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Groundwater dynamics and arsenic contamination in Bangladesh

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Abstract

Although arsenic contaminated groundwater in Bangladesh is a serious health issue, little is known about the complex transient patterns of groundwater flow that flush solutes from aquifers and carry solutes into the subsurface. Hydrologic modeling results for our field site in the Munshiganj district indicate that groundwater flow is vigorous, flushing the aquifer over time-scales of decades to a century, and also transporting solute loads into the aquifer with recharge from ponds, rivers and rice fields. The combined hydrologic and biogeochemical results from our field site imply that the biogeochemistry of the aquifer system may not be in steady-state, and that the net effect of competing processes could either increase or decrease arsenic concentrations over the next decades. Modeling results suggest that irrigation has greatly changed the location, timing and chemical content of recharge to the aquifer, flushing water through the system more quickly, and also cycling large fluxes of water through rice fields during the dry season that could mobilize arsenic from oxides in near-surface sediments. Furthermore, the hydrologic model reveals that ponds, many of which have been excavated over the last 50 years, now provide much of the groundwater recharge. These ponds receive most of the waste from the villages and thus provide another potential source of organic carbon to the groundwater system.
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1. Introduction

Over the last 45 years most of the population of Bangladesh and West Bengal switched their water supply from ponds and rivers to well water. As many as 10 million new domestic wells have been installed, providing drinking water for over 130 million people. Tragically, much of the region's groundwater is dangerously contaminated by arsenic and approximately 57% of these people now drink water with arsenic concentrations above 10 ppb, the standard of the World Health Organization (Yu et al., 2003). Irrigation wells, mostly extracting from the shallow aquifer, were installed across the country concurrent with this transition of the domestic water supply. According to BADC (2003), a total of 924,023 shallow tubewells and

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23,434 deep tubewells were used for irrigation in Bangladesh during the 2003 dry season. Groundwater irrigation greatly increased agricultural production enabling Bangladesh to become self-sufficient in food even though the population nearly tripled over the last four decades. Irrigation now sustains production of dry-season rice called Boro, which provides greater yields than the traditional rice grown during the wet season (Fig. 1). During the 2003 dry season, about 87% of the total irrigated area of about 4 million hectares (about 28% of the total area of the country) was under Boro cultivation and Boro accounted for about 49% of the total rice production (MoA, 2004). Thus, issues of groundwater quality and quantity have become vital for both the supply of drinking water and the production of food in Bangladesh.

A wide range of evidence indicates the importance of groundwater flow to the subsurface biogeochemistry in Bangladesh, however little work has been directed towards understanding the physical groundwater system. The hydrogeologic characterization that has been conducted across Bangladesh is small relative to that conducted at groundwater contamination sites in the US where groundwater is not used for drinking. This paper focuses on how groundwater flow and solute transport through Bangladeshi aquifers affects arsenic concentrations. We first describe the biogeochemical processes that control the aqueous/solid phase partitioning of arsenic in Bangladesh, and consider possible explanations for observed vertical profiles of chemical parameters within the aquifers. We then discuss the processes that drive groundwater flow in Bangladesh by analyzing hydraulic data we have collected from our field site in Munshiganj, which includes detailed diurnal and seasonal hydraulic head cycles, as well as seasonal water levels in ponds, rice

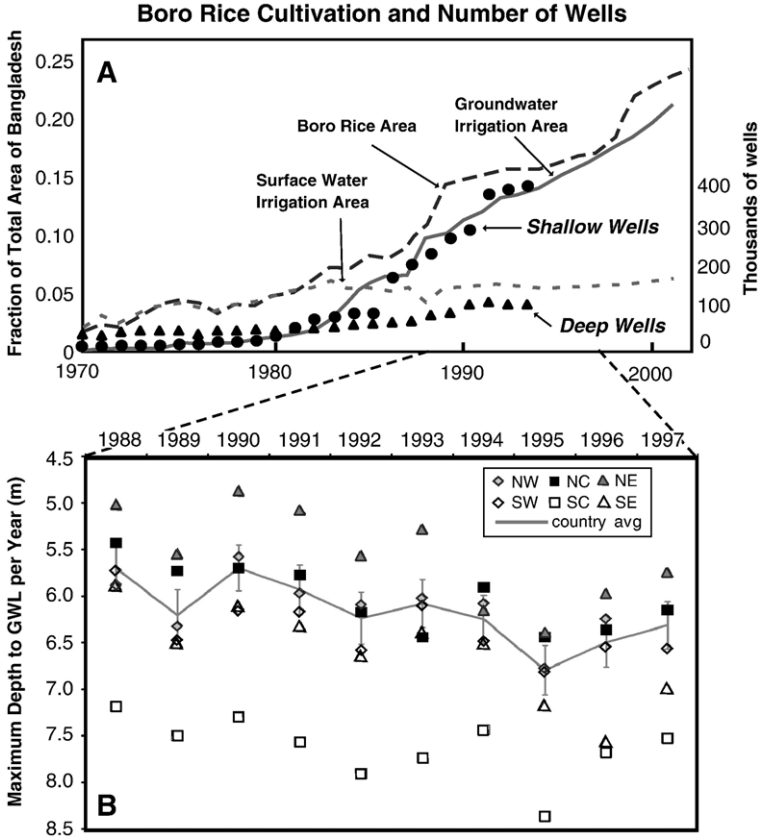

Fig. 1. (A) Cultivation of high-yielding boro rice has greatly expanded since 1970 to cover approximately 20% of Bangladesh, or approximately 45% of the cultivatable area. Most boro is irrigated by groundwater so extraction has also risen. Data taken from Hossain et al. (2003). (B) Yearly maximum depth to groundwater in wells between 1988 and 1997 (data source: WARPO, 2000). The filled and unfilled symbols represent the average yearly maximum depths in six geographic regions of Bangladesh: the north and south, divided into east, central and west sections. The solid line represents the country average of yearly maximum depths. Error bars represent the standard error of the mean (standard deviation divided by square root of $n-1$). The country average, as well as all the hydrologic regions, has a pattern of increasing maximum depths.

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