OR/14/070 Concluding remarks – emerging questions & links to policy: The Bengal Deep Groundwater Statement 2014

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Taylor, R G[1], Burgess, W G[1], Shamsudduha, M[1], Zahid, A[2], Lapworth, D J[3], Ahmed, K[4], Mukheriee, A[5] and Nowreen, S[6]. 2014. Deep groundwater in the Bengal Mega-Delta: new evidence of aquifer hydraulics and the influence of intensive abstraction. *British Geological Survey Internal Report*, OR/14/070.

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The *Deep groundwater in the Bengal Mega-Delta: new evidence of aquifer hydraulics and the influence of intensive abstraction* case study has generated evidence which is enabling a greater understanding of BAS at the depths where abstraction is rapidly accelerating, of the relationship between the deep and shallow parts of the aquifer system, and the likely impact of climate change on rainfall intensity. This new evidence will enable more robust evaluation of the response of deep groundwater in the GBM delta region to increasing development and to climate change. Discrete and original observations have been made of groundwater head and groundwater chemistry including environmental isotopes and age indicators in vertical profiles to a maximum depth of 320 m at eight locations in the southern and coastal region of the delta region. A new assessment has been made of changes in rainfall intensity that may be expected as a result of climate change towards the end of the 21st century. Considered together, and in the light of allied research, the headline conclusions are:

- Temporal variations in deep groundwater levels, remote from intensive abstraction, are dominated by the elastic responses of the aquifer sediments to surface loading associated with tidal water bodies and monsoonal flooding. These annual changes in terrestrial water storage are largely independent of groundwater flow.
- Changes in the sources of recharge to deep groundwater in response to prolonged intensive groundwater abstraction pumping are suggested by chemical tracers (CFC-12, SF_6, stable isotope ratios of O and H) and new high-resolution piezometric observations.
- The volume and intensity of rainfall is projected to increase as a result of climate change in the Bengal Mega-Delta with a potential benefit to groundwater recharge where storage can be made available through intensive shallow groundwater abstraction for dry season irrigation of boro rice. Induced groundwater recharge serves, however, to flush mobile As, redistributing it to the soil.

Clear guidance for policy makers has been made in relation to the deep groundwater resource of the GBM delta region: *The Bengal Deep Groundwater Statement 2014* (below). Nevertheless, critical questions remain to be addressed in support of the resource management and further policy development:

- To complement the findings of this study, the extent and discontinuity in fine sediment layers confining deep groundwater in BAS and variation in their effective vertical permeability need

to be further established.
- Despite much progress (*e.g.* Figure 4), further work is necessary on the spatial extent and vertical layering of groundwater salinity in the delta region.
- For the continuing and expanded development of deep groundwater as a secure source of water, the implementation and strengthening of robust structures and infrastructure for monitoring and management are an essential requirement.
- Broader hydrological questions remain in relation to water distribution and storage throughout the IGB basin, the impacts of changes in climate on the hydrology of the GBM delta region, and especially in the context of this study the impacts on surface water storage and recharge to the BAS.

The Bengal deep groundwater statement 2014: deep groundwater in Bangladesh: a vital source of water

This Statement is the consensus outcome of collaboration between groundwater scientists and engineers working in academia (Dhaka University, Bangladesh University of Engineering & Technology, University College London, IIT Kharagpur) and Government survey/monitoring departments (Bangladesh Water Development Board, British Geological Survey), in discussion with planners in Bangladesh Government agencies (PSU, WARPO) and international bodies (UNICEF).

Deep groundwater is a vital resource for public water supply and irrigation in Bangladesh. The aim of ***The Bengal Deep Groundwater Statement 2014*** is to provide a status update for the benefit of those with responsibility for water supply in Bangladesh, particularly for policy makers.

The Statement summarises the consensus reached at a Seminar[1] and Workshop[2] attended by key representatives of the Policy Support Unit (PSU, Local Government Division, Ministry of LGRD & Cooperatives), the Water Resources Policy Organisation (WARPO), the Bangladesh Water Development Board (BWDB), the Geological Survey of Bangladesh (GSB), the Bangladesh Agricultural Development Corporation (BADC), donors including UNICEF, national and international universities and NGOs. Evidence and experiences of deep groundwater conditions in Bangladesh and West Bengal, including new research results, were considered and their implications for policy were discussed.

