Contesting with the Ganges Water Machine in South Asia: Theory versus Reality

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Recently, there has been much interest in how to manage the water resources of the Ganges River Basin (GRB), the cradle of Asian civilization, currently supporting >500 million people (Figure 1a). This also includes cleaning up the Ganges river, regarded as one of the most polluted mega-rivers of the world[1]. Historically, the transboundary Ganges river and its tributaries, flowing through India, Nepal, and Bangladesh, have become extensively polluted and disrupted, mostly because of river engineering and increased discharge of industrial and urban waste. Compounding the problem, in the past few decades, intense groundwater abstraction from the GRB aquifers has led to unprecedented groundwater level depletion in some locations[2] (Figure 1b). At present, the GRB groundwater levels are strongly influenced by depth-dependent abstraction, which is predicted to intensify in the future, given the increasing water demand.[3] Thus, with impending climate change, designing the coupled river water−groundwater management necessary to meet the goal for sustainable access to clean water for a huge population, has become an arduous challenge[4].

To meet this challenge, planners are strongly advocating reviving the “Ganges Water Machine” (GWM) [5], and recommend shifting the water demand of the very densely populated GRB entirely to groundwater. Theoretically, this would lead to the release of the river waters currently held by dams and canals of the Ganges and tributaries, thereby dramatically increasing the Ganges river flow, diluting the polluted water as well as providing sufficient water in the backyard of every household [1].

The concept of the GWM relies on the assumption that the Ganges river runs through a high-yield, homogeneous porous aquifer that can be used to store transient flood waters through infiltration during the monsoon season and thus act as a perpetual source of water for withdrawal throughout the rest of the year5 (Figure 1c). However, the aquifer is far from homogeneous, with recent studies showing considerable lateral and vertical variability in aquifer properties and geochemistry.[6] Also at present, >60% of irrigation water is already sourced from aquifers.[7] India is the largest consumer of groundwater on the planet; abstraction from the Indo-Gangetic Basin aquifers represents a quarter of the entire world's groundwater abstraction and has been instrumental in sustaining India's "green revolution" since the 1970s.[8]

Studies in parts of the Ganges River delta, which is characterized by a relatively homogeneous sand aquifer, have demonstrated that increased capture of surface water through distributed pumping is possibly already taking place.[9,10] However, unrestrained groundwater withdrawal for irrigation in the widespread Ganges alluvial plains with a complex hydrostratigraphic framework[4,6,7] has made it one of the most stressed aquifers in the world, accompanied by alarming side effects: rapidly falling groundwater tables,[3,11] increased salinity of the soil and shallow groundwater, and mobilization of arsenic, fluoride, and uranium[7,10,12] (Figure 1d). Some of these impacts are mitigated by the widespread incidental recharge of groundwater from unlined canals and irrigation return flow, but the large-scale application of the GWM would substantially reduce this unintentional mitigation and accelerate groundwater degradation.[6,7].

In addition, the Ganges being a predominantly gaining river, ≥40% of the river water in present-day summer time may be sourced to local groundwater baseflow. The baseflow has already decreased by ~60% of its volume since before 1970[13] (Figure 1e). Therefore, increasing summer groundwater abstraction across the aquifer could diminish groundwater storage, dwindle baseflow and lead to a further reduction in the Ganges flow, thereby concentrating the river pollutant load, endangering aquatic wildlife, and increasing the risk of drought and food security for >100 million people.[13]

