  

Groundwater resources in the Indo-Gangetic Basin

Resilience to climate change and abstraction

Executive Summary

Groundwater within the Indo-Gangetic Basin (IGB) alluvial aquifer system forms one of the world's most important and heavily exploited reservoirs of freshwater. In this study we have examined the groundwater system through the lens of its resilience to change – both from the impact of climate change and increases in abstraction. This has led to the development of a series of new maps for the IGB aquifer, building on existing datasets held in Pakistan, India, Nepal and Bangladesh, a review of approximately 500 reports and papers, and three targeted field studies on under-researched topics within the region. This brief synthesises the major findings of the study, and forms the Executive Summary of the final project report.

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IGB GROUNDWATER RESILIENCE

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Keywords
Indo-Gangetic Basin; groundwater; resilience; abstraction; climate change.

The IGB groundwater system

1. The IGB alluvial aquifer system comprises a large volume of heterogeneous unconsolidated sediment in a complex environmental setting. Annual rainfall varies from <25 mm per annum in southern Pakistan to > 2000mm in the Bengal basin, and the system is dissected by the major river systems of the Indus, Ganges and Brahmaputra. The groundwater system has been modified by the introduction of large scale canal irrigation schemes using water from the Indus and Ganges since the 19th and early 20th centuries.
2. High yielding tubewells can be sustained in most parts of the alluvial aquifer system; permeability is often in the range of 10 – 60 m/d and specific yield (the drainable porosity) varies from 5 – 20%, making it highly productive.
3. High salinity and elevated arsenic concentrations exist in parts of the basin limiting the usefulness of the groundwater resource. Saline water predominates in the Lower Indus, and near to the coast in the Bengal Delta, and is also a major concern in the Middle Ganges and Upper Ganges (covering much of the Punjab Region in Pakistan, southern Punjab, Haryana and parts of Uttar Pradesh in India). Arsenic severely impacts the development of shallow groundwater in the fluvial influenced deltaic area of the Bengal Basin.
4. Recharge to the IGB aquifer system is substantial and dynamic, controlled by monsoonal rainfall, leakage from canals, river infiltration and irrigation returns. Recharge from rainfall can occur even with low annual rainfall (350 mm) and appears to dominate where rainfall is higher (> 750 mm). Canal leakage is also highly significant and constitutes the largest proportion of groundwater recharge in the drier parts of the aquifer, partially mitigating the effects of abstraction on groundwater storage.

