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The impact of irrigation development on regional groundwater resources in Bangladesh

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ABSTRACT

There is increasing concern over falling groundwater levels in some areas of Bangladesh, and there is undoubted overuse of groundwater in the Barind Tract in northwest Bangladesh and around Dhaka. However, the volumes of water availability and use, and hence the sustainability of use, are not well known. We developed monthly water balances for the main regions of Bangladesh to investigate historic trends in water use and availability and possible future trends under changed management to lessen groundwater use by using more surface water for irrigation. Our results show that for many areas the fall in pre-monsoon groundwater levels (at the regional average level) over the last few decades may be largely explained by the continual withdrawal of ever greater volumes of water with the three-fold increase in the area of irrigation. Thus, for many areas, if there were no further increase in the area irrigated by groundwater, the rate of decline in groundwater levels would likely reduce and levels could even attain a new equilibrium at a lower level, implying that current pumping rates could be maintained (subject to the lower groundwater levels being acceptable on environmental, economic and social grounds). Post-monsoon groundwater levels are largely influenced by yearly rainfall variability. Thus, groundwater use in some areas may not be as unsustainable as feared, and policies to reduce groundwater use in such areas may not be as necessary or urgent as thought. However, our analysis is approximate and detailed local studies are required to assess the sustainability of use.

1. Introduction

In many parts of the world, irrigation is critical to food security, and groundwater use has increased in recent years to become a major source for irrigation water, especially in China and South Asia (Shah et al., 2007; Siebert et al., 2010). In many areas of intensive use, there are concerns about overuse of groundwater and falling groundwater levels.

Bangladesh is a case in point. Groundwater irrigation, particularly of dry season *Boro* rice, has increased greatly over the last few decades and is central to the food security of the country (Mainuddin and Kirby, 2015). The principal supply of groundwater for irrigation is from shallow tubewells, the numbers of which have grown from around 100,000 in the early 1980s to more than 1.5 million today (Qureshi et al., 2014). However, falling groundwater levels in some areas have led to concerns about unsustainable groundwater use. Shamsudduha et al. (2009), Shahid and Hazarika (2010), Kirby et al. (2013), Ahmad et al. (2014) and Alam (2015) concluded that the use of shallow aquifers for irrigation in the Barind area of northwest Bangladesh is unsustainable. Rahman and Roehrig (2006) used a numerical groundwater model to analyse the water balance for the Barind area of northwest Bangladesh, and showed that recharge is insufficient in some parts of the area. While the recharge may have been just sufficient prior to 2006 in some areas, continued development of irrigation presumably means that more of the area has since fallen into the category of insufficient recharge, and the situation overall is thus becoming more unsustainable. Groundwater extraction for urban and industrial use around Dhaka is also unsustainable (Hoque et al., 2007), though the overall urban and industrial groundwater use is small relative to use in irrigation with a total urban and industrial water use of around 3 billion cubic metres (bcm) compared to a total irrigation water use of around 30 bcm (CSIRO et al., 2014). Ali et al. (2012) suggest that falling water levels in the northeast of Bangladesh are also due to excessive use of groundwater.

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However, it is not clear that use is unsustainable in the sense of continuing and ultimately catastrophic or irreversible decline in most areas of Bangladesh. Shamsudduha et al. (2011) show that recharge is less than potential recharge except in the western extreme of Bangladesh. Islam et al. (2014) concluded that there was no shortage of groundwater in part of the northwest region and that the current use of water is only about two-thirds of the safe yield.

A water balance, or water account, is generally regarded as fundamental to the understanding of water availability in a region and hence to the development of sustainable policies and plans for water management (Molden and Sakthivadivel, 1999). Zhu et al. (2004) compared water accounts for the Yellow River Basin and showed that declining runoff combined with little unused water will make it hard to set aside water for ecological and sediment flushing needs. Ahmad et al. (2005, 2007) and Karimi et al. (2013) used water accounts to assess the sustainability of groundwater and surface water use in the Indus Basin in Pakistan, with overuse of groundwater and low water productivity cited as amongst the main water resource management issues. Humphreys et al. (2010) used a water balance to show that the groundwater use and declining water levels in northwest India are unsustainable, and suggested improved management techniques to arrest the decline. Similarly, Peranginangin et al. (2004) used a water account to suggest means of augmenting the limited dry season water supply in the Singkarak–Ombilin River basin in Indonesia.