Thus, the concept of the GWM, although theoretically attractive, has several grave shortcomings. (1) The Ganges basin aquifers are already severely overstressed, and enhanced abstraction would only hasten their demise. (2) These aquifers are extremely heterogeneous and have complex and spatially variable river−groundwater interactions;[7,13] therefore, annual monsoon flooding on the main river channels may not replenish the areas of the aquifer where groundwater is most needed. (3) Parts of the Ganges river catchment are already subject to rapidly declining river levels and cannot sustain further reduction of baseflow from groundwater. (4) The natural groundwater recharge process for the Ganges basin aquifer is slow and heterogeneous,[3,6] and unintentional recharge from distributed irrigation return flow and unmaintained canals already acts as a huge unintended artificial recharge structure;[7] therefore, any further overdraft abstraction would destabilize the dynamic equilibrium of the recharge processes. (5) Major parts of the Ganges aquifer are affected by large-scale natural groundwater contamination, particularly arsenic,[4,12] and other emergent contaminants, e.g., pesticides, polyaromatic hydrocarbons, etc.[14] Although the exact mechanisms are debated, there is reasonable evidence that irrigation may exacerbate arsenic mobilization.[10,12] (6) Increased groundwater use for irrigation can also significantly increase salinity in groundwater. Given these serious concerns, the potential for effective and widespread application of the GWM concept is limited. Substantially increased pumping of the Ganges aquifers and/or artificial recharge, without developing a systematic understanding of the physical and chemical feedback effects of the Ganges river−groundwater interactions,[7,8,13] would have potentially catastrophic implications for water security.

On the contrary, a scientifically prudent approach to balancing groundwater use with river water and excess rainwater, through a comprehensive water management plan for the Ganges river, canals, and aquifers, does have the potential for success. Hence, we advise against the application of the GWM concept in a "one-size-fits-all" approach. A basinwide, in-depth study of groundwater−Ganges river water interactions is required before any further policy augmentation. There are still many aspects of this unique water system that we do not understand, and past mistakes should serve as a warning not to undertake large-scale changes and hydrological engineering, without careful consideration, which can otherwise lead to irreversible catastrophic outcomes.

References

(1) Shah, T.; Ray, C.; Lele, U. How to clean up the Ganges? Science 2018, 362, 503−503.

(2) Bhanja, S. N.; Mukherjee, A.; Rodell, M. Groundwater storage change detection from in situ and GRACE-based estimates in major river basins across India. Hydrological Sciences Journal 2020, 65, 650–659.

(3) Malakar, P.; et al. Three decades of depth-dependent groundwater response to climate variability and human regime in the transboundary Indus-Ganges-Brahmaputra-Meghna mega river basin aquifers. Advances in Water Resources 2021, 149, 103856.

(4) Mukherjee, A.; et al. Groundwater systems of the Indian subcontinent. Journal of Hydrology: Regional Studies 2015, 4, 1−14.

(5) Revelle, R.; Lakshminarayana, V. The Ganges water machine. Science 1975, 188, 611−616.

(6) Bonsor, H. C.; et al. Hydrogeological typologies of the Indo- Gangetic basin alluvial aquifer, South Asia. Hydrogeology Journal 2017, 25, 1377.

(7) MacDonald, A. M.; et al. Groundwater quality and depletion in the Indo-Gangetic Basin mapped from in situ observations. Nature Geoscience 2016, 9, 762−766.

(8) Saha, D.; Zahid, A.; Shrestha, S. R.; Pavelic, P. Groundwater resources. In The Ganges River Basin; Routledge, 2016; pp 58−85.

(9) Shamsudduha, M.; et al. The bengal water machine: Quantified freshwater capture in Bangladesh. Science 2022, 377, 1315−1319.

(10) Mukherjee, A.; Fryar, A. E.; Howell, P. D. Regional hydrostratigraphy and groundwater flow modeling in the arsenicaffected areas of the western Bengal basin, West Bengal, India. Hydrogeology Journal 2007, 15, 1397−1418.

(11) Bhanja, S. N.; Mukherjee, A. In situ and satellite-based estimates of usable groundwater storage across India: Implications for drinking water supply and food security. Advances in Water Resources 2019, 126, 15−23.

(12) Harvey, C. F.; et al. Arsenic mobility and groundwater extraction in Bangladesh. Science 2002, 298, 1602−1606.

(13) Mukherjee, A.; Bhanja, S. N.; Wada, Y. Groundwater depletion causing reduction of baseflow triggering Ganges river summer drying. Sci. Rep. 2018, 8, 12049.

(14) Lapworth, D. J.; et al. Deep urban groundwater vulnerability in India revealed through the use of emerging organic contaminants and residence time tracers. Environ. Pollut. 2018, 240, 938−949.