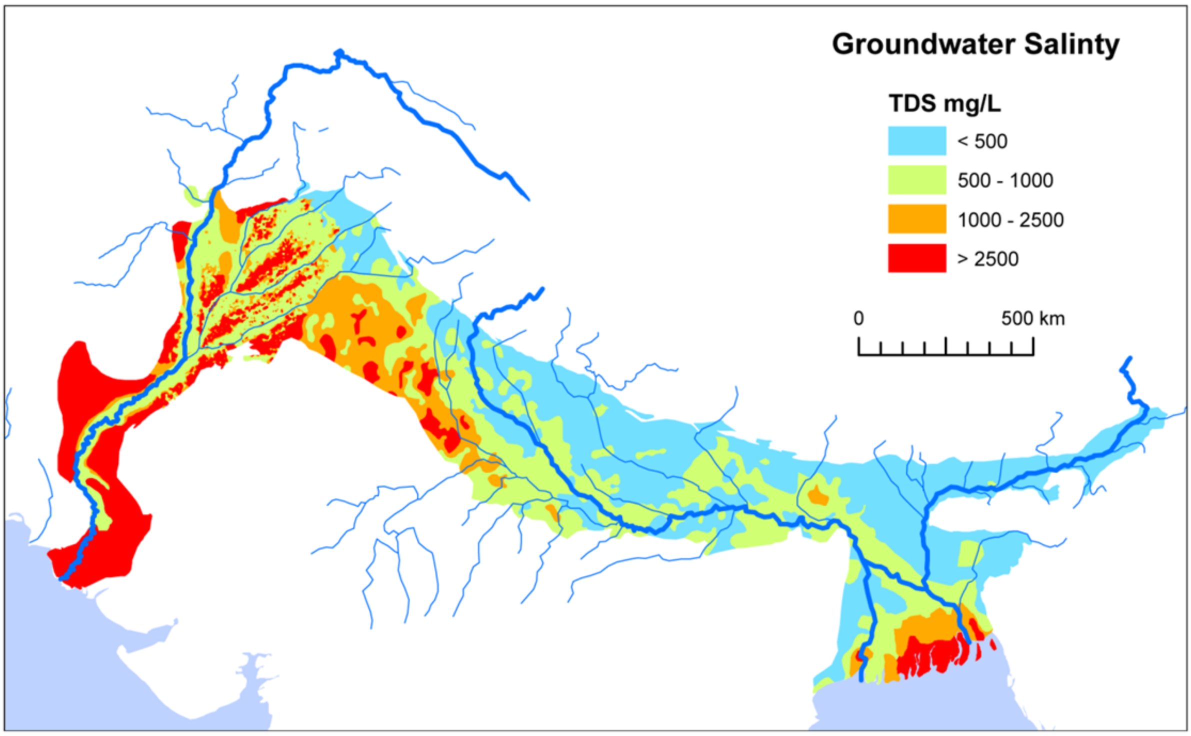


Figure 1 Groundwater salinity in the IGB aquifer system

5. Deep groundwater (>150 m) in the Bengal basin has strategic value for water supply, health and economic development. Excessive abstraction poses a greater threat to the quality of this deep groundwater than climate change. Heavy pumping may induce the downward migration of arsenic in parts of Bangladesh, and of saline water in coastal regions, but field evidence and modelling both suggest that deep groundwater abstraction for public water supply in southern Bangladesh is in general secure against widespread ingress of arsenic and saline water for at least 100 years.

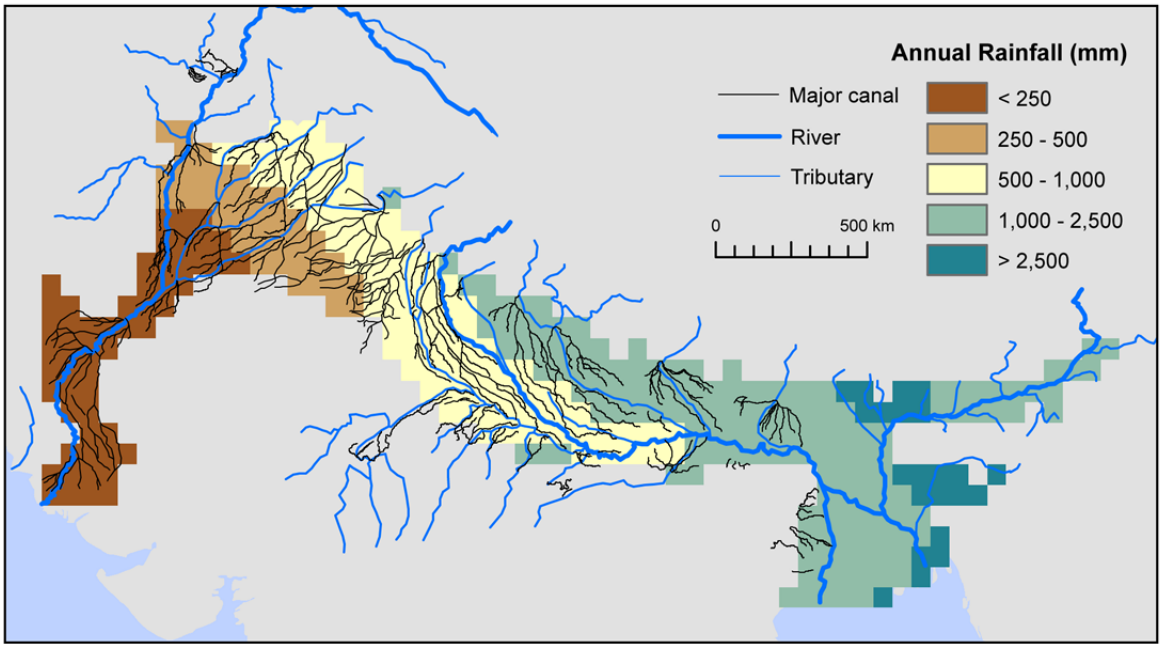


Figure 2 Rainfall, rivers and canals in the IGB all contribute to groundwater recharge

IGB Groundwater typologies

The IGB alluvial aquifer system has been divided into seven major and four minor typologies each with different characteristics which define how resilient groundwater is to change. These typologies are: 1. The piedmont margin; 2. The Upper Indus and Upper-Mid Ganges; 3. The lower Ganges and Mid Brahmaputra 4, the fluvial influenced deltaic area of the Bengal basin; 5. The Middle Indus and Upper Ganges; 6. The Lower Indus; and 7. The Marine influenced deltaic areas.