The Statement identifies 7 points of consensus (A to G below) drawn from new research[3] on deep groundwater conditions in the Bengal Basin. To facilitate contribution to the aims of the Bangladesh 'Water Act'[4], these points subsume conclusions and recommendations taken from the 2013 Ruposhi Bangla Deep Groundwater Statement[5], integrating new findings with observations, field investigations and modelling results subsequent to the first substantive discussion on deep groundwater[6] in 2000, when few facts were available.

The 'Water Act' drives the requirement for policy development, but this Statement also recognises the context jointly provided by the UNEP IHP Trans Boundary Waters Assessment Programme (WAP) No.16 for Central Asia[7], media and other reports of groundwater depletion across parts of the Indo-Gangetic plains[8], the water-food-health nexus[9] with its requirement for adaptive strategies to strengthen resilience in the face of climate change, and many cases across Bangladesh[10] of urban and mega-city reliance on groundwater for water supply where the sustainability of the groundwater resource is uncertain or under threat.

Deep groundwater pumping has become the most popular, practical and economic mitigation[11] response to the arsenic crisis, with many tens of thousands of deep tubewells installed for hand-pumped domestic supplies, rural piped systems, and municipal and commercial supplies. High-yielding deep wells have been installed in over 100 rural water supply schemes and at more than 20 towns. At some sites, researchers have made detailed studies of deep groundwater. Also a number of modelling studies have been performed. Against a backdrop of concern for the sustainability of deep groundwater resources, and their security against invasion by arsenic and in coastal regions, salinity, there has to date been no adverse impact on quality or water levels that can be attributed to deep groundwater pumping, except in Dhaka. [In the Dhaka metropolitan area, groundwater levels continue to decline as the number of deep boreholes increases; no-where else in southern Bangladesh is the water demand as large and as concentrated as in Dhaka]. There is still much to learn, but the stage has been reached when clear conclusions pertaining to the managed development of the deep groundwater resource, with concurrent monitoring of quality and water levels, are justified.

We emphasise the following conclusions and recommendations as advice to policy makers[12]:

A. Deep groundwater defined

The subject of the Statement is ‘deep groundwater’. We take ‘deep groundwater’ to be groundwater at greater than 150 m depth below the ground surface of the Ganges-Brahmaputra-Meghna (GBM) floodplains of the Bengal Basin, irrespective of its age and the age or nature of its host sediments. We emphasise that the sediments of the Bengal Basin have a common geological origin and form one single, inter-connected aquifer, the Bengal Aquifer System (BAS)[13], which stores and transmits groundwater over time in an interconnected fashion. The deep groundwater resource remains poorly defined, however, and the spatial variability of BAS is not well characterised. Interconnectedness dictates that pumping from one level may have impact beyond, above and/or below the point of pumping. Over short times (weeks, months) these impacts may not be significant. Locally, identifiable sub-division of BAS into discrete aquifers might be useful.

However over long time periods (years, decades) and at large scales it should be expected that the effects of pumping will be widely experienced. Therefore:

- we recognise ‘deep groundwater’ rather than ‘the deep aquifer’;
- we note that there is a need to delineate more fully the quantity and extent of deep groundwater resources;
- we emphasise the imperative to monitor the effects of deep groundwater pumping across the full depth sequence of BAS sediments;
- we note that the BAS is a transboundary aquifer, crossed by an international boundary;
- we stress the value of a co-operative approach to groundwater resource management, and the wider benefits of knowledge sharing.

B. Strategic importance of deep groundwater for water supply, health and development

There is consensus between the institutions and individuals with concern and responsibility for water supply in Bangladesh in recognising the significance of deep groundwater to the future of Bangladesh. The consequences of not developing deep groundwater would be: less-secure water sources would be targeted; arsenic exposure of the rural population would decline less than otherwise or not at all; and the potential for development offered by a safe, secure water supply would not be realised.

C. Threats to sustained good quality of deep groundwater

Whereas at shallow depth across the GBM floodplains, arsenic is a pervasive groundwater contaminant, and in many coastal areas groundwater at shallow and/or intermediate depth is saline, the quality of deep groundwater is generally very good. It is recognised that heavy pumping of deep groundwater may induce the downward migration of arsenic in many parts of Bangladesh, and of salinity in coastal regions[14]. Sea-level rise, amplification of storm surges and intensification of rainfall that result from climate change may exacerbate threats to the quality of deep groundwater. There is, nevertheless, consensus that:

- Excessive abstraction poses a greater threat to the quality of deep groundwater than does climate change
- Changes in groundwater quality will be gradual, and monitoring should provide adequate warning of adverse effects, giving time for a managed response

D. Equitable access requires strong regulation

Intensive pumping of shallow groundwater has in some areas, and particularly where fine-grained soils restrict replenishment by monsoonal recharge, led the water table to fall[15], restricting groundwater access to those able to afford deeper wells and increasing dependence upon deep groundwater resources. We draw attention to the inequity in access that results from unregulated pumping of groundwater, and we recommend strong regulation of deep groundwater pumping as a pro-poor policy.

