over India[15,16,17]. Recent research indicates that a combination of greenhouse gas emissions, aerosol emissions and land use change is responsible for weakening the monsoon[18]. In addition, several researchers have identified the cooling effect of large-scale irrigation across the Indo-Gangetic plains as a possible mechanism reducing monsoon rainfall[19]. Projections of future mean monsoon rainfall generally show weak positive trends as a result of the enhanced moisture content of the atmosphere above the Indian Ocean, partially offset by an overall weakening in the large scale monsoon circulation[16].

The monsoon is associated with intra-seasonal variations between active and break periods of precipitation which vary in length from several days to several weeks[20]. Analysis of observed rainfall data has shown an increase in the frequency and magnitude of extreme rainfall events from 1951 onwards and a decrease in the frequency of moderate rainfall events[21]. There is also evidence of changes to the seasonal monsoon pattern over the last 50 years, with the period of maximum frequency of active periods shifting towards the end of the monsoon period and break periods moving towards the beginning of the monsoon[22]. Furthermore, since 1951 there has been an increase in the intensity and spatial extent of moderate droughts, as well as a robust trend of increasing drought severity and frequency over the Indian monsoon region[23].

Variations in the frequency and duration of active and break periods during the monsoon season can have severe consequences for agricultural production and livelihoods[16], particularly if they coincide with important stages in the crop growth cycle. Furthermore, long break periods are associated with decreased mean monsoon rainfall across India[21], with repercussions for regional water resources[24]. For example, an extended dry spell around July 2002, in which rainfall was 56% below normal, contributed to a decrease in the mean annual rainfall of 21%[25], resulting in drought conditions across India and falls in agricultural production and economic growth. In this context, groundwater will assume a greater importance for protecting food production against intra-seasonal monsoon variability. However, increasing reliance on groundwater resources will also intensify pressure on regional water resources: "climate change will act as a force multiplier; it will enhance groundwater's criticality for drought-proofing agriculture and simultaneously multiply the threat to the resource"[26].

Climate change adaptation strategies for water resources management

Water resources management in India is the ultimate responsibility of the Ministry of Water Resources, River Development & Ganga Rejuvenation, a department of the Government of India. The policy agenda of the Ministry is guided by the National Water Policy (NWP), which was first released in 1987, updated in 2002 and again in 2012. The NWP is based on the principles of integrated water resources management, which is defined by the Global Water Partnership as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems". A central theme of the NWP is the need to improve the resilience of India's groundwater resources to social, economic and environmental change. Here we identify three policy areas to realise this goal: Shifting cultivation patterns, energy and water supply pricing, and integrated management of surface water and groundwater resources.

Shifting cultivation patterns

The intensive rice-wheat cropping system in north-west India has persisted as a result of guaranteed procurement prices and subsidised energy for groundwater irrigation[6] (Figure 3). In the 1960s, as the green revolution was taking hold, State governments pursued policies of rural electrification as a means to stimulate agricultural development. While the electricity supply was initially metered, the logistical challenges associated with billing rural customers soon led to the introduction of flat rate tariff[26]. Meanwhile large parts of north-east India, including eastern Uttar Pradesh, Bihar and West Bengal, have undergone rural de-electrification since the 1980s in an attempt by the respective State Electricity Boards to reduce overall electricity consumption[28]. The relatively high operating costs of diesel pumps means that small and marginal farmers are unable to fully exploit the groundwater resource[27].

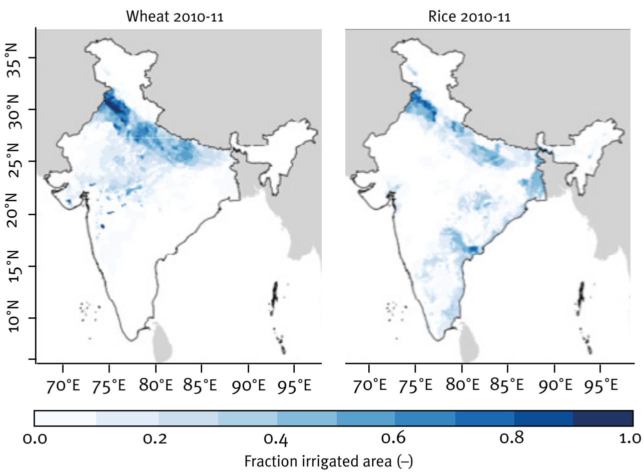

Figure 3: Spatial distribution of irrigated wheat and rice for the year 2010-11. Irrigated areas are clearly concentrated around north-west India in the green revolution states of Punjab, Haryana and western Uttar Pradesh.

