

## **The vulnerability of the Dupi Tila aquifer of Dhaka, Bangladesh**

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**Abstract** Dhaka relies almost exclusively on groundwater for its water supply. Intensive abstraction from the Dupi Tila aquifer has led to induced recharge from rivers and enhanced vertical leakage from regions containing contaminated land. Low quality water has invaded the aquifer from a polluted stretch of river. Vertical hydrochemical profiles show that urban pollution has reached the upper levels of the aquifer within the city, but not the level of groundwater abstraction except in isolated cases. The aerobic environment of the aquifer may support the natural attenuation of contaminants. Contaminant transport modelling demonstrates that a general deterioration of groundwater quality is inevitable even if all sources of contamination are removed immediately. The model could be used to guide groundwater quality monitoring as part of a protection policy for this strategically important aquifer. A programme of waste management should be based on factors identified as governing aquifer vulnerability.

### **INTRODUCTION**

#### **Groundwater development from the Dhaka aquifer**

Dhaka, the capital city of Bangladesh, relies on groundwater from Plio-Pleistocene fluvio-deltaic sands of the Dupi Tila Formation for 95% of its water supplies. The Dupi Tila sands form an aquifer system divided into an upper and lower layer by a discontinuous clay. The aquifer is overlain and was originally confined by the Pleistocene Madhupur Clay, and by more recent organic-rich alluvial sands and clays of the Bashabo Formation in the lower-lying regions adjacent to the major rivers bounding the city (Fig. 1). Direct recharge to the aquifer is therefore largely prevented. Nevertheless, the aquifer is very productive. Public water supply (PWS) boreholes have been installed to depths of 120–180 m in the lower part of the aquifer system. The aquifer transmissivity is typically  $500\text{--}2000\text{ m}^2\text{ day}^{-1}$  and individual borehole yields of  $50\text{ l s}^{-1}$  are common. Moreover, groundwater from the Dupi Tila sands is of very high quality; the background total dissolved solids content (TDS) is generally less than  $150\text{ mg l}^{-1}$ .

Until recently this excellent aquifer enabled the staged development of water supply to Dhaka, reliable in both quantity and quality. At the time of the Independence of Bangladesh in 1971, the population of Dhaka was less than 2 million and

