Deep and strategic groundwater resources in the Gangetic Plains

Can environmental isotopes be effective assessment tools?

Dipankar Saha
dsaha002@gmail.com

The Gangetic Plains, occupying the central part of the 1.1 million km^2 spread Ganga Basin, holds some of the rich aquifer systems of the world. At places, the aquifers are very deep and hold immense groundwater resources recharged hundreds/thousands of years ago. This component, lying below the replenishable resource recharged every year, is termed as a static groundwater resource. In case of emergency such as successive drought years, the static resource can be used in a planned and coordinated manner. Application of environmental isotopes of water (2H & 18O) and radioisotopes (3H & 14C) can play a critical role in understanding and assessing this static resource.

T

The Ganga Basin, with catchment spread over 1.1 million km^2 , is the most populated and intensively cultivated area in the world. The basin spreads across India, Nepal, Bangladesh and China. The major part of the basin lies in India, receiving good rainfall and drained by perennial rivers, fed both by the glaciers in higher Himalayas as well as by the rainfall. In a hydrological year, the basin receives about 1200 Billion Cubic Meter (BCM) of precipitation of which about 500 BCM is stream flow. A part of the remaining 1000 BCM infiltrates to recharge groundwater, while the remaining returns to atmosphere through evaporation or evapotranspiration (Jain et al 2016). The hydrology of the basin is monsoon driven where 85% of the rainfall occurs during May to September, causing excess water in monsoon and scarcity in dry season. The potential of the hilly area in terms of water resources utilization has not developed fully. The water infrastructure to store runoff during monsoon is yet to be fully developed. On the other hand, the Plain areas are marked with considerable groundwater resource development. The Ganga basin may be divided into three major groups based upon the broad hydrogeological characters (Fig.1):

a] Himalayan terrain: hilly and rugged terrain, rocks are consolidated to semi-consolidated in Nepal, India and China. Low groundwater potential

b] Gangetic Plains: underlain by unconsolidated sediments of variable thickness. Moderate to high groundwater potential. This unit may be further subdivided into the following units;

i) Bhabar belt-along the base of Himalaya, 10-30 km wide in general

ii) Terai belt- along the southern part of the Bhabar belt 10-50 km wide

iii) Central Alluvial Plain- vast stretches along the both side of the Ganga River.

iv) Marginal Alluvial Plain- along the base of the hard rock upland of peninsular India.

v) Deltaic Region- at the southern part of the basin, where the Ganga River meets the Bay of Bengal.

C] Southern Peninsular region: hilly and undulating terrain underlain by consolidated to semi consolidated variety of rocks with moderate to low groundwater potential.

The Central Alluvial Plain covers the major part of the Ganga Basin in India, that spans over 2,50,000 km (Singh, 1996). Unconsolidated thick Quaternary deposits (even more than 2000 m at places) hold rich aquifers at various depths. Immense groundwater resource has made this unit as one of the most extensively exploited regions of the world. The Quaternary alluvial deposits grade to semiconsolidated Upper Tertiary deposits at depth. The sand layers, with occasional mix of pebble & gravel, form highly potential multi-layered aquifer systems. The detailed aquifer configurations could be made available up to 300 m below ground, through National Aquifer Mapping (NAQUIM) Programme, carried out by Central Ground Water Board (CGWB). In the Middle Ganga Plain, lying between the Munger-Saharsa ridge in the east & the Faizabad ridge in the west, is particularly rich with multi-tiered aquifer systems. Very high transmissivity(5163-6974 m^2/day) was reported from these aquifers (Saha et al., 2010). The replenishable groundwater resource, which is rejuvenated every year is estimated in 2011 as 164.4 BCM for the Indian part of the Ganga Basin (Saha et al 2016). No accurate data is available for the Gangetic Plains underlain by unconsolidated deposits holding good aquifers. However, safely it can be assumed that about 80% of the resource, i.e., 132 BCM is confined in this part. The overall stage of exploitation of groundwater resource for the Indian part of the Ganga Basin is around 66%. However, considering large scale exploitation of the groundwater in the Plains through millions of borewells, we can assume that the stage of exploitation would be much high. In fact, in the western part of the Gangetic Plains, falling in the state of Uttar Pradesh, significant number of blocks are classified as over-exploited, indicates groundwater extraction exceeds the recharge in an annual scale. The replenishable resource represents volume lying between the pre- and post-monsoon groundwater levels and it is only a small fraction of the total groundwater resource trapped in the entire column of the sediments. The resource available below the premonsoon water level, till the hard rock basement, is termed as Static Resource. This resource remains untapped if the stage of groundwater exploitation is <100%. No estimation is available on the static resource available in the Gangetic Plains. However, it can be safely assumed that volumetrically this component of groundwater resources would exceed even 50 times of the replenishable resource. It can be even more in the Central Alluvial Plains, where aquifers are thicker and the basement lies at greater depths.

