Institution: University College London

Unit of Assessment: 7 – Earth Systems and Environmental Sciences

Title of case study: Groundwater arsenic pollution: Informing policies, mitigation and monitoring programmes, leading to improved public health security in Bangladesh

Period when the underpinning research was undertaken: 2000-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
William Burgess	Professor of Hydrogeology	1990-present
John McArthur	Professor of Geochemistry	1979-present

Period when the claimed impact occurred: 2013-2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

UCL research findings about the source, transport and fate of arsenic in sediments exploited for water supply in the Bengal Basin have underpinned the development and implementation of policy by the Bangladesh government and of international donors and non-governmental organisations (NGOs) in the wider region (*e.g.* Pakistan, India). UCL's explanations of the geochemical and hydraulic processes controlling groundwater arsenic have underpinned the Bangladesh government's strategies for monitoring and mitigating the crisis and reducing arsenic exposure in the population. This has led to improvements in public health security among approximately 5,000,000 people across southern Bangladesh. UCL's discovery of the poroelastic character of the Bengal Aquifer System has further informed the expansion of the Bangladesh national infrastructure for monitoring the groundwater resources, and reconsideration of the national groundwater monitoring infrastructure in India.

2. Underpinning research (indicative maximum 500 words)

Arsenic (As) exposure – the adverse effects of which include cancers, diseases of the vascular system, and death – presents a serious global threat to public health. Since 1990, extensive arsenic pollution of groundwater has been recognised in Quaternary fluvio-deltaic sediments exploited for water supply. The problem is especially acute across the densely populated floodplains of Southeast Asia, where shallow groundwater constitutes the only bacteriologically safe source of water for more than 100,000,000 inhabitants. In places, shallow groundwater contains arsenic at concentrations up to 100 times the World Health Organization (WHO) guideline limit for drinking water – throughout the region some 70,000,000 people are exposed to excessive arsenic and secure mitigation solutions are far from universally implemented.

Research conducted since 2000 by John McArthur and William Burgess in the Department of Earth Sciences at UCL has addressed the distribution, source, transport and fate of arsenic in the Bengal Basin of West Bengal (India) and Bangladesh, taken as a type area for Quaternary fluvio-deltaic aquifers. McArthur and Burgess' early contribution in 2000 (with graduate student Nickson and collaborators in Bangladesh) set out their deduction, from the geochemical context and analysis of water from 46 wells in Bangladesh, that groundwater arsenic derives from reduction of arsenic-bearing iron oxyhydroxides in the sediments (**R1**). This finding demonstrated that arsenic pollution in Bangladesh is a natural phenomenon, overturning the previous consensus that arsenic enters groundwater by oxidation of arsenic-bearing pyrite in response to water-table lowering by irrigation pumping.

Extensive fieldwork and laboratory analysis of groundwater and sediment cores from West Bengal, conceived by McArthur and executed in conjunction with lead collaborator DM Banerjee (University of Delhi) and other collaborators in the UK and India (as indicated by the author lists in reference (**R2**), were conducted between 2000 and 2008. This work exposed buried peat as the main cause of the chemical reaction giving rise to severe arsenic pollution in the groundwater, and led to the development of the team's "palaeosol" model (**R2**) to propose that the current distribution of arsenic in groundwater reflects the distribution of palaeo-channels and palaeo-interfluves which developed between 125,000 and 18,000 years ago as sea-level fell and a late-Pleistocene landscape developed across the Bengal Basin. The model was potentially applicable to delta regions worldwide which host organic matter in marshland and swamp. Further research using published data from 2387 wells and 176 new analyses of groundwater along a 115km traverse across the southern Bengal Basin, demonstrated the "palaeosol" model to be applicable at scale (**R3**). As a result, it became valuable as an aid to understanding regional distribution of As-pollution, as a guide for groundwater monitoring and future groundwater development and for the avoidance of As-pollution and siting of arsenic-safe tubewells (for example across the Indus River plain and in West Bengal and Bangladesh).

Also between 2000 and 2008, Burgess worked in an equal collaboration with P Ravenscroft (consultant in Dhaka) and KM Ahmed (Dhaka University) on an interpretation of more than 3,000 groundwater analyses, supplemented by sediment core analysis and permeability measurements. Using data from these studies, they established a hydrogeological synthesis of arsenic occurrence across southern Bangladesh (**R4**). Burgess, with graduate students at UCL, then developed conceptual and numerical models to show how groundwater flow controls present-day arsenic concentration at shallow pumping wells, and to posit future trends. At basin-scale, Burgess worked with UCL research student Hoque, doctoral researcher Shamsudduha and collaborators in Bangladesh to determine the potential for deep groundwater, which is free of excessive arsenic, to provide a safe alternative water supply. Via their analysis of more than 2,000 borehole records and development of numerical models, Burgess and his collaborators described the major elements of the Bengal Aquifer System to >350m depth, its development over Plio-Quaternary time and the extent of its vulnerability to contamination by arsenic as a consequence of excessive pumping (**R5**). This evaluation underpinned recognition by Burgess and colleagues of the potential for deep groundwater to serve as a secure mitigation option throughout the Bengal Basin. Research findings were presented to Bangladeshi government authorities at workshops co-convened by the UCL team in Dhaka in 2013 and 2014, and they supported an evaluation by the UCL team, together with international partners, of groundwater depletion/security throughout the wider Indo-Gangetic Basin using a total of 3,429 in-situ observations.