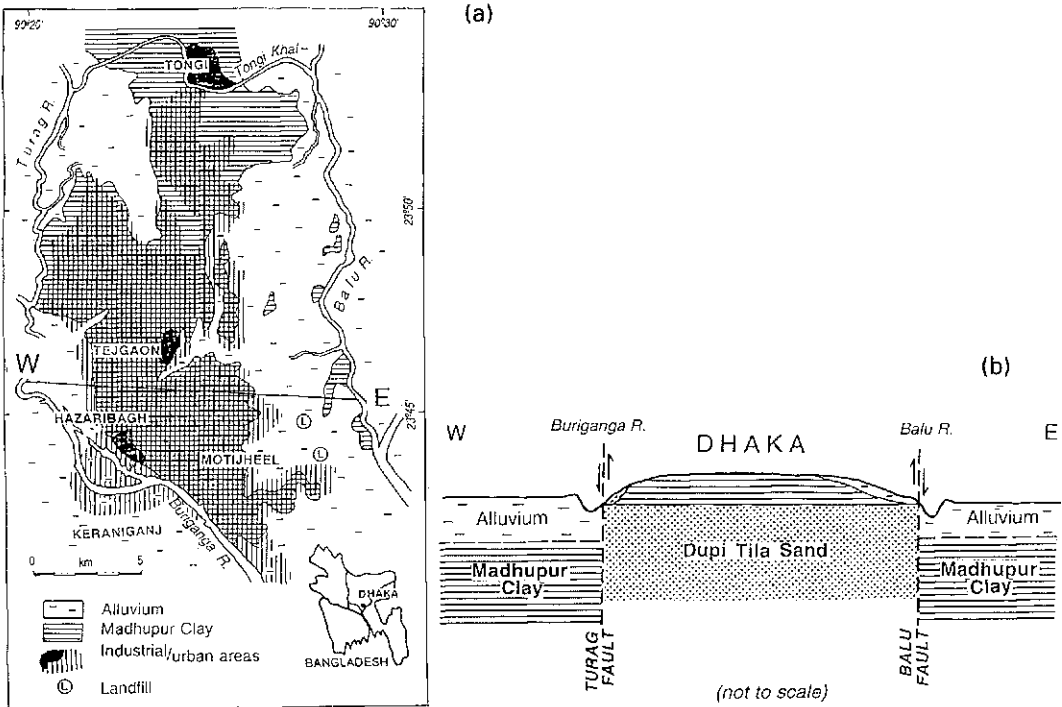
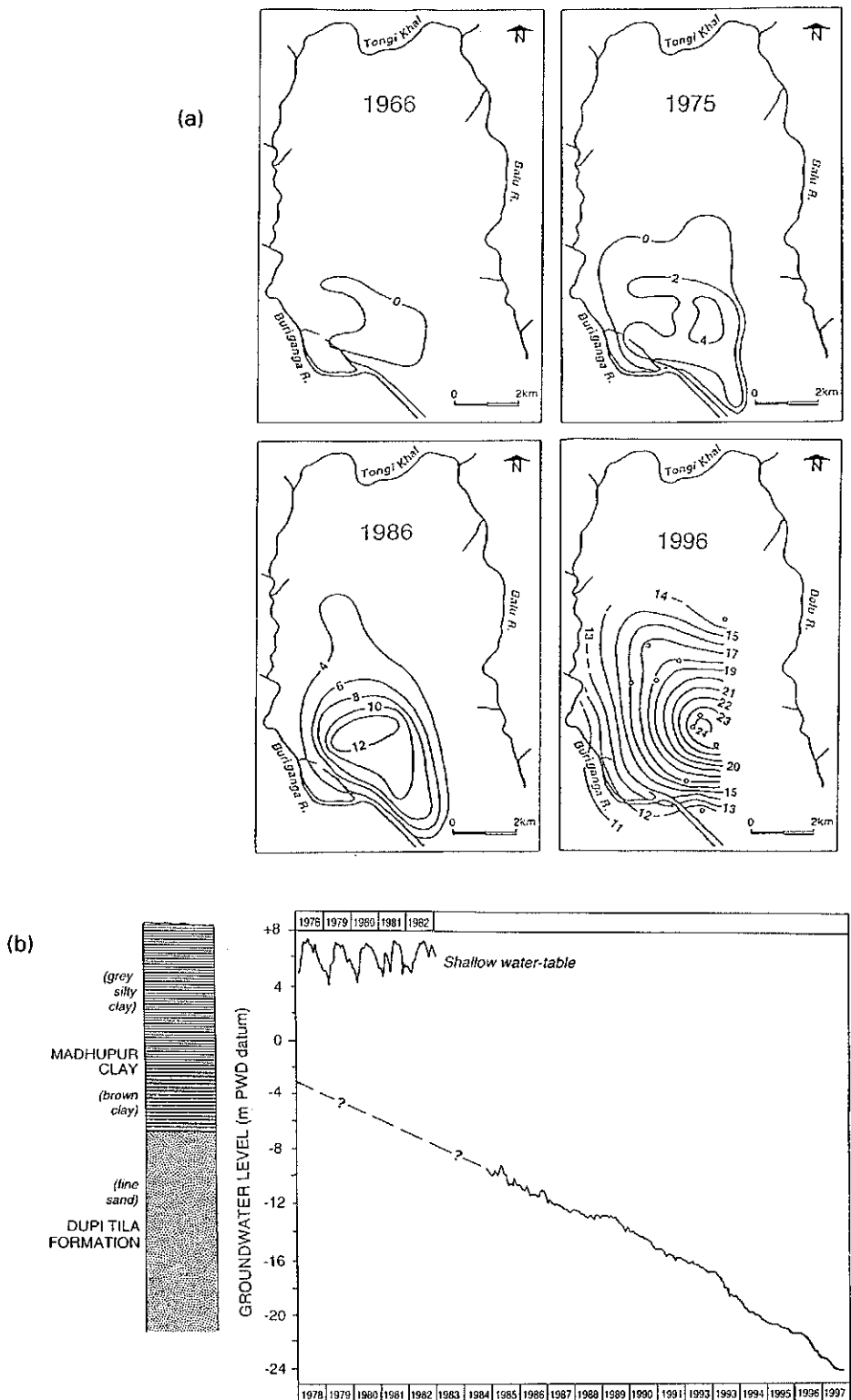


