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Research paper

Sustainability of groundwater use for irrigation of dry-season crops in northwest Bangladesh

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ABSTRACT

Groundwater is the main source of irrigation for modern rice varieties in many countries including Bangladesh. However, this important resource is being over-exploited and depleted beyond natural replenishment of aquifers from rainfall and river flow. The aim of the study is to formulate policies by identifying key factors constraining sustainable use of groundwater for irrigation in the context of maintaining food security in the northwest Bangladesh. Both primary and secondary data considering environmental, social and economic aspects were used for assessing sustainability of groundwater use for irrigation. Analysis revealed a declining trend of groundwater table in the northwest Bangladesh during 1981–2014, where the most depleted groundwater table was in Rajshahi followed by Pabna, Bogra, Dinajpur, and Rangpur district. The magnitude of depletion of groundwater table in Rajshahi district was 4–12 m during 1981–2014. The major influencing factors for natural replenishment of aquifer such as, total annual rainfall significantly reduced by about 25.6% during 1981–2014; average annual river water levels slightly declined; wetland areas significantly reduced by about one-third; while the area irrigated for dry season rice (*boro*), the main driver of groundwater depletion, has increased about three folds during 1981–2014. Efficient irrigation management practices, such as low water demanding high value crops, volumetric water charging system, wet and dry irrigation system, etc. can be introduced widely to reduce excessive withdrawal of groundwater. Efficiency of existing water lifting devices including STW and DTW can be enhanced for increasing command area, and discouraged for new installation of tubewell. Bangladesh has recently experienced moderate rainfall during September-October. If the *boro* rice transplantation is completed by November, *boro* cultivation may benefit from late-monsoon rains and place less pressure on groundwater resources.

1. Introduction

Globally, irrigated agriculture is the largest abstractor and predominant consumer of groundwater resources (Foster and Shah, 2012; Foster and Garduño, 2013), but its sustainable use has become a major concern in many parts of the world. Irrigation is the most important water use sector accounting for about 70% of the global freshwater withdrawals (WWAP, 2016) and for more than 90% of total consumptive water use (Doll, 2009). Groundwater is an important resource for ensuring food security of billions of people, especially in parts of Asia including India, Northern Sri Lanka, the Pakistani Punjab, Bangladesh, and the Northern China Plain, where shortage and inconsistencies in surface water supplies has resulted in huge reliance on groundwater as the mainstay for agriculture (Qureshi et al., 2015). Although groundwater use for irrigation is significant and increasing, in many regions, declines of the groundwater table have been reported with reductions of river base flow and over-exploitation of groundwater storage at rates above groundwater recharge; triggering associated impacts on aquatic ecosystems (Siebert et al., 2010).

Groundwater is the main source of irrigation for crop production in

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Bangladesh, and ground and surface water are known to be interdependent. Agriculture is important to the economy of Bangladesh, and over two-thirds of cultivatable land is cropped two or more times each year (FAO, 2015). This is mainly due to the availability of groundwater for irrigation, which has provided opportunities to farmers to increase cropping intensity and almost continuously produce improved rice varieties, which have been developed by national research institutions in collaboration with the international agricultural research centers. This increased groundwater accessibility resulting from the expansion of deep and shallow tubewells has helped Bangladesh attaining near self-sufficiency in rice, with national output increasing over 15 million tons in the last two decades (Qureshi et al., 2015). Irrigation was institutionalized under the auspices of the Bangladesh Agricultural Development Corporation (BADC, previously EPADC, the East Pakistan Agricultural Development Corporation). BADC's Barind Integrated Area Development Project (BIADP) was initiated in northwest Bangladesh in 1962 with the installation of 381 deep tube wells (DTWs). In the course of different BADC projects, 1378 DTWs, 40,331 shallow tube wells (STWs), and 66,400 hand tube wells (HTWs) were made available to different user groups. By 2004, 6047 DTWs, 70,000 STWs, and other modes of irrigation were used in the area, covering almost 57% of the total irrigated area (BMDA, 2006); the remaining 43% was planned to be covered by DTWs installed via the groundwater model study for DTW installation project in Barind project. Recently, the Barind Multipurpose Development Authority (BMDA) has installed over 10,000 DTWs in Barind, and a large number of low-capacity STWs have been installed in the region through private initiatives (Ahmad et al., 2008). Up until now, 22,768 DTWs and 14,99,333 STWs have been installed to facilitate groundwater irrigation in northwest region, covering the Rajshahi and Rangpur division (BADC, 2013). Despite the rapid expansion of the irrigated area over the last two decades, poor performance and low efficiency of water use are still prevalent (Dey et al., 2006). Shortage and unavailability of surface water and relatively easy access to groundwater through installed STWs and DTWs has resulted in large scale groundwater withdrawals for irrigation in northwest region of Bangladesh. Although groundwater dominates the total irrigated area, its sustainability is at risk in terms of quantity in the northwest region (Simonovic, 1997; Shahid, 2011). Considering quality issue of water, study shows that 44% of shallow tubewells (≤ 30m of depth) in the northwest region are at medium risk related to microbial contamination from point sources of pollution (within 10 m of tubewells) according to the World Health Organizations' sanitary inspection guidelines, implies a growing concern for ensuring quality water to meet relevant target of sustainable development goals (Dey et al. 2016b). Due to a paucity of knowledge, indiscriminate installation of tubewells, and a lack of availability of modern technologies, farmers inappropriately use water without considering the sustainability of groundwater sources. This, in turn, affects other sources and the water table, which has declined alarmingly in many areas of Bangladesh. As a result, the groundwater table has declined substantially in this region over the last decade, threatening the sustainable use of water for irrigation in this region and impacting on crop growth and drinking water supplies (Jahan et al., 2010a, 2010b; Shamsudduha et al., 2012; Shahid, 2008; Shahid and Behrawan, 2008). Frequent water shortages in the region have had an economic, social, and environmental impact (Takara and Ikebuchi, 1997; Sajjan et al., 2002; Dey et al., 2011).