Between 2013 and 2014, Burgess and collaborators made high frequency (hourly) measurements of groundwater pressure over one full hydrological year, in vertically stacked, co-located wells at six sites across southern Bangladesh, exposing for the first time the magnitude of hydro-mechanical (poroelastic) influences of surface water loads across the Bengal Basin in perturbing, and in places dominating, groundwater levels in monitoring wells (**R6**). Previously, groundwater levels have always been interpreted as determined solely by hydraulic processes. Burgess's recognition of the hydro-mechanical nature of the Bangladesh aquifer and the common dominance of mechanical processes has led to a re-evaluation of the groundwater monitoring strategy in Bangladesh.

3. References to the research (indicative maximum of six references)

R1. Nickson R, **McArthur JM**, Ravenscroft P, **Burgess WG**, Ahmed KM. (2000). Mechanism of arsenic release to groundwater, Bangladesh and West Bengal. *Applied Geochemistry*, 15, 403-413. doi.org/10.1016/S0883-2927(99)00086-4
R2. **McArthur JM**, Ravenscroft P, Banerjee DM, Milsom J, Hudson-Edwards KA, Sengupta S, Bristow C, Sarkar A, Tonkin S, Purohit R. (2008). How paleosols influence groundwater flow and arsenic pollution: A model from the Bengal Basin and its worldwide implication. *Water Resources Res.,* 44, W11411. doi.org/10.1029/2007WR006552

R3. Hoque MA, **McArthur JM**, Sikdar PK. (2014). Sources of low-arsenic groundwater in the Bengal Basin: investigating the influence of the last glacial maximum palaeosol using a 115-km traverse across Bangladesh. *Hydrogeology Journal*, 22, 1535–1547. doi.org/10.1007/s10040-014-1139-8
R4. Ravenscroft PR, **Burgess WG**, Ahmed KM, Burren M, Perrin J. (2005). Arsenic in groundwater of the Bengal Basin, Bangladesh: distribution, field relations, and hydrogeological setting. *Hydrogeology Journal,* 13, 727-751. doi.org/10.1007/s10040-003-0314-0
R5. **Burgess WG**, Hoque MA, Michael HA, Voss CI, Breit GN, Ahmed.KM (2010). Vulnerability of deep groundwater in the Bengal Aquifer System to contamination by arsenic. *Nature Geoscience*, 3, 83-87. doi.org/10.1038/ngeo750
R6. **Burgess WG**, Shamsudduha M, Taylor RG, Zahid A, Ahmed KM, Mukherjee A, Lapworth DJ, Bense.VF (2017). Terrestrial water load and groundwater fluctuation in the Bengal Basin. *Scientific Reports,* 7, 3872. doi.org/10.1038/s41598-017-04159-w

4. Details of the impact (indicative maximum 750 words)

UCL's research into arsenic pollution of groundwater and the hydrodynamics of the Bengal Aquifer System in Bangladesh has had significant impacts on policy, practice and public health security in Bangladesh, 2014-2020. UCL's research has guided the development and refinement of national policy on groundwater pumping in response to the groundwater arsenic crisis in Bangladesh and has underpinned practical approaches adopted by the Department for Public Health Engineering (DPHE) and the Bangladesh Water Development Board (BWDB) towards arsenic mitigation and groundwater monitoring. This has led to **improved public health security and security of access to safe water supplies across the region**. Key UCL research findings have been shared widely with stakeholders beyond academia, partly as a natural outcome of the collaborative nature of the research, to which Bangladesh government departments contributed through provision of access and data. The **reach of the impact was extended by Burgess co-convening successive national conferences and workshops in Bangladesh** (2013, 2014, 2017 and 2020). Furthermore, Burgess was interviewed on BBC 'Science in Action' (25/6/2017), broadcasted via the BBC World Service platform (weekly viewers 350,000,000) (**S1**). Globally, the research has contributed to the implementation of UNICEF policies relating to investigation and mitigation of arsenic contamination and to water resource security assessments by the World Bank. In India, UCL's research has **influenced the development of national guidance** for groundwater monitoring under the National Hydrology Project.