E. Monitoring deep groundwater — *you cannot manage what you do not monitor*

Shallow groundwater in Bangladesh is one of the most intensively monitored groundwater regimes in the world; the monitoring database developed by BWDB has generated valuable insights of the sustainability of shallow domestic and irrigation pumping and the vulnerability of the shallow groundwater resources to contamination. In contrast, deep groundwater remains largely unmonitored[16], despite its strategic importance (point B). We emphasise that '*you cannot manage what you do not monitor*'. Recent, localised and high-frequency monitoring of deep groundwater pressure and chemistry has shown that BAS is susceptible to a variety of influences[17] that are still not fully understood. We recommend:

- continued exploration and testing of deep groundwater conditions and the hydraulic character of BAS at depths between 150 and 350 m
- implementation of a coordinated, national-scale, purpose-designed 'deep groundwater monitoring programme' combining both groundwater level and groundwater quality

F. Groundwater and adaptation — increasing seasonal water capture and storage

Substantial increases in demand for water for domestic purposes, irrigation and industry are anticipated in coming decades. The intensification of rainfall projected for Bangladesh as a result of climate change (see point C above) is expected to amplify seasonality in availability of water resources of Bangladesh. Successful adaptation strategies are likely to require improved capture and storage of monsoonal flows to enhance the sustainability of shallow groundwater use and in doing so to reduce dependence upon deep groundwater resources. We recommend adaptation strategies that increase seasonal water capture through:

- expansion of schemes for the creation of shallow freshwater lenses through Managed Aquifer Recharge (MAR)[18]

- consideration of MAR more widely in areas underlain by permeable soils, where monsoonal replenishment of groundwater abstracted for dry-season irrigation may be possible

G. Groundwater governance

Currently in Bangladesh, multiple agencies are involved in the governance and development of groundwater resources (BWDB, WARPO, PSU, DPHE, BADC, DWASA, KWASA, others?). There remain barriers to the sharing of data and communication of knowledge between research institutions, water supply providers, and agencies of governance. We recommend:

- implementation of the Water Act through a single agency, with a clearly defined structure for devolved responsibilities
- strong inter-ministerial coordination and a dedicated framework (e.g. Task Force) to streamline data storage and access at national level
- capacity strengthening, with particular attention to disciplines including groundwater hydrology, earth sciences and environmental engineering, to underpin the needs of groundwater resources evaluation, monitoring and governance

References

1. ↑ 'Resilience of Deep Groundwater in the Delta Region of Indo-Gangetic Basin', convened by Professor Richard Taylor (University College London) and Prof Kazi Matin Ahmed (Dhaka University), 26th Nov 2014, Dhaka.
2. ↑ 'Groundwater monitoring in the Bengal Basin: identifying research strategies and their policy implications', convened by Dr William Burgess (University College London), Professor Kazi Matin Ahmed (Dhaka University) and Mr Kazi Abdul Noor (Policy Support Unit, Local Government Division, Ministry of LGRD & Cooperatives), 27th Nov 2014, Dhaka.
3. ↑ The case study 'Deep groundwater in the Bengal Mega-Delta: new evidence of aquifer hydraulics and the influence of intensive abstraction' was funded by UKAid under the programme 'Groundwater resources in the Indo-Gangetic Basin: resilience to climate change and pumping', managed by the British Geological Survey (BGS). Access to piezometers at six sites across coastal Bangladesh, and contextual data, were provided by the Bangladesh Water Development Board (BWDB).
4. ↑ 'The Coordinated Development, Management, Extraction, Distribution, Use, Protection and Preservation of Water Resource' (Bangladesh National Parliament, 2 May 2013). Objectives under the Water Act require guidance on safe yield and sustainable limits of water resource bodies.
5. ↑ Policy Note submitted to PSU, 2013. Available as Appendix H of the Report 'The Security of Deep Groundwater in Bangladesh: Recommendations for policy to safeguard against arsenic and salinity invasion' (UCL, 2013).
6. ↑ 'Deeper Aquifers of Bangladesh — A Review Meeting', (DPHE/UNICEF/WB 2000). Organised by DPHE with support from UNICEF and WSP-SA, World Bank, and the LGD, Ministry of LGRD and Co-operatives, Government of the People's Republic of Bangladesh. The meeting addressed the prospects for a postulated 'deep aquifer'. Over ensuing years the concept 'deep groundwater' has become preferred to 'deep aquifer', as hydraulic continuity within the 'Bengal Aquifer System' is now recognised at regional and whole-basin scales — see Point A.
7. ↑ http://www.geftwap.org/; http://www.unwater.org/downloads/UNW_TRANSBOUNDARY.pdf
8. ↑ Rodell et al., 2009. *Nature* 460, pp.999–1002; Tiwari et al., 2009. *Geophysical Research Letters* 36, L18401; Shamsudduha et al., 2012. *Water Resources Research* 48, W02508.
9. ↑ World Economic Forum (WEF), 2011. Water Security: The Water-Food-Energy-Climate Nexus. 2011. WEF Initiative, Washington, DC: Island Press; BRAC, 2013. Sustainability of

