

## Protection of deep aquifers from arsenic contamination in Bengal Basin

Several drinking water wells in the villages of seven districts of West Bengal are affected by arsenic contamination. The presence of arsenic in groundwater was first noticed in 1978. The studies conducted between 1990 and 1996 by the School of Environmental Studies (SOES), Jadavpur University, Calcutta, have brought out the extent of arsenic contamination in the aquifers of younger deltaic deposition (YDD) in West Bengal<sup>1</sup>. The recent studies undertaken by SOES in parts of Bangladesh indicated an extension of arsenic contamination in the same YDD aquifers across the Padma river<sup>2</sup> (Figure 1). Though the exact mechanism of arsenic contamination is not clear, the increase in the affected areas corresponds with the increased groundwater utilization for irrigation in those areas. Deeper sources previously found to be free from contamination, show arsenic contamination with time. It is therefore necessary to protect the presently

uncontaminated deeper aquifers through effective hydrogeological management.

There are no well-defined aquifer stages in the arsenic-affected areas of Bengal Basin apart from the shallow water table aquifer. However, due to the presence of varying thicknesses of aquitard at different depth levels, the aquifers at depth attain a state of semi-confined to confined conditions. While thickness of shallow aquifer varies from a few meters to a few tens of meters and is under-exploited, the middle level aquifers (depth range 30–80 m) are exploited to a maximum extent for irrigation wells. Incidentally, the maximum reported arsenic contamination in groundwater is from this aquifer which is under semi-confined condition due to the presence of semi-pervious silty-clay layers. Wide variations are reported in the arsenic content within the same aquifer zone<sup>3</sup>.

During 1990, the Public Health Engineering Department (PHED) had drilled

eight deep tube wells to depths of 150 m to tap safe water at Ghatugachi village in Nadia district. Initially these wells were reportedly supplying arsenic-free water but later, with time, arsenic contamination was reported<sup>4</sup>. Therefore it is necessary to understand the hydrogeological situations which are responsible for the contamination of the deeper aquifers as well.

Thus on the basis of hydrogeological settings of the aquifer in the area, we can divide the aquifers into three stages depth-wise, namely the shallow, middle and deeper. Initially, the aquifer zones in the middle stage were maximally affected by the arsenic contamination<sup>3</sup>. However, exploitation of the deeper aquifer for arsenic-free water led to their contamination as well with passage of time. The probable reasons for this are:

- The intervening confining layers, mostly of sandy-clay or silty-clay (aquifuge), allow interaction between the aquifers.
- The confining clayey bands of arsenic-rich mineral assemblage release arsenic from their storage into the deeper aquifers.
- The arsenic water from the confining layers and from the overlying aquifer may enter into the deeper aquifers at ease, if the tapping zones at deeper aquifers are nearer to the interface zone (bottom line of confining layer).
- Abandoning of wells at pilot level or later on after the development due to reasons like bad construction, poor yield from the aquifer or partial removal of casing pipes and leaving the borehole open, results in migration of contaminants.
- Development of deep irrigation wells which tap the aquifers at various stages, thereby accelerating the migration of arsenic.
- From deeper aquifer matrix itself, arsenic might be released.

The vertical flow inducement through confining layers plays an important role in the migration and spreading of the contaminant from the confining layers

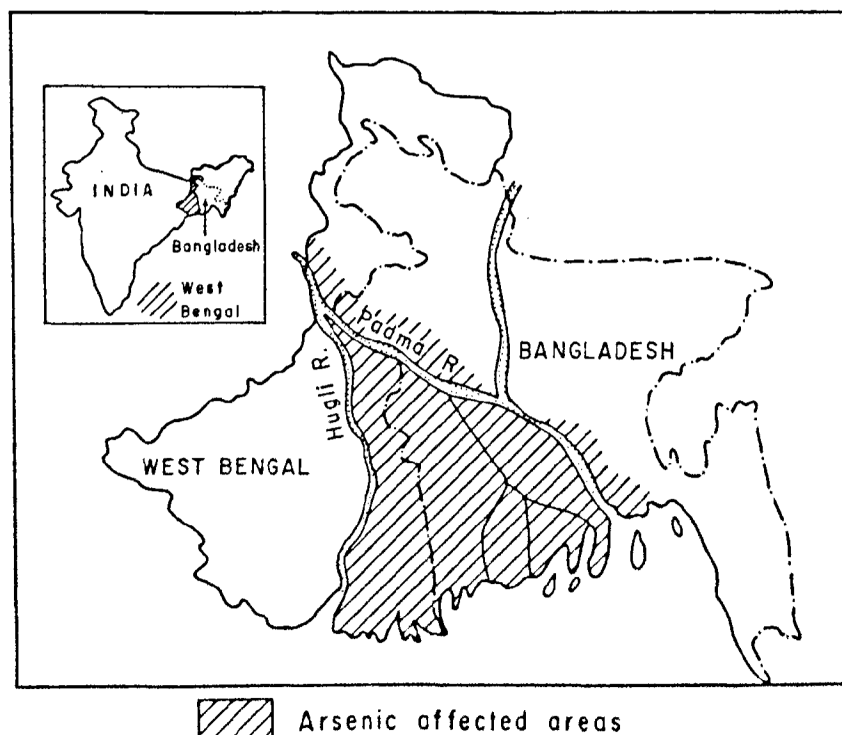


Figure 1.

and from the overlying contaminated aquifers.