Summary table of the different typology environments

	permeability	storage (Sy)	thickness (m)	Salinity	arsenic	Recharge *mechanism*	abstraction	Water-levels
Piedmont margin	High	V High	<100	No	local	High *rainfall*	Mod	stable
Upper Indus and Upper-Mid Ganges	V High	High	>200	local	local	High *rainfall canals*	V High	Variable mostly falling
Lower Ganges and Mid-Brahmaputra	V High	High	>200	No	local	High *rainfall & rivers*	Variable	Shallow mostly stable
Fluvial influenced deltaic area of the Bengal basin	High	Mod	>350	No	V High *Low at depth*	High *rainfall*	High	Shallow mostly stable
Middle Indus and Upper Ganges	High	High	200	Yes	local	Moderate *canals & irrigation*	High	Mostly falling rapidly
The Lower Indus	Mod	Mod	200	Extensive	local	Moderate *canals & irrigation*	Low	Rising
The marine influenced deltaic areas	Mod - Low	Low	350	Extensive	local	variable	at depth Bangla-desh	Shallow and Variable

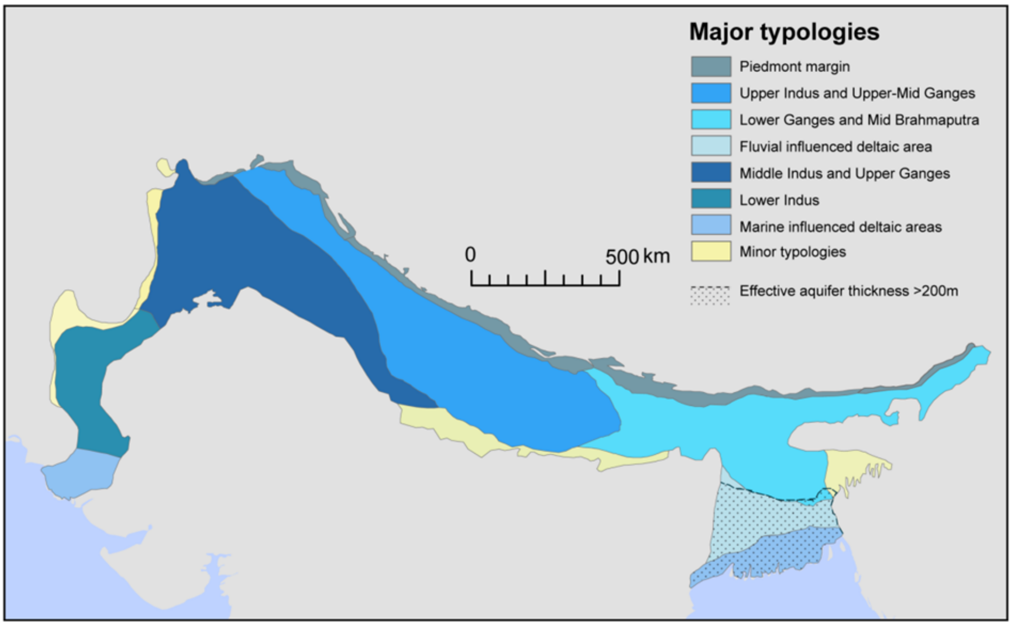


Figure 3 The major groundwater typologies in the IGB aquifer system

Groundwater abstraction and groundwater levels

Data on groundwater abstraction and groundwater levels have been collated from national datasets, regional studies and analysis of data from a subset of individual tube wells with the best available data on groundwater level variations.