The water accounts of Molden and Sakthivadivel (1999), ABS (2004), Lenzen (2004) and Karimi et al. (2013) are static water accounts based on a single year, usually an average year. In contrast, Kirby et al. (2010) developed dynamic monthly water balances for several river basins in developing countries in order to understand the potential impacts on future water use of constraints (such as the impact of climate change), opportunities (such as increased diversions for irrigation), and trade-offs (such as changed land use improving dryland productivity but leaving less water for downstream use).

However, notwithstanding the usefulness of a water balance and concerns over unsustainability, the overall water balance for Bangladesh is not well known. An early water balance for Bangladesh (called East Pakistan at the time) by Khan and Islam (1966) focussed on rainfall and soil moisture. They noted that soil moisture was in deficit in the dry season particularly in the west of Bangladesh, whereas rain exceeded the soil storage capacity in the wet season leading to runoff. The National Water Management Plan (WARPO, 2000) is the main source of water balance information to date. However, it does not give a comprehensive water balance: it treats the groundwater and surface water separately, and does not give the exchange between the two; much of the discussion is in terms of demand rather than actual use, and surface water is often given in terms of dependable flows rather than the actual amount of water available and its variation from wet to dry years.

Our purpose in this paper is to address the two key knowledge gaps identified above. We first develop water balances for five regions of Bangladesh which cover the whole of the country except for the Eastern Hill Tract region in the south east, to provide an overall assessment of water availability and use. We then use the water balances to assess the relative contributions of groundwater pumping and rainfall variation to the observed declines in the groundwater level. In particular, we assess whether the observed declines at the regional level are due to groundwater pumping for irrigation, or due to rainfall declines in recent years, or both. As we will show, this provides us with some new perspectives on sustainability of groundwater use, though it does not (and a simple regional model cannot) fully resolve sustainability and safe levels of groundwater use. Finally, we assess the potential for greater use of surface water to address concerns over groundwater sustainability.

Fig. 1. The regions of Bangladesh and the main rivers referred to in this paper.

2. Regional water balance modelling method

We calculated monthly water balances for the 26 year period from 1985 to 2010 for five regions as shown in Fig. 1. (In many studies, such as Qureshi et al., 2014, the southwest region is split into a southwest and a south central region. However, the river modelling available to us lumped the southwest and a south central region together, and we have used this lumped region in this study.) The three main rivers, the Jamuna (the name of the Brahmaputra in Bangladesh), Padma (the name of the Ganges in Bangladesh) and Meghna are at the boundaries of regions for some or all of their length in Bangladesh, and are not included in the regional water balances, though exchange of water from the regions to the rivers is included. The overall water balance comprised three linked water balances, a surface water balance, a shallow groundwater balance and a river water balance; we discuss each in turn below. In what follows, for clarity we drop time indices from the equations except where it is necessary to show the updating of stores from one monthly timestep to the next.

2.1. Surface water balance

The surface water balance is calculated separately for each district (a second level administrative unit in Bangladesh) in each region; there are 64 districts in Bangladesh. The water balance model is shown conceptually in Fig. 2. Within each district, the water balance is calculated separately for irrigated and non-irrigated land. For non-irrigated land the withdrawal of water from the capillary fringe (shown in Fig. 2) is assumed to be important, as discussed below, but the process is assumed not to be important in irrigated areas. For non-irrigated land the withdrawal of groundwater by pumping for irrigation is absent. The areas of irrigated and non-irrigated land change throughout the year.

The water balance of non-irrigated land is calculated through a simple catchment rainfall-runoff model, described below. Evapotranspiration from the non-irrigated parts of the landscape remains high even in the driest part of the year (Ahmad et al., 2014). The landscape is underlain in most places by shallow groundwater; observed regional average water levels depths vary from about 2