Consequently agricultural productivity in this region does not reach its full potential despite considerable water resources, fertile land and access to labour.

The Indo-Gangetic basin is characterised as an area of "water scarcity with relative abundance of electricity supply in the western basin contrasted with water abundance and electricity scarcity in the eastern part"[6]. Thus, a clear strategy to reduce pressure on water resources in Punjab, Haryana and western Uttar Pradesh and improve the resilience of India's agricultural sector would be to shift the rice-wheat system eastwards[29]. To achieve this goal it would be necessary to reform incentives such as inflated procurement prices of rice and wheat for farmers in north-west India while pursuing a policy of rural electrification in underdeveloped regions of north-east India[29], along with introducing new and promising technologies such as solar pumps.

Energy and water supply pricing

Volumetric pricing of groundwater, which is considered the best approach for encouraging efficient water use[29], is virtually impossible in India at present where there are millions of tubewells in operation. An alternative, more practicable solution is to charge for the energy used for groundwater extraction. However, as discussed previously, in most parts of India electricity is heavily subsidised. In addition, many farmers outside north-west and south India do not have access to electricity and instead rely on diesel pumps. Apart from the practical difficulties associated with metering millions of rural customers, in a country where more than 60% of the population depend on the agricultural sector for their livelihoods, politicians on all sides have been reluctant to enforce policies to reduce energy subsidies that would hit the rural poor the hardest.

Since the turn of the millennium, the International Water Management Institute has argued that, despite some drawbacks, the most effective way to limit groundwater demand is to ration electricity to agricultural users[30]. The Jyotigram scheme involves a policy originating from the western State of Gujarat to manage rural electricity supply with the aim of reducing the exploitation of groundwater resources and ensuring the solvency of State Electricity Boards[26]. The scheme, implemented by the Gujarat government between 2003-2006, led to the rewiring of the rural electricity network to separate agricultural electricity supply from other users. Now, agriculture users receive free electricity for eight hours each day at agreed times while domestic and other users, who place a far lower demand on the system, receive 24 hour metered supply. The scheme has reduced the volume of groundwater withdrawals and halved the electricity subsidy to farmers[26]. Moreover, by improving the reliability of electricity supply to non-agricultural users it has stimulated the rural economy. In Uttar Pradesh this has been shown to reduce the incidence of rural poverty[31]. The success of the Jyotigram scheme has resulted in plans to extend it to the rest of India.

Rationing electricity is only appropriate in areas with established power supply, so alternative approaches are required across much of India. Solar pumps offer a promising alternative to fossil fuel-derived energy, providing a method of irrigation and water abstraction free from the constraints of electricity supply and the fluctuations of diesel prices. These pumps can also provide individuals or villages with income by supplying electricity back to the grid when the pump is not in use. Regional governments might be encouraged to set up supportive policy in return for central government provision of solar pumps. Solar pumps would be of particular use in the north west of India, where the available water resources have been under-utilised.

Unlike groundwater, canal water can be priced as it is supplied and controlled by the State irrigation department. In reality, fees are rarely collected and when they are it is typically at a rate much lower than the cost of supplying the canal water, resulting in significant sections of the system falling into disrepair. Because canal users do not pay for the service they have little recourse to demand a working system[40]. Charging a socially acceptable amount through an enforceable payment system would allow for necessary maintenance and a more reliable supply of canal water.