6. Groundwater abstraction across the IGB alluvial aquifer system is high, 205 km^3 (20 – 25% of global groundwater abstraction) and estimated to be rising at 2 – 5 km^3 per year. Abstraction occurs through an estimated 15 – 20 million tube wells. Abstraction is not evenly spread, but concentrated in the Indian States of Punjab and Haryana, the Punjab Region of Pakistan, and northern Bangladesh. Ninety percent of abstraction is used for irrigation. Hotspots of intense abstraction are also associated with major cities, most noticeably Dhaka, Lahore and New Delhi.
7. Groundwater levels within the IGB alluvial aquifer system are typically shallow: < 5 m below ground surface with important exceptions. In areas of high groundwater abstraction in north west India and the Punjab in Pakistan, groundwater levels can be 20 – 50 m bgl and are falling at rates of 0.5 – 1 m/yr. In similar areas of high irrigation abstraction within Bangladesh, groundwater levels remain shallow (<10 m bgl) due to much higher recharge. Groundwater levels are deep and falling in many urban areas, and particularly in large groundwater dependant cities. Rising groundwater levels can be found in the Lower Indus, parts of the Bengal basin and in places throughout the basin as a consequence of leakage from canals and rivers and from irrigation returns. Throughout much of the rest of the basin, groundwater levels are relatively stable.
8. At the scale of an individual canal command, there is considerable spatial variation in groundwater levels with evidence of groundwater levels in individual wells rising or falling within several kilometres. In general, groundwater levels are likely to be rising or stable at the head of a canal command where leakage is high and abstraction generally less, and falling towards the end of a canal command, where abstraction is greater and there is less canal water available.

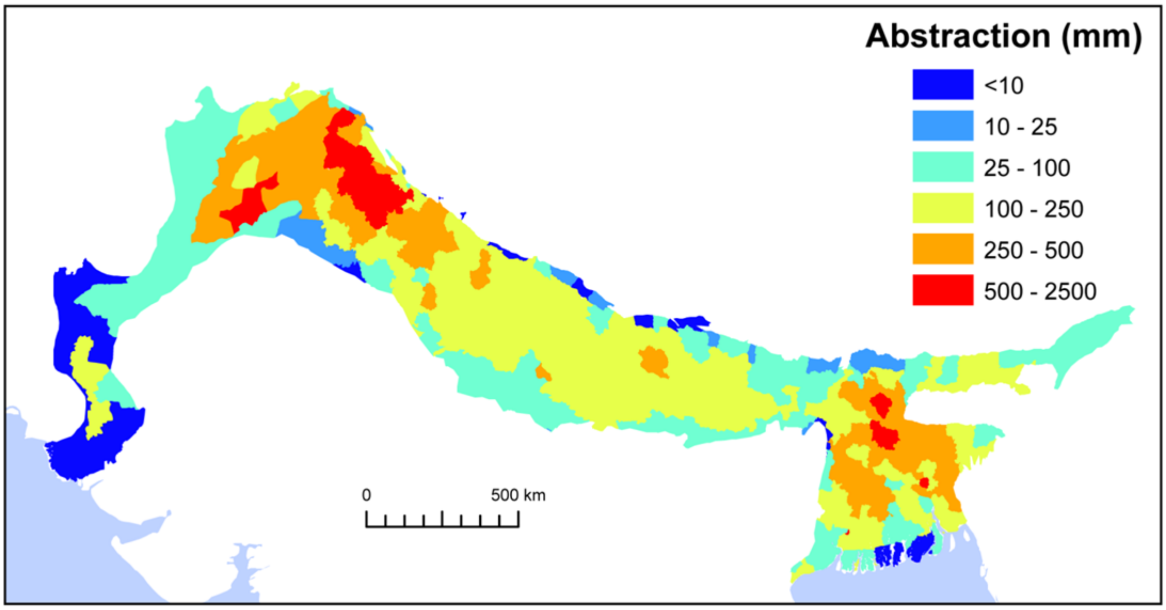


Figure 4 Groundwater abstraction across the IGB alluvial aquifer. The total abstraction for2010 is estimated as 205 km^3, a quarter of the earth's total groundwater abstraction.

9. There has been considerable change to the groundwater levels within the IGB over the last 150 years. The widespread construction of canal systems in the Indus and Ganges in the 19th and early 20th centuries led to rising groundwater levels and water-logging as early as 1875. Current groundwater depletion should, therefore, be viewed in the wider context of past groundwater accumulation and water-logging.