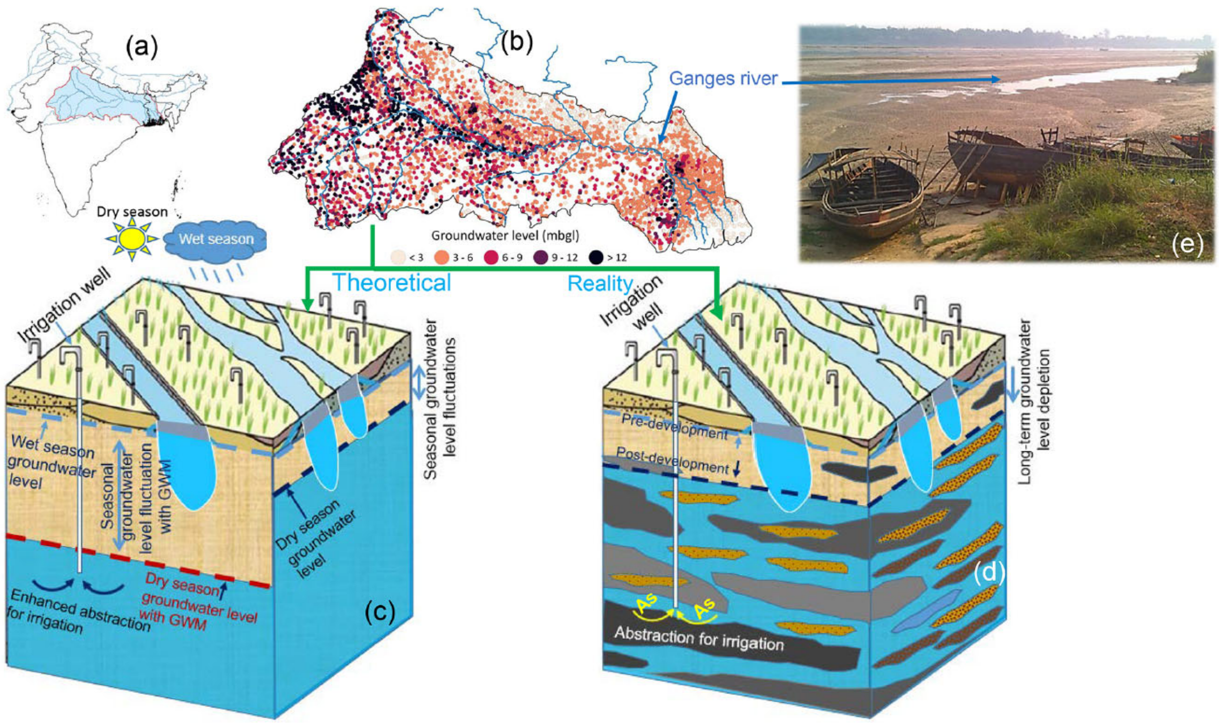

Figure 1: Composite figure showing (a) a map of parts of South Asia, displaying the extent of the Ganges River basin (GRB, blue), (b) a map of the GRB showing the long-term (1985−2015) mean groundwater level changes in monitoring wells (n = 5435), and (c) a box model showing the hypothetical scenario proposed in the Ganges water machine (GWM). The GWM scenario imagines the subsurface aquifer of the GRB as a roughly homogeneous sandbox, with discernible natural, seasonal groundwater fluctuations as a response to dry and wet seasons. From this hypothetical GRB aquifer, groundwater can be abstracted at an enhanced rate to substantially decrease the dry season groundwater level. Subsequently, the wet season rainfall water should infiltrate to replenish the GRB aquifer to the wet season groundwater level, the GRB subsurface thus working like a transient repository of the groundwater. However, in reality, (d) the subsurface of the GRB is highly anisotropic, and incessant groundwater abstraction for irrigation has resulted in continuous groundwater depletion over the past several decades (as shown in panel b). In addition, such abstraction has the potential to accentuate geogenic groundwater contamination (e.g., arsenic and uranium). Panel e shows the outcome of summer drying of one of the lower Indian reaches of the Ganga River (photographed in May 2016 in West Bengal), likely as a consequence of reduced baseflow and river capture due to abstraction-induced groundwater level and storage depletion in the GRB.