UNICEF policy and directives on arsenic pollution, and implementation of World Bank assessments

UNICEF has been a leading international provider and facilitator of mitigating actions responding to the arsenic crisis in Southeast Asia. The organisation has adopted UCL's explanation of the underlying processes and causes of groundwater arsenic in the Bengal Basin as the standard paradigm for understanding arsenic pollution in alluvial aquifers worldwide (**S2**). UCL's research provided fundamental support for UNICEF's assessment of global health impacts of groundwater arsenic, which **underpins its development of policies and directives** for its country offices. By demonstrating that the existing state of contamination in Bangladesh was both predictable and manageable, UCL's research notably **facilitated UNICEF's proposals for rational and effective responses** (**S2, S3**), which have continued to be implemented throughout the period 2014-2020. Significant projects supported by UNICEF and the World Bank since 2014, grounded in those proposals, include **implementation of the Bangladesh Government's Department of Public Health Engineering (DPHE) 15-year water supply and sanitation 'Sector Development Plan'** 2011-2025 (**S4, S5**). UNICEF Bangladesh's former Water and Environmental Sanitation Specialist stated: "UCL's arsenic programme [has] continued, to a significant degree, to **define the research and policy agenda**" (**S2**). Separately, UCL research supported the World Bank's 2019 assessment of water security in Pakistan (**S6, S7**), enabling a comprehensive review of groundwater depletion and identifying pollution as the greatest long-term risk to groundwater sustainability, with UCL's contribution acknowledged by the World Bank Senior Water Resources Management Specialist for South Asia (**S8**).

Guiding Bangladesh government policy development

The DPHE Policy Support Unit leads the development of government policy in the water supply and sanitation sector in Bangladesh. The Dhaka workshops "Deep groundwater in Bangladesh: UCL research in support of policy development" (January 2013), and "Groundwater monitoring in the Bengal Basin: research strategies and their policy implications" (November 2014), co-convened by Burgess for UCL, with Dhaka University and the DPHE-PSU, were attended by representatives of the DPHE, the Bangladesh Water Development Board (BWDB), the Bangladesh Agricultural Development Corporation, the Geological Survey of Bangladesh, the Water Resources Policy Organisation, and the donor (including UNICEF and WaterAid) and NGO communities (**S9**). The advisory "Bengal Deep Groundwater Statement 2014, Deep Groundwater in Bangladesh - a vital source of water" (**S9**), co-authored by the Workshops' attendees, is acknowledged by the DPHE to have influenced their policy decisions (**S5**) towards promoting the use of deep groundwater for water supply. The statement promotes deep groundwater as a long-term secure water source to mitigate the effects of arsenic and salinity in southern Bangladesh, identifying seven points of consensus around which policy should be framed, and making recommendations for extension of the national groundwater monitoring infrastructure. The DPHE Superintending Engineer confirms that "The outcomes [of UCL research] **continue to help shape our policies and practices** towards deep groundwater pumping across the southern Bangladesh" (**S5**).

Informing arsenic mitigation programmes

The DPHE is the Bangladesh government authority with principal responsibility for arsenic mitigation through provision of safe water supplies. UCL research has been used by the Arsenic Management Division of the DPHE to **develop deep groundwater pumping as a mitigation strategy** (**S5**). Decisions on the optimum depth of arsenic mitigation wells in the DPHE 2011-2025 WASH Sector Development Plan (**S4**) were underpinned by UCL research on the spatial and depth-distribution of the arsenic source, and the hydraulic structure of the Bengal aquifer system. The Sector Development Plan describes national strategy for the investment of approximately USD20,000,000,000 in the water, sanitation and health (WASH) sector, of which approximately USD1,750,000,000 has been managed by DPHE over the period 2014-2020 (**S5**). The DPHE Superintending Engineer acknowledges "the **very significant impact your department's [UCL Earth Sciences] research has had in the mitigation of the groundwater arsenic crisis** in Bangladesh" (**S5**).

Consensus framework for improving public health security

Deep groundwater in Bangladesh is free of excessive arsenic. The implementation of deep groundwater pumping strategies by DPHE between 2014 and 2020, through the 2011-2025 WASH Sector Development Plan (**S4**), informed by UCL research (**S5, S9**), is estimated to have reduced arsenic exposure – thereby **enhancing health, welfare and quality of life – among a combined total of some 5,000,000 people** across southern Bangladesh (**S5**). Public health security has also been protected by the UCL research finding that arsenic pollution in Bangladesh is natural, and not caused by pumping for irrigation (**R1**). This finding has helped underpin the maintenance of food-grain self-sufficiency in the country since 2000 to the present day (**S2**). In 1998, there were demands both within civil society and at ministerial level for a ban on groundwater irrigation, then thought to be the cause of arsenic pollution. UCL research since 2000 catalysed and informed public debate about the issue, supporting counter-demands that ensured the continuation of groundwater irrigation. The enduring impact of this reversal is affirmed by the former UNICEF's Bangladesh Water and Environmental Sanitation Specialist, who notes that UCL research "**created a consensus conceptual framework for understanding the problem** and, in particular, quashing demands for a blanket ban on groundwater irrigation", and "the overall impact of tubewell irrigation continues to this day to have a **massive net benefit in terms of maintaining food-grain self-sufficiency** in Bangladesh and India" (**S2**).