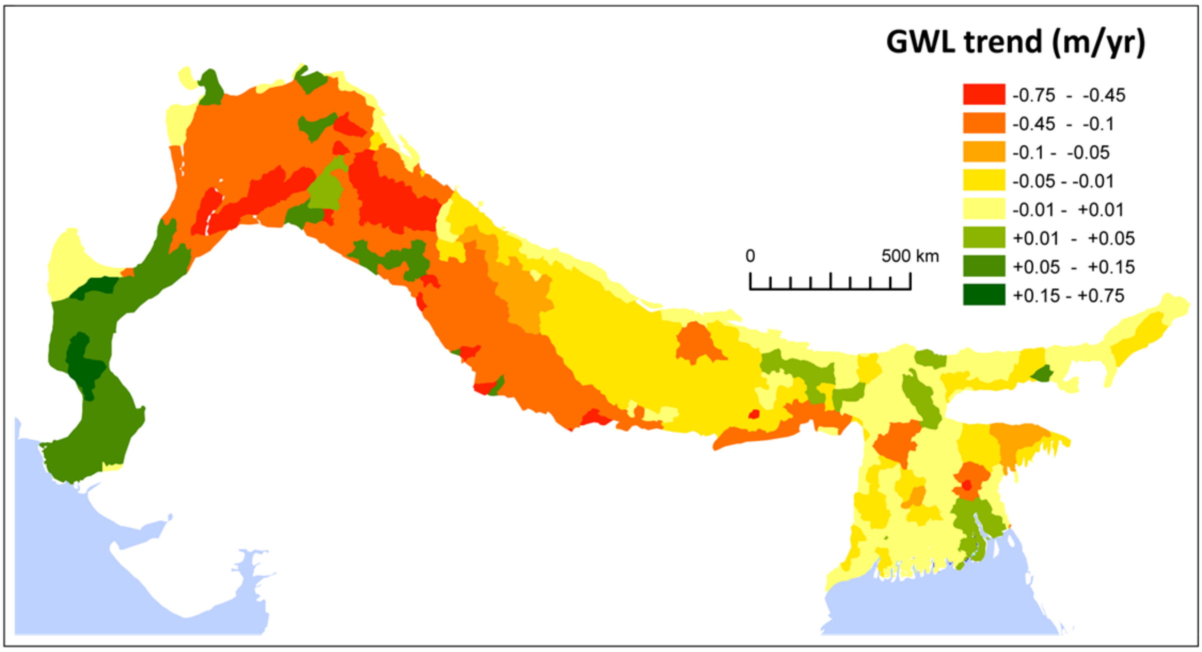


Figure 5 Average annual groundwater level trend in the IGB, in some areas groundwater is falling by >0.75 m per year, but in other areas groundwater levels are rising.

Resilience to future climate and abstraction: trends in groundwater storage and quality

With uncertainty about future precipitation and the likelihood of continued increases in abstraction, impacts on the groundwater resource are best investigated by assessing its resilience to change. Groundwater resilience to change is governed by the volumes of freshwater in storage, the permeability of the aquifer system and likely long term recharge (Foster and MacDonald 2014).

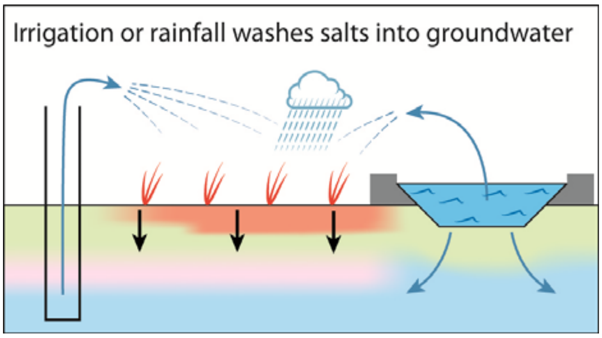
10. Groundwater storage within the top 200 m of the aquifer is in the order of 30,000 ± 10,000 km^3 with approximately 7,000 km^3 having salinity greater than 1000 mg/L. This compares to average annual flow in the rivers within the basin of 1,000 – 1,500 km^3 per year, and estimated current recharge of approximately 200 km^3. This large volume of groundwater storage offers significant buffering to short term changes in abstraction and climate variability. However, even small declines in groundwater levels within the aquifer can impact aquatic ecosystems and river flows, and restrict access for those relying on shallow wells.