Fig. 1 Dhaka urban area (a) and a W-E geological cross-section (b).

groundwater abstraction was less than  $50 \text{ Mm}^3 \text{ year}^{-1}$ . The population has increased to 9 million since that time and groundwater abstraction has increased disproportionately to over  $330 \text{ Mm}^3 \text{ year}^{-1}$ . Progressive groundwater development has resulted in a continuous decline of piezometric levels in the aquifer (Fig. 2), which has become unconfined over much of the city (Ahmed *et al.*, 1999), and modification of the recharge regime. Significant drawdowns extend to the large rivers which bound the city and which in places have direct contact with the aquifer. Downward vertical hydraulic gradients have increased, and the recharge to the aquifer from vertical leakage has been enhanced.

The sustainability of future groundwater abstraction will depend on the ability of induced river recharge and enhanced vertical leakage to balance the increasing abstraction. This is in doubt as piezometric levels in the aquifer continue to decline at  $1 \text{ m year}^{-1}$  on average (Fig. 2). It appears inevitable that a large-scale surface water supply scheme will become necessary in the near future. Under this scenario, the importance of the Dupi Tila aquifer would be as a source of high quality water for emergency and strategic use. Protection of the aquifer therefore remains a priority. The purpose of this paper is to show the vulnerability of the Dhaka aquifer to the separate effects of induced river recharge and enhanced vertical leakage, and the relative significance of each contaminant source determined by modelling. Results of the modelling have implications for aquifer protection, monitoring priorities and likely future trends in groundwater quality.



**Fig. 2** Piezometric trends in the Dhaka aquifer. (a) Piezometric contours (m below sea level, the Public Works Datum, PWD) 1966–1996. (b) Hydrograph of a monitoring borehole, central Dhaka.

### Sources of pollution to the aquifer

Expansion of Dhaka has been accompanied by industrialization, chiefly in the south-western, south-central and northern parts of the city (Fig. 1) where tanning, dyeing, metal working and engineering activities are concentrated. Solid industrial and domestic wastes are deposited within the city in unlined landfills where there is no provision for leachate management and monitoring. The sparse data available demonstrate that shallow groundwater is polluted by landfill leachate in places (Ahmed *et al.*, 1995). Untreated liquid industrial effluents and many foul sewers drain via canals directly to the River Buriganga. The main drain to the River Buriganga for industrial effluents, sewerage and urban run-off has an electrical conductivity ( $E_c$ ) of  $10\,000\ \mu\text{S cm}^{-1}$  (DoE, 1993), an indication of its heavy pollutant load. Comparison of river bed elevations with the top of the Dupi Tila sands demonstrates that direct contact between the River Buriganga and the aquifer is possible along certain reaches (Hasan *et al.*, 1998a). The Madhupur clay has been observed to be absent in site-investigation boreholes drilled at a bridge construction site in the southwest of the city. It is possible that contact between the rivers and the aquifer is more extensive than this. The Bashabo Sands within the river floodplains might directly overlie the aquifer, but the extent of the overlap is unknown in detail. However, there is clearly the potential for induced recharge of low quality river water to pollute the aquifer, especially in the southwest where the river pollution is most extreme.