Influence on groundwater monitoring practice

The BWDB is the Bangladesh government authority with responsibility for monitoring the quality and quantity of the groundwater resources nationally. McArthur's research findings on the rate of

groundwater flux at the arsenic source regions, and Burgess's research on the rate of migration of arsenic towards pumping wells (**R4, R5**), alerted BWDB (**S10**) and UNICEF (**S2**) to the requirements and timescales for groundwater monitoring. Burgess's identification of the effects of aquifer poroelasticity (**R6**) further **alerted the BWDB to requirements for expansion of the national groundwater monitoring infrastructure**. The research findings also **influenced the BWDB's approach to groundwater monitoring**, in particular regarding the security of deep groundwater. It also informed their expansion of the national groundwater monitoring network, including 69 new monitoring points since 2019 [and continuing] and 905 piezometers selected for automation (**S10**). BWDB continues to **appraise the design of its national deep groundwater monitoring programme in light of UCL research**, most recently through consultation at the UCL-convened workshops "Aquifer poroelasticity in Bangladesh: observations, modelling and implications for groundwater resources monitoring" (February 2017), and "Implications of aquifer poroelasticity for groundwater levels: what groundwater managers in Bangladesh need to know" (January 2020), both in Dhaka. According to the BWDB Director [of Ground Water Hydrology], "Over the past two decades…excellent fundamental research of the [UCL Earth Sciences] Department…helped the BWDB develop its approach to groundwater investigation and monitoring. At the 2017 and 2020 Workshops in Dhaka, guiding principles for groundwater monitoring in Bangladesh were proposed and re-affirmed by the wider community of…water managers in Bangladesh, leading to **installation of clustered [monitoring] wells at 69 new locations all over the country…and 905 piezometers…selected for automation**" (**S10**). In India, UCL research on poroelasticity has influenced the Central Ground Water Board (CGWB) and National Institute of Hydrology (NIH), through a Guideline document accepted by the National Hydrology Project in India being supplied to all State groundwater agencies (**S2**).

5. Sources to corroborate the impact (indicative maximum of 10 references)

S1. BBC World Service Platform viewership – corroborates estimated reach of the Professor Burgess's interview on 'Science in Action'.
S2. Correspondence from the former Water and Environmental Sanitation Specialist, UNICEF Bangladesh – corroborates the impact on UNICEF policy design, the continuing benefits of UCL's role in preventing a ban on groundwater irrigation in Bangladesh, and the influence on groundwater monitoring practice.
S3. The Arsenic Primer - Guidance on the Investigation and Mitigation of Arsenic Contamination, UNICEF, New York (2018) – UCL research influenced chapters 1, 2 and 7.
S4. Sector Development Plan, 2011-2025. DPHE-PSU – evidences the decisions made by the DPHE on the optimum depth of arsenic mitigation wells (supported by the UCL research), e.g. see pages 33-34 and 49-50.
S5. Correspondence from the Superintending Engineer, DPHE – corroborates the influence and impact of UCL research on DPHE deep groundwater pumping mitigation actions.
S6. Pakistan: Getting More from Water. Water Security Diagnostic. World Bank, Washington DC (2019) – evidences assessment of water security in Pakistan.
S7. Groundwater in Pakistan's Indus Basin: Present and Future Prospects. World Bank, Washington, DC (2021) – evidences assessment of water security in Pakistan. UCL research influenced chapter 3.
S8. Correspondence from the World Bank Senior Water Resources Management Specialist for South Asia – corroborates UCL's research in aiding the World Bank's assessment of groundwater in the Indus River and Indo-Gangetic basins.
S9. The Bengal Deep Groundwater Statement 2014. Deep Groundwater in Bangladesh: a vital source of water. Appendix to Workshop papers, 'Groundwater monitoring in the Bengal Basin: research strategies and their policy implications' (November 2014) – corroborates that UCL research informed the development of an advisory policy statement.
S10. Correspondence from the Director (Ground Water Hydrology), Bangladesh Water Development Board (BWDB) – corroborates the contributions of UCL research to BWDB's approach to groundwater monitoring (specifically deep groundwater security).