> WITH AN annual extraction around 240 billion cubic meters, India is the largest extractor of groundwater in the world. Because of various reasons, including the uncertainty imposed on availability of surface water due to climate change, dependence on groundwater resources will rise in the future.

There are two major concerns on sustainable groundwater management of the Gangetic Plains:

a) Rising exploitation to meet up the drinking and irrigation demands

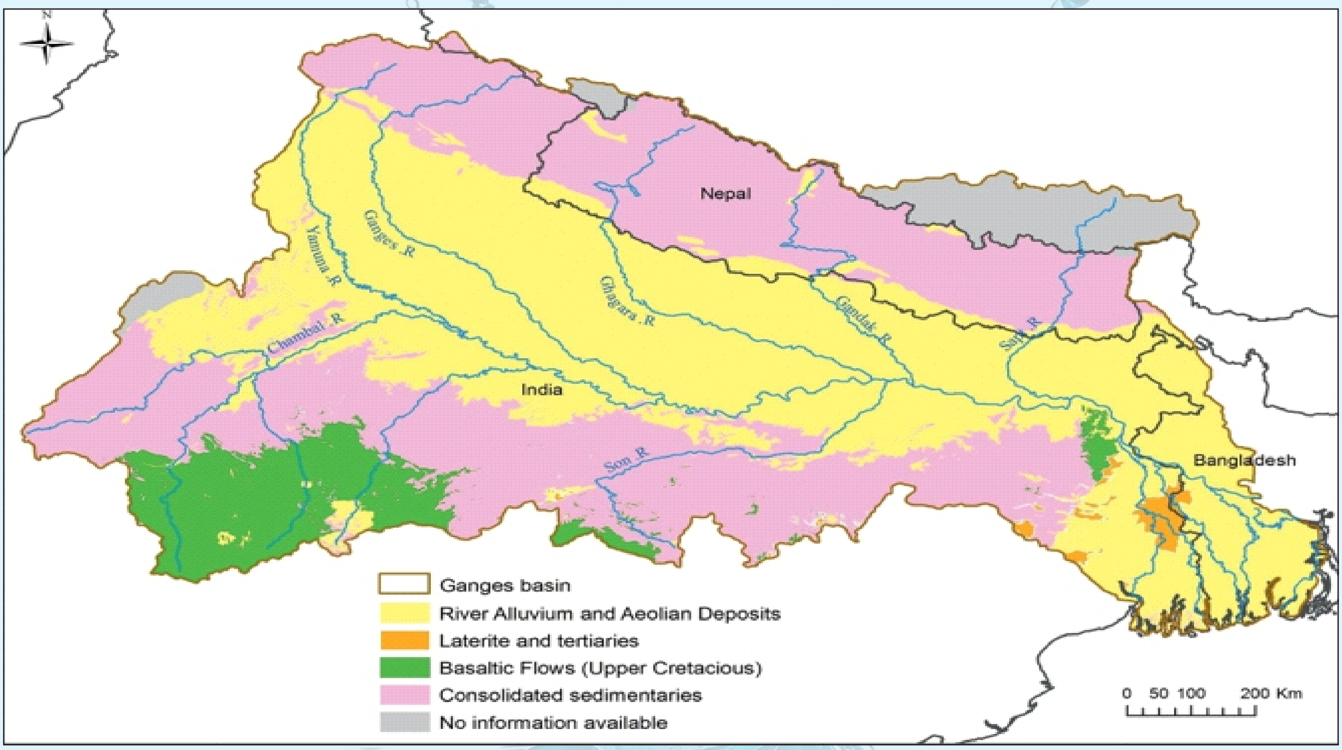

Fig.1: The figure showing the River Alluvium which holds all the five sub units. The Himalayan Terrain is located in the north and the Peninsular Region borders the south. In both the regions the major rock types viz., consolidated sediments, basaltic flows and laterites are also shown.

b) Possible adverse impact because of uncertainties in rainfall and rising temp imposed by climate change

As a country, with an annual extraction around 240 BCM, India is the largest extractor of groundwater in the world. Because of various reasons, including the uncertainty imposed on availability of surface water due to climate change, dependence on groundwater resources will keep on increasing in future. Under such a scenario in large areas, the extraction would exceed replenishable resource and mining of static resource will increase. We must have an accurate assessment of static resource for developing a comprehensive plan to exploit it judiously, as this component of groundwater resource takes much more time to recharge. In first stage, this assessment can be made up to the depth of 300 m below ground, which has been considered as depth of investigation under NAQUIM. In next stage the assessment could take forward till 600 m depth.