These sources of pollution raise the issue of the vulnerability of the Dhaka aquifer to contamination. Until recently little was known about the spatial variability of the quality of groundwater which is only periodically monitored by the Bangladesh Water Development Board (BWDB), at two boreholes. In central Dhaka, nitrate has increased from less than  $1\ \text{mg l}^{-1}$  to over  $20\ \text{mg l}^{-1}$  during the past 15 years (Burgess *et al.*, in press). No other monitoring data exist for specific contaminants of concern to health, but a recent reconnaissance survey has demonstrated the presence of a range of hydrocarbons and chlorinated hydrocarbons (principally benzene and trichloroethylene) beneath the Tejgaon industrial area (Hasan *et al.*, 1998b). Occasional more extensive surveys of inorganic groundwater quality (Ahmed *et al.*, 1999) demonstrate an apparently progressive movement of lower quality water into the aquifer from the southwest (Fig. 3(a)). A possible cause is induced recharge of water from the River Buriganga, but this is also the site of the old industrial area of Hazaribagh. There is significantly greater contamination at shallower levels ( $E_c$  up to  $1500\ \mu\text{S cm}^{-1}$ ) than at the depths of the PWS boreholes (maximum  $E_c$   $600\ \mu\text{S cm}^{-1}$ ), particularly beneath areas of the city where industry and landfilling are concentrated (Fig. 3(b)). It seems likely that there will be further deterioration of the quality of groundwater pumped from the aquifer for public water supply as water from these shallower, more polluted levels is drawn downwards under the vertical gradients enhanced by intensive abstraction. The declining quality of water pumped from the aquifer is likely to be due to the combined effects of induced river recharge and vertical leakage through areas of contaminated ground. The timing and impact will depend on the groundwater flow rates and solute fluxes.

A solute transport model of the aquifer system has been developed to investigate the relative importance of these two main sources of pollution. The transport model is

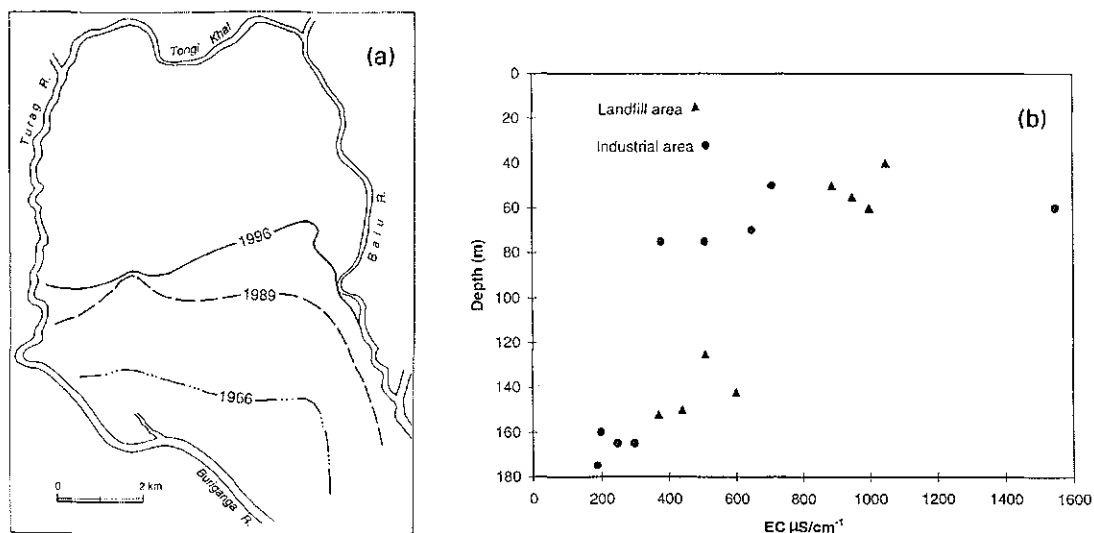


Fig. 3 Groundwater quality trends in the Dhaka aquifer. (a) The  $300 \mu\text{S cm}^{-1}$  Ec contour, 1966–1996. (b) Vertical profiles of Ec in the aquifer.

based on a groundwater flow model calibrated against the observed piezometric response of the aquifer to pumping since 1964 (Burgess *et al.*, in press).