Integrated management of surface water and groundwater resources

Optimising the use of India's limited water resources requires an integrated approach to the management of surface water and groundwater resources. One way to reduce pressure on groundwater resources is to increase the availability of surface water for agricultural and other users. For example, fieldwork has shown that many farmers rely exclusively on groundwater even in locations ostensibly served by canals; a situation which has arisen as canals have fallen into disrepair and competition between users has intensified. Moreover, water supply from canals is unreliable and frequently inadequate to meet crop water demands. Counterintuitively, leakage from canals in many areas slows groundwater depletion, providing a significant volume of water to underlying aquifers, helping to buffer water resources. However, upgrading and repairing the canal network in selected areas would increase the chances of adequate volumes of water reaching all areas within the irrigation command areas, and reduce pressure on groundwater resources.

While part of the solution lies in developing surface storage water and distribution schemes; canals, tanks and reservoirs are subject to substantial losses from evaporation which are expected to rise under climate change as temperatures increase[7]. To alleviate evaporation, there needs to be a shift from surface storage to aquifer storage. Prior to the green revolution, when groundwater withdrawals amounted to between 10-20km^3, there was little aquifer storage available. Now it is estimated that there is between 230-250km^3 of storage space in India's alluvial aquifers[7]. Thus, managed aquifer recharge (Figure 4) should be promoted and developed as an alternative to traditional surface water schemes to capitalise on the benefits of groundwater irrigation.

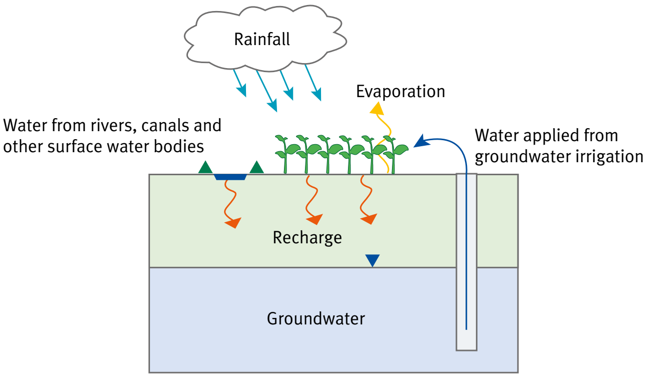

Figure 4: Aquifer recharge. (Image from Jimmy O'Keeffe)

Policy recommendations

According to the Constitution of India water is a State subject. In reality, aquifers and surface water bodies transgress political boundaries, inevitably leading to disagreements and conflict. This is further complicated by the fact that the central government departments that oversee India's water resources – the Central Water Commission (CWC) and the Central Groundwater Board (CGWB) – effectively work as independent entities with limited powers and little intercommunication[38].

Although restructuring has been proposed[39], it is currently the responsibility of State governments to implement effective schemes to meet the goals of the National Water Policy.

The availability of adequate and manageable energy provides a means for State governments to control groundwater abstractions and ensure the solvency of State Electricity Boards. In turn, expanded electrification promotes economic and social development because non-agricultural energy consumers have a more reliable supply of electricity and small and marginal farmers have reduced overheads.

Associated with rural electrification is the need to introduce effective schemes to manage electricity supply for groundwater pumping. The Jyotigram scheme is a promising approach to both control the energy and water consumed by farmers and to stimulate local economies. However, State governments must ensure that the policy has been adapted to local hydrological and socioeconomic conditions[3]. Locally-informed policy is also pertinent in the introduction of solar pumps; a technology that could have considerable potential in water rich but energy scarce regions such as Bihar. Energy generated by solar panels when a pump is not in use can be sold back to the grid or nearby villages, creating an additional stream of income for farmers

Box 1: Investigating water management in Uttar Pradesh

Uttar Pradesh, situated in northern India and containing a large proportion of the Indo-Gangetic plain, is India's most populous and densely populated State. Around 62% of the total workforce is employed in the agricultural sector, which contributes 25% to the GDP of Uttar Pradesh and about 8% to the GDP of the country. However, there are substantial regional variations in the performance of agricultural systems and the rate of rural and economic development across the State as a result of diverse biophysical and socioeconomic conditions[31].