> ENVIRONMENTAL ISOTOPE techniques can play a significant role in assessment of static water resource from depths of 300m to 600m. It would aid efforts of researchers to understand better the recharge path mechanism for different aquifers, the age of the groundwater and the hydraulic interaction between aquifers.

Environmental isotope techniques can play a significant role in assessment of the deeper concealed static resource. Isotopes such as hydrogen-2, oxygen-18, tritium and radiocarbon are helpful in understanding the following complexities of the static resource: a) Recharge path a mechanism for different aquifers at depths holding static resource. b) Age of groundwater from different aquifers, which would further elaborate recharge mechanism c) Hydraulic interaction between different aquifers, vertically and laterally. Significant research has been carried out in this direction in the Gangetic Plains by CGWB and other agencies in collaboration with BARC. Keesari et al. (2021) revealed a three-tiered aquifer system, till the depth of 600 m, along a section, between the river Ganga and the southern basin margin ending with the hard rock upland. A 3-tiered aquifer system is identified representing unique groundwater flow regime, aquifer conditions and geometry. The dominant recharge in the shallow unconfined Aquifer-I was found to be from rainfall with mean transit time of about 20 to 23 years. This aquifer system is extensively exploited for irrigation and domestic purposes. Aquifer-I is rejuvenated through river inflows and rainwater percolation through paleo-channels (Fig.2). The semi-confined to confined Aquifer-II holds fresh groundwater with a modelled age of around 400 years. This aquifer system is less tapped for irrigation but intensively exploited in the urban areas through heavy duty deep tubewells. Recharge takes place along the basin margin, where this aquifer is exposed to surface. A part of the recharge to Aquifer-II is contributed by leakage from aquifer-I. The deep confined Aquifer-III (>220 m depth) holds fresh groundwater and is characterised by 3.5 to 4.7 ka ages. Any extraction from Aquifer-III needs a long-term and aquifer-specific recharge plan. In another study, radiocarbon evidence from a network of multilevel monitoring wells in the Bengal Aquifer System showed residence times of between 1000 and 10000 years for groundwater at depths >150 m (Lapworth et al., 2018). The regional security of deep groundwater from the ingress of shallow contaminated groundwater is