## MODELLING CONTAMINANT TRANSPORT IN THE DHAKA AQUIFER SYSTEM

### Groundwater flow

Groundwater flow modelling represented the aquifer system as four layers, using the MODFLOW code (McDonald & Harbaugh, 1988), and including the rivers as head-dependent boundaries in the upper aquifer layer where appropriate. This enabled a calibrated water balance to be achieved (Burgess *et al.*, in press). The validity of the conclusions rely on the realistic representation of the rivers within the model, and many difficulties remain in modelling river boundaries (Winter *et al.*, 1998). For the Dhaka aquifer the methodological difficulties are compounded (Hasan *et al.*, 1998a) by:

- paucity of piezometric data beyond the river boundaries;
  - lack of data on the extent and permeability of the river bed sediments;
  - incomplete knowledge of the extent of the Bashabo Sands/Dupi Tila sands contact.
- Furthermore, there remain the uncertainties inherent in modelling recharge in the urban environment; the distribution of recharge across the urban area of Dhaka is unknown in detail. Nevertheless, the groundwater flow model indicates the vulnerability of the aquifer under conditions of the modified recharge regime. The contribution of induced recharge from the Buriganga and Turag rivers to the aquifer water balance is calculated (for 1994) as 30% ( $104 \text{ Mm}^3 \text{ year}^{-1}$ ). This represents a relative as well as an absolute increase from less than 13% contribution from river recharge in 1966. Recharge

through the Madhupur Clay, of which about half is through the urban area which contains contaminated ground, contributes 66% (228 Mm<sup>3</sup>).

### Contaminant transport in the Dhaka aquifer

The USGS particle tracking code MODPATH (Pollock, 1994) has initially been used to calculate particle movement and travel times within the calibrated steady-state groundwater flow field generated by MODFLOW. To demonstrate the flow paths and travel times, hypothetical particles have been placed in the upper levels of the groundwater flow system (i.e. within the Madhupur Clay) close to the influent river boundary of the River Buriganga and elsewhere within the urban area.

The results (Table 1) show that the PWS boreholes are most vulnerable in the short term to contamination from induced river recharge. In the longer term (i.e. after 10–15 years) contaminants from leakage through the industrial, landfill and urban areas would be expected to reach the levels of abstraction of the PWS boreholes. These MODPATH simulations provide a demonstration of the aquifer vulnerability to contamination in general. Incorporation of solute dispersion, sorption and degradation into a contaminant transport model will allow a more specific and detailed examination of threats posed by contaminants in the future, and forecasts of the likely scale of groundwater quality deterioration.

**Table 1** Transport times for contaminants entering the aquifer.

Source	Particle transport times (years):	
	To base of Madhupur Clay	To PWS boreholes
Buriganga (SW Dhaka)	n/a	5
Hazaribagh industrial area	3	>15
Landfill area (SE Dhaka)	3	>15
Urban Dhaka (central region)	2	>10

## DISCUSSION: PROTECTING THE GROUNDWATER RESOURCES OF DHAKA

Despite the vulnerability of the aquifer, our survey of the groundwater quality shows the overall effect of contamination is limited at present. Oxygen is present in the groundwater at 10 to 70% saturation at the depths of the PWS boreholes. The aerobic environment may create a capacity for the degradation of hydrocarbon contaminants and the immobilization of toxic metals. For example, benzene has been identified in a preliminary survey, but its occurrence appears restricted (Hasan *et al.*, 1998b). Arsenic, a widespread contaminant associated with reducing groundwater conditions across large regions of southern Bangladesh (Nickson, 1997) is present at concentrations less than 3 µg l<sup>-1</sup> throughout the Dhaka aquifer. Whether this is primarily due to the absence of As-rich oxyhydroxides in the Dupi Tila sediments, as well as the aerobic environment induced in the aquifer, is not yet clear.