11. Estimates of trends in groundwater storage for the IGB alluvial aquifer system, derived from ground based measurements of groundwater levels and estimates of specific yield,

indicate a net average annual groundwater loss of 10 km^3 with significant variation across the basin. The largest depletion occurs in the areas of high abstraction and consumptive use in northern India and northern Pakistan, where between 25 and 150 mm of groundwater can be depleted annually, and in the Middle Indus and Upper Ganges typology where depletion is generally 10 – 25 mm. Across the rest of the basin changes in groundwater storage are generally modest (±2 mm), apart from in the Lower Indus where rising groundwater levels and waterlogging are ongoing issues.

12. In the future, given current forecasts of future rainfall and river flow, groundwater recharge is likely to be maintained within the bounds observed through current climate variability. A greater risk to groundwater recharge is posed by changes to canal leakage, which provides a large proportion of groundwater recharge in drier areas. For example programmes to line tertiary irrigation canals in areas where leakage does no flow to saline sinks, could significant impact the groundwater balance.

13. Degradation of water quality in the IGB aquifer system is a major concern, and is likely to pose a greater threat than widespread depletion. There is evidence of increased areas subjected to salinization due to both phreatic salinization from shallow water tables and water-logging and excessive pumping mobilising older saline groundwater within the drier and coastal typologies in the basin. There is evidence that the recycling of irrigation water and contamination from agricultural and industrial chemicals are leading to degradation in groundwater quality, which can only be abated through changes to land use planning, agricultural practices and industrial controls.



14. Two field studies within this project have shown the variation in response of deep groundwater in different parts of the IGB aquifer system. In the Bengal basin, abstraction from deeper groundwater beneath shallow, arsenic-contaminated groundwater has not led to vertical leakage and recharge from shallow groundwater at a regional scale, but there is evidence of localised leakage around some individual abstraction tubewells. In the upper Indus, however, where the aquifers are more isotropic and low permeability layers less extensive, deeper abstraction has led to increased recharge from shallow groundwater and anthropogenic contaminants being drawn deeper into the aquifer.

15. A third field study in the Middle Hills of the Himalayas, demonstrated that groundwater has an important function in regulating river flows in the headwaters of the IGB and also provides reliable water supplies for domestic use and irrigation. There remains a high reliance on springs in higher valley regions and these depend on seasonal rainfall with a smaller proportion of discharge from older (possibly decade-old) baseflow. Therefore, although much of the spring flow is not resilient to climate change, some water may still be available through drier years.

16. Many of the cities within the IGB (such as Lahore, Dhaka and New Delhi) are dependent on groundwater. The intensity of both private and public abstraction required to meet growing water demand has led to rapidly declining water-levels within the cities, a

problem compounded by contamination from industrial pollutants and sewerage. These city supplies are unsustainable, and strategies will need to be developed to manage demand, control pollution and to augment city pumping with surface water or groundwater from outside urban areas.

Implications for policy

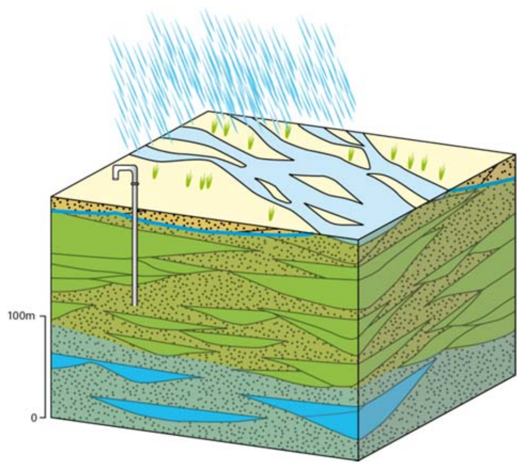
The issues and challenges of managing groundwater in IGB alluvial aquifer system are recognised by the regulatory authorities in each country. Given the volume of abstraction, the large number of private tubewells, and the transboundary nature of the resource, groundwater governance is highly complex. This is compounded by the impact of government policies outside the water sector – particularly in agriculture and energy – which have a major influence on the use of groundwater and pollution loads. Within this section we highlight some of the particular aspects of the groundwater system that will impact on emerging policies for managing groundwater. A central issue is ensuring that the resources and regulatory focus are sufficient to match the scale of the challenge.