The lack of robust information on aquifer reserves, their withdrawal patterns, changes in quality, and consequences of use for irrigation are poorly understood in Bangladesh (Qureshi et al., 2015), which has risked the sustainable use of groundwater in agricultural purpose. Recharge of aquifers is a complex hydro-geological incidence influenced by a number of factors such as intensity and duration of precipitation, base flow from nearby river, geomorphology, geology and pedology of the land surface, vegetation cover and land use pattern of that region. In this paper, these factors have been considered to assess the potential of aquifer recharge; which is an important determinant of sustainable use of groundwater. Here we define groundwater sustainability as the development and use of groundwater in a manner that can be maintained indefinitely without causing unacceptable environmental, economic, or social consequences. Groundwater sustainability must be defined within the context of the complete hydrologic system, of which groundwater is only a part. Ecosystems and their groundwater interactions are often ignored in decision-making processes, leading to a lack of investment in ecosystem development or measures to protect the depletion and degradation of groundwater; ultimately, this results in economic loss (Emerton and Bos, 2004). Researchers and policymakers must advocate sustainable development as the optimal approach for current and future water problems (Loucks, 2000; Cai et al., 2001) to achieve and sustain food security and adequate water availability for domestic, commercial, and industrial use.

Against this backdrop, we used the latest technology, including satellite imaging, to assess 21 years of changes in the wetlands in northwest Bangladesh, an important source for groundwater replenishment. We assessed groundwater sustainability using some vital indicators not previously systematically applied in similar studies. The aim of the study was to formulate policies by identifying key factors constraining the sustainable use of groundwater for irrigation in the context of ensuring food security of Bangladesh.

2. Methodology

2.1. Study area

The study was conducted in five districts, namely Rajshahi, Dinajpur, Pabna, Rangpur, and Bogra, situated in northwest region of Bangladesh. Location of the study area including river systems, observation wells for measuring groundwater table depth in meter, stations for measuring river water level in mPWD (meter PWD, measured from mean sea-level) and rainfall in mm is shown in Fig. 1. The study area, a part of Barind Tract, the largest Pleistocene era pysiographic unit in the Bengal Basin extends from 23° 48′ 14.3″ N to 26° 03′ 16.8″N latitude and 88° 18′ 44.99″ E to 89° 43′ 50.71″ E longitude geographically.

The area is crisscrossed by a number of rivers and underlined by distinct oxidized red soils and sediments of Plio-Pleistocene and Holocene ages (Rashid et al., 2015). The study area falls mostly under flood plain and some proportion in uplifted terrace mainly in Barind tract in Rajshahi district. Many areas of this region contains a thick layer of clay, which acts as aquitard, impedes the natural recharging of groundwater and increase surface runoff. The soil formation process differs significantly between floodplain and terrace. The texture of the soil is predominantly clay loam in Rajshahi and Pabna districts, silty loam in Rangpur, sandy loam in Dinajpur and silty loam and clay loam in Bogra district. Ganges-Brahmaputra river system, comprising of the rivers Ganges (Padma), Tangon, Atrai, Little Jamuna, Tulsiganga, Baral, Nagar, Mahananda, Punarbhaba, Kulic, Karatoya, Ghaghat and Teesta is the major drainage system in this region. Being characterized by high temperature and low rainfall compared to the average condition of Bangladesh, this region often experiences severe dry and drought environment (Dey at el., 2011). Agricultural activities of the study area is mostly dependent on groundwater irrigation.

2.2. Framework for assessment of sustainability of groundwater use for irrigation

Environmental, social, and economic aspects were considered when assessing groundwater sustainability for irrigation. The selected indicators, measurement tools, and criteria for ensuring groundwater sustainability for irrigation are presented in the schematic in Fig. 2.