Nevertheless, it has been shown that as a result of intensive groundwater development in recent decades, the Dhaka aquifer is vulnerable in the short term to

contamination, albeit limited, entering in induced river recharge, and in the longer term to contamination in the vertical leakage from the urban and industrialized areas. If the high quality of the Dupi Tila groundwater is to be maintained and the aquifer is to be managed as a strategically important resource, a protection policy is required. This should include measures to minimize the entry of pollutants into surface water and the sub-surface, and a much-expanded programme of monitoring groundwater quality. Field observations and the results of modelling demonstrate that, to be effective, monitoring should be depth-specific, and should include boreholes in the shallow Madhupur clay and the upper parts of the Dupi Tila aquifer, as well as at the depths of abstraction for public water supply. Furthermore, monitoring should initially be focused close to the influent stretches of the rivers, particularly the River Buriganga in the southwest, and at the major industrial sites and landfills. Monitoring should target specific classes of contaminants, including total hydrocarbons and total chlorinated hydrocarbons, as well as the particular compounds whose presence has been identified. General indicators of inorganic contamination should be determined routinely, with complete inorganic analyses, including trace constituents, regularly completed. The solute transport model of the aquifer provides the framework within which the results of monitoring could be judged.

**Acknowledgements** MKH acknowledges a scholarship from the Commonwealth Commission (UK). The groundwater flow model was initially developed using a database provided by Jan van Wonderen of Mott MacDonald (UK) Ltd. Groundwater chemical analysis was carried out at the Wolfson Laboratory in the Department of Geological Sciences and at the NERC ICP-AES laboratory at Royal Holloway College, University of London; we thank Mr A. T. Osborne and Ms S. Paige (inorganic analyses), and Ms H. Prince (organic analyses) for assistance.

## REFERENCES

- Ahmed, K. M., Hasan, M. K., Burgess, W. G., Dottridge, J., Ravenscroft, P. & van Wonderen, J. (1999) The Dupi Tila aquifer of Dhaka, Bangladesh: hydraulic and hydrochemical response to intensive exploitation. In: *Groundwater in the Urban Environment: City Case Studies* (ed. by P. J. Chilton). Balkema, Rotterdam.
- Ahmed, K. M., Hasan, M. A., Chowdhury, S. Q., Sharif, S. U., Haque, M. E. & Hossain, A. T. M. S. (1995) Urbanisation and geohazards: Dhaka scenario. In: *Geohazards and Engineering Geology* (ed. by J. G. Maund, S. Penn & M. G. Culshaw) (Proc. 31st Annual Conf. Engng Geol. Group of Geol. Soc. London, Coventry, UK), 327–336. Geol. Soc. London.
- Burgess, W. G., Ahmed, K. M., Hasan, M. K., Dottridge, J., Ravenscroft, P. & van Wonderen, J. (in press) The Dupi Tila sands of Dhaka, Bangladesh: the effects of intensive groundwater development on an urban aquifer. *Hydrogeol. J.*
- DoE (Department of the Environment) (1993) Water quality data of Rivers Buriganga, Meghna, Balu, Sitalakhya, Jamuna (1981–1990). Government of Bangladesh, Dhaka.
- Hasan, M. K., Burgess, W. G. & Dottridge, J. (1998a) Hydraulic and hydrochemical implications of river-aquifer interaction, Dhaka, Bangladesh. In: *Gambling with Groundwater - Physical, Chemical and Biological aspects of aquifer-stream relations* (ed. by J. van Brahana *et al.*) (Proc. Joint Meeting XXVIII Congress of IAH and Annual Meeting American Institute of Hydrologists, Las Vegas, Nevada, September 1998), 413–418.
- Hasan, M. K., Burgess, W. G., Dottridge, J. & Ahmed, K. M. (1998b) Impact of intensive exploitation on groundwater quality in the Dhaka aquifer, Bangladesh. Abstract in: *Proc. Geoscience and Urban Development Seminar* (Dhaka, Bangladesh, February 1998).
- McDonald, M. G. & Harbaugh, A. (1988) A modular three-dimensional finite-difference groundwater flow model. *USGS Techniques of Water Resources Investigation. Book 6*, Chapter A1.
- Nickson, R. (1997) Origin and distribution of arsenic in groundwater, central Bangladesh. MSc Thesis, University College London, London.

- Pollock, D. W. (1994) Users Guide for MODPATH, version 3: A particle tracking post-processing package for MODFLOW. *USGS Open-file Report 94-464*.
- Winter, T. C., Harvey, J. W., Franke, O. L. & Alley, W. M. (1998) Ground water and surface water: a single resource. *USGS Circular no. 1139. Denver, Colorado*.