Groundwater is more vulnerable to abstraction than climate change. Currently groundwater level change and water quality is being driven by abstraction rather than climate change. Given the current forecasts for future climate and river flows, it is likely that abstraction will remain the main driver of change within the basin.

Groundwater storage, permeability and resilience to change. The groundwater system is characterised by extensive storage – many times greater than the annual volume of groundwater abstraction, and potentially 20 times the annual flow of the river systems. This provides an important buffer to change, although declining groundwater levels can have devastating impacts on aquatic ecosystems and significantly reduce access to groundwater.

Adaptive management: the spatial and vertical heterogeneity of the groundwater system. The study has shown that there is considerable variation in the nature of the aquifer, recharge and quality of groundwater across the IGB aquifer systems. The groundwater typologies developed in this study can be used to help formulate appropriate management strategies for different parts of the IGB aquifer system. Each typology presents its own unique set of challenges and opportunities for groundwater development. The typologies could be used to help prioritise and tailor programmes of groundwater monitoring, exploration and investigation, and inform future groundwater development and management strategies. They can also be used to help identify areas where there is potential for increased groundwater abstraction.

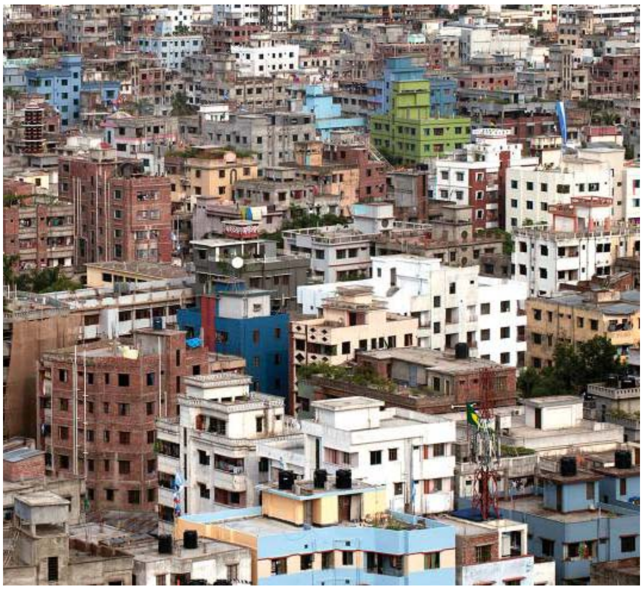
Deeper groundwater in the Bengal basin. The deep groundwater in the Bengal Basin is a vital source of good quality groundwater in a context where shallow water is contaminated by arsenic. There is little evidence of modern recharge or widespread downward movement of shallow groundwater into this deeper aquifer (although individual abstraction wells can draw down shallow water). Given the finite nature of this resource, its continued use for drinking water should be carefully monitored and managed.



Degradation in groundwater quality is a greater concern than depletion. Most research has focussed on documenting depletion in the IGB aquifer system using remote sensing. However, the increases in salinity driven by irrigation and abstraction, and the contamination of groundwater from both agriculture and industry, pose bigger degradation threats than aquifer depletion.

Canal leakage dominates groundwater recharge in drier areas. In much of the drier parts of the aquifer, canal leakage is an important source of recharge to the aquifer. While policies to line canals and reduce leakage may therefore have a positive impact on water delivery and crop productivity, they may have a negative impact on the groundwater balance. Attempts to save water should therefore focus on reductions in non-beneficial consumption, with channel lining restricted to those areas where return flows are lost to further use, or threaten the quality of drinking water or key environmental flows.

Urban groundwater. High rates of abstraction have resulted in local depletion in some cities with groundwater levels falling rapidly (>100 m depth in some locations). In addition, widespread contamination from both sewerage and industrial pollutants has degraded shallow groundwaters, although stratification of the aquifers helps protect some of the deeper groundwater. Maintaining good quality groundwater supply in the largest cities will therefore become more difficult over time unless steps are taken to address degradation threats within cities, and develop protected urban well fields beyond them.



The importance of monitoring. Changes in groundwater quality and groundwater storage within the IGB aquifer system will generally be gradual, and monitoring should provide adequate warning of adverse effects, giving time for a managed response. Continued exploration, testing and monitoring of shallow and deeper groundwaters across the aquifer system is needed to enable timely management systems to be developed to identify and mitigate further degradation.