Groundwater Use for Irrigation in Northwest Bangladesh. Report to the National Food Policy Capacity Strengthening Programme (NFPCSP).

10. ↑ UCL (2013). The security of deep groundwater in southeast Bangladesh: recommendations for policy to safeguared against arsenic and salinity invasion. Final Report, EPSRC/UCL-BEAMS Knowledge Transfer Project, London. 78 pp; Burgess, W G, Hasan, M K, Rihani, E, Ahmed, K M, Hoque, M A, and Darling, W G. (2011) Groundwater quality trends in the Dupi Tila aquifer of Dhaka, Bangladesh: sources of contamination evaluated using modelling and environmental isotopes, International Journal of Urban Sustainable Development (3), 56–76.
11. ↑ Deep tubewells account for 70% of the mitigation response to the arsenic crisis, across Bangladesh (DPHE/JICA, 2009. Situation Analysis of Arsenic Mitigation. Local Government Division Bangladesh, Department of Public Health Engineering (DPHE), and Japan International Cooperation Agency (JICA) Bangladesh, Dhaka, pp.77).
12. ↑ These points follow from research reported in ‘The Security of Deep Groundwater in Bangladesh: Recommendations for policy to safeguard against arsenic and salinity invasion’ (UCL, 2013), and broader discussions during the Seminar and Workshop of 15/16th January 2013.
13. ↑ Michael, H A, and Voss, C I. (2009) Controls on groundwater flow in the Bengal Basin of India and Bangladesh: regional modeling analysis. *Hydrogeology Journal* 17 (7), 1561–1577. Burgess, W G, Hoque, M A, Michael, H A, Voss, C I, Breit, G N, Ahmed, K M. (2010). Vulnerability of deep groundwater in the Bengal Aquifer System to contamination by arsenic. *Nature Geoscience* 3(2), 83–87.
14. ↑ These points follow from research reported in ‘The Security of Deep Groundwater in Bangladesh: Recommendations for policy to safeguard against arsenic and salinity invasion’ (UCL), and broader discussions during the Seminar and Workshop of 15/16th January 2013.
15. ↑ Shamsudduha, M, Chandler, R E, Taylor, R G, and Ahmed, K M. 2009. Recent trends in groundwater levels in a highly seasonal hydrological system: the Ganges-Brahmaputra-Meghna Delta. *Hydrology and Earth System Sciences*, 13: 2373–2385.
16. ↑ The notable exception is the BWDB network of 39 nested piezometer sites across the coastal area of Bangladesh monitored throughout 2012–2013 under the ‘Climate Change Trust Fund (CCTF) of the Ministry of Environment. We applaud the vision of this monitoring programme, and encourage its continuation and extension.
17. ↑ Burgess et al., 2014. *Poster H51O-0819*. AGU Fall Meeting, San Francisco 15–19 December 2014.
18. ↑ Managed aquifer recharge experiments focussing on shallow groundwater are delivering positive results at locations in south-west coastal regions (Sultana, S, Ahmed, K, Mahtab-Ul-Alam, S, Hasan, M, Tuinhof, A, Ghosh, S, Rahman, M, Ravenscroft, P, and Zheng, Y. (2015). ‘Low-Cost Aquifer Storage and Recovery: Implications for Improving Drinking Water Access for Rural Communities in Coastal Bangladesh.’ *J. Hydrol. Eng*. 20, SPECIAL ISSUE: 8th International Symposium on Managed Aquifer Recharge, B5014007.)

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