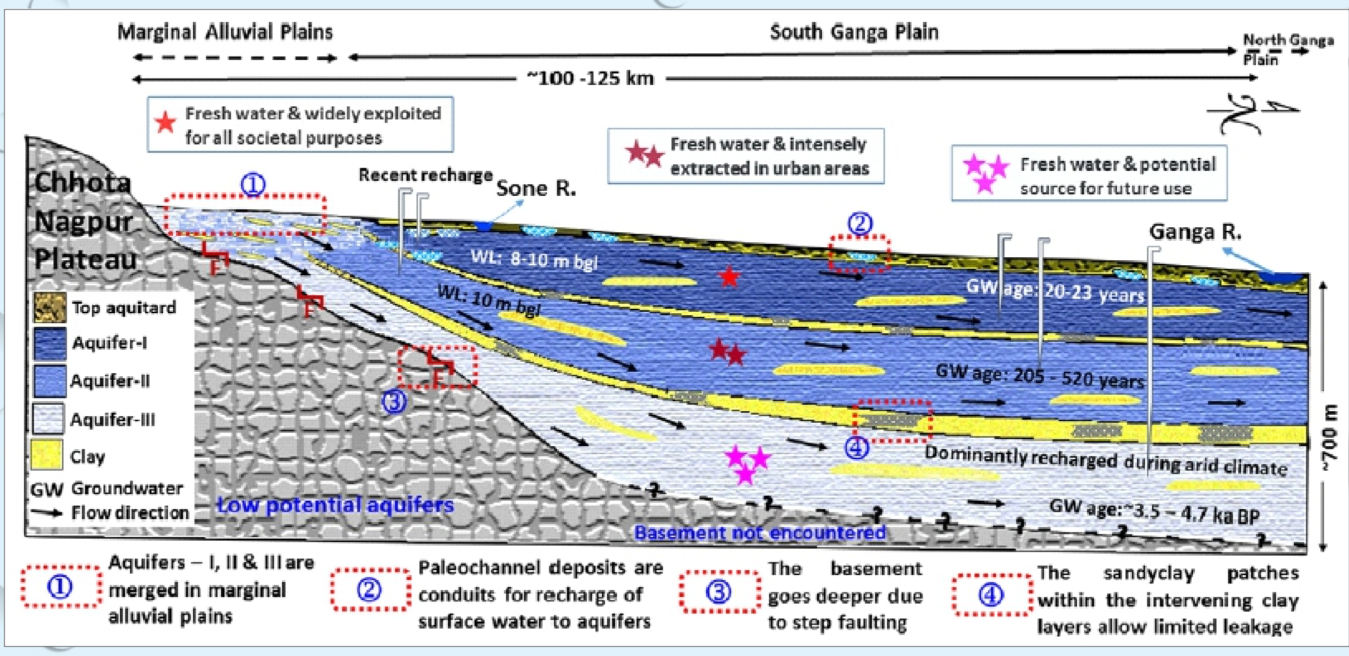

Fig.2: Three tier aquifer system shown as north-south transect in the Middle Ganga Plain in the south of the River Ganga (Keesari et al., 2021).

confirmed by age vs.depth profiles. Sikdar and Sahu (2009) reported high tritium content in shallow groundwater in the shallow aquifers in the Gangetic Plains of West Bengal, suggesting local recharge. While the deep groundwater was found to contain very low tritium implying distant recharge. Authors also observed mixing of groundwater of between shallow and deep aquifers at places. Khanna (1992) has reported four-tiered aquifer system within 425 m depth in the region made up of western part of the Middle Ganga Plain and eastern part of the the Upper Ganga Plain in the state of Uttar Pradesh.

Conclusions

As per the policy adapted in India, groundwater utilization should not exceed the replenishable resource available so that the stage of overexploitation is not reached. However, the factors like rising water demand and the adverse impact of climate change are gravitating the society to rely more on groundwater resources. This is particularly true for the Gangetic Plains, particularly the Central Alluvial Plain - a thickly populated and intensively cultivated region underlain by thick alluvial and deltaic deposits. The replenishable groundwater resource, which is recharged every year is only a fraction of the total groundwater resource available within the thick unconsolidated sediments. At present the groundwater wells are mostly confined within 150 m depth and the average extraction is within the safe limit, though number of overexploited blocks is emerging in the western part because of unsustainable groundwater extraction. In future groundwater extraction is likely to increase further in the central and eastern parts also, which is presently marked with lower stage of development, to meet up rising demand from irrigation. As the groundwater demand increases in the Gangetic Plains, the Static resource, occurring at deeper levels, can be used in a limited scale and under a planned manner, if the replenishable resource is under pressure. In-case of emergency like, successive years of drought or rain failure Static resource can be a huge support. This component of resource can be used strategically with proper planning and supporting interventions for its recharge and replenishment. Given the importance of this resource, and expected future demand, all-out precaution should be taken to avoid vertical leakage of contaminated shallow groundwater to deeper zones due to leakage through intervening aquitards or faulty well construction. Applications of environmental isotopes can play a pivotal role in understanding the recharge paths and mechanisms and also estimating the volume of Static resource, trapped within a complex web of multi-tired aquifer system in the Gangetic Plains.

Dr. Dipankar Saha is a professional on water resource management, having more than three-and-a-half decades of experience in Government organisations and International agencies. A Ph.D. from Indian Institute of Technology (Indian School of Mines Dhanbad) on groundwater management, he worked in Central Ground Water Board under various capacities including, Regional Director of Bihar and Jharkhand States, as Member (HQ) and also as Member Secretary of Central Ground Water Authority. He spearheaded the National Aquifer Mapping Programme as the National Coordinator. Post superannuation, he provided services as advisor to Gujarat Govt on groundwater and Adjunct Prof in Department of Water Resources Engineering, IIT Kharagpur. He executed number of International Consultancy through IWMI, IAEA and SDC. He has numerous recognitions to his credit, including the National Geoscience Award 2010 from Govt of India on Groundwater Exploration, Eminent Water Resource Engineer 2019 Award from Indian Water Resources Society, IIT Roorkee. Presently he is Chair Prof in MRIIRS at Faridabad and Board President of Water for People.