A field survey carried out by universities in India and the UK, including IISc Bangalore, IIT Kanpur, IIT Roorkee and Imperial College London, identified strong disparity in water use and irrigation practices between farmers in two districts in the central region of Uttar Pradesh. The research involved a series of field visits and farmer interviews, with questions focusing on the volume of water applied, methods of irrigation, price paid for irrigation, crop yield and water source[37]. Farmers in the district of Sitapur, located north of the State capital Lucknow, applied substantially more irrigation water (approx. 4,000 m^3/Ha) during wheat cultivation compared to their counterparts in Jalaun (approx. 2,500 m^3/Ha), situated in the more drought-prone Bundelkhand region of the south. In addition, the survey found that farmers in Sitapur pay around 12,782 rupees (190 USD) per hectare to irrigate their land during the wheat season while farmers in Jalaun spend only 5,733 rupees (85 USD).

While soil conditions play a role in the volume of water applied for irrigation, an important reason for the dramatic difference in water use and the cost of irrigation in the two districts lies in the source of water and the methods used for irrigation. Although both districts contain extensive canal networks, farmers in Sitapur rely almost exclusively on groundwater for irrigation since their canals are rarely operational. Few farmers in this area have access to electricity so they use diesel pumps and spend a large proportion of their income on fuel. In contrast many farmers in Jalaun have access to canal water which is considerably cheaper than extracting groundwater with diesel pumps. Thus, while the supply is somewhat unreliable, farmers have extra capital to invest in water efficient technologies, particularly sprinkler systems, which enable them to maximise the utility of canal water when it arrives. Investment in more efficient irrigation technologies is further justified by the fact that many farmers have experienced an increase in their crop yield.

In Sitapur, rural electrification would remove the financial burden of diesel fuel costs and reduce rural poverty. Schemes to ration electricity supply such as the Jyotigram scheme would encourage the adoption of more efficient irrigation technology, while a more reliable source of electricity to non-agricultural users would stimulate local economies and enhance employment outside the agricultural sector which, in Uttar Pradesh, has been shown to reduce rural poverty[31]. The fieldwork has shown variability in irrigation practices must be considered when developing appropriate solutions to improve the sustainability of water resources and food production in India.

and providing a more environmentally friendly and independent source of electricity for local users. Despite the potential of such technology its introduction would need to include policies which reduce the chances of over-abstraction of groundwater, such as smart meters to limit pump usage depending on weather.

While volumetric charging of groundwater is unlikely, its application in canal water supply should be considered an important part of maintaining adequate system operation. The increased income allows for canal maintenance and provides paying service users justification to protest when the canal system is running below its potential.

Managed aquifer recharge will play a central role in sustaining India's food and water security. Under the State Panchayati Raj Act State governments can transfer responsibility for minor irrigation, water management and watershed development to local governments at district, tehsil (sub-district) and village levels. Promoting the implementation of good water use practice at the community level, rather than through top-down interventions, will encourage farmers to manage groundwater as a community resource rather than as private property[7]. One area where the involvement of Central and State government may be helpful is in providing appropriate education to local politicians to ensure the schemes are implemented properly. Correspondingly, there is a need for a consistent framework for the proposed policies, both in terms of the performance of the infrastructure and the socioeconomic impact of the scheme on the community[33]. All proposed policies will require a detailed and expansive data set which carefully integrates and manages information from many sources, and makes this accessible to researchers and officials alike. Such information will be essential for successful aquifer mapping and monitoring, rejuvenation of rivers and research into water security.

Ultimately, India's water resources are dependent on the South Asian monsoon. Accurate forecasts about the behaviour of the South Asian monsoon under climate change, especially concerning sub-seasonal variability, are critical to enable policy makers to make effective water management decisions[34,35,36]. These include calculating changes in groundwater storage and, therefore, the buffering capacity of aquifers during low rainfall periods. In addition, there is a need for a systems approach for integrating water demand and water management activities to support policy-makers as they seek to understand the impact of potential decisions on communities and local and regional water resources.

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The Grantham Institute is committed to driving research on climate change and the environment, and translating it into real world impact. Established in February 2007 with a £12.8 million donation over ten years from the Grantham Foundation for the Protection of the Environment, the Institute's researchers are developing both the fundamental scientific understanding of climate and environmental change, and the mitigation and adaptation responses to it. The research, policy and outreach work that the Institute carries out is based on, and backed up by, the worldleading research by academic staff at Imperial.

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For more information about this subject, to discuss how the issues covered affect you and your work, or to contact the authors, please email us at: **grantham@imperial.ac.uk**