The confining beds of an artesian aquifer are, in fact, not completely impermeable. In general, the hydraulic conductivity of the semipervious layer is very small compared to that of the main aquifer. When saturated flow passes from a medium of hydraulic conductivity,  $K_1$ , to that of conductivity,  $K_2$ , a refraction in flow lines occurs such that  $\tan\theta_1/\tan\theta_2 = K_1/K_2$ , where  $\theta_1$  and  $\theta_2$  are the angles which the flow lines make with the normal at the interface (Figure 2). Thus, if the conductivity  $K_1$  of the semipervious layer is small compared to  $K_2$ , the conductivity of the main aquifer, as is usually the case ( $K_1/K_2$  is more than 500), and since at the interface the vertical component of the velocity in the main aquifer is not zero, the flow in the semi-pervious layer will be nearly vertical; that is, the horizontal components of the flow therein are so small that in practice they may be neglected<sup>5</sup>. Therefore, pumping the deeper confined aquifer at high discharge rate results in vertical flow through the thin semi-pervious confining layers which causes hydraulic continuity between the two aquifers.

It has been observed that the migration of arsenic into the deeper zones is at a faster rate when the deeper aquifer is tapped close to the confining bed. An examination of the borehole lithologs and the details of well assembly revealed that, in most of the cases, the deeper aquifer opens into the well by stainer slots present just beneath the confining bed. A drinking water well near Katlamari village in Raninagar Block of Murshidabad district in West Bengal was constructed and developed (1995) between the depths 163 and 190 m, while the confining clay ended

at 161.5 m. The discharge from the well is reported to be 29,400 gallons per hour. This example clearly shows that positioning of slots immediately below the confining interface followed by heavy withdrawal is a common practice<sup>6</sup>.

When the abstraction rates are small or moderate, the lateral transfer of water in the deeper confined aquifers is usually expected to be dominant. However, if the withdrawal of water from a well is high, the lateral transfer of water from a distant recharge source may only meet a small proportion of the abstraction demand. In alluvial aquifers, a similar situation arises if the regional groundwater gradient is too small to permit the lateral transfer of larger quantities of water to regions of higher exploitation, despite high transmissivity properties. As a result, large quantities of water are pulled vertically downwards from the aquifers lying above. Rushton<sup>7</sup> has quantified the contribution of vertical flow component in highly-exploited deeper aquifer conditions by taking example from the Gujarat alluvial aquifers. Phadtare<sup>8</sup> has estimated that more than two-thirds of discharge of water through pumping deeper aquifer is from the aquifers lying above the confining layers.

An average slope of 10 cm/km and groundwater movement of the order of 500 cm/year was reported<sup>9</sup> for the aquifers in the arsenic-affected tracts of West Bengal. The average yield of deep tube wells (110–150 m) is about 100 per cu m/h. The velocity of groundwater near the strainer (or slotted position) in the aquifer is estimated to vary between 0.01 and 0.05 m/s (ref. 7). The pumping operations act as stirrer and bring about mixing in the zone of influence. This induced action in the aquifer will be more effective in mixing the incoming arsenic-rich water from the aquitard/above aquifers when the slots are placed near the interface. Both the very low horizontal velocity and heavy withdrawal of water jointly favour an induced condition of seeping of arsenic-contaminated water to deeper aquifers.

Similarly, the analysis of litholog and construction details of irrigation wells of Chakdaha block in Nadia district of West Bengal<sup>10</sup> indicates that the aquifers at different depths are interconnected through positioning of strainer

slots at different levels in many cases. Though it is difficult to understand the actual aquifer interaction processes during non-pumping period, exchange between the aquifers is expected to occur due to the pressure differences created through pumping. This process may lead to migration of contaminants from one level into another. It is therefore necessary to have the drinking water wells away from such irrigation well clusters in affected areas.

Assuming that the deeper aquifers are to be tapped for safe drinking water supply, care must be taken on the following lines:

- The aim of the tubewell for more withdrawal for drinking water supply programme should be to tap aquifer zone at the deepest level, rather than tap several zones within the same aquifer.
- The withdrawal from the deeper aquifer zones should be optimum to avoid any vertical leakage. This may imply development of more tube wells to meet the demand.
- The slotted casing should not be placed near the interface boundary (bottom of the confining layer).
- The cement sealing at middle level contaminated aquifer zones should be perfect to avoid any leakage along the annular space.
- Decision on development of drinking water tubewell must be taken only when the drilling operations encounter thick clay/silty clay confining layers. Presence of such a confining layer above, is expected to avoid the downward movement of contamination from the middle aquifer.
- The abandoned wells should be grouted perfectly through entire section.
- It is necessary to have a law on restricting the depth of drilling for irrigation wells in Bengal Basin.
- It is necessary to encourage harvesting of rain water at individual household level for meeting their drinking water requirements. Social awareness and participation of villagers are necessary to accomplish this task.

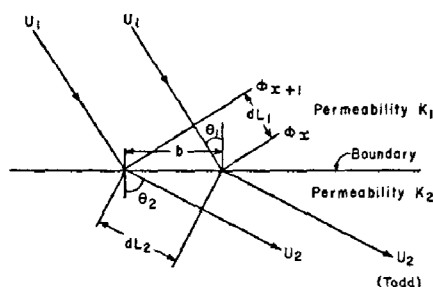


Figure 2.

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## Ecosystem flips in cultural landscapes: The case of Kolli Hills

The concept of 'cultural landscapes' recognizes the complex interrelationships between humans and nature in the construction, formation and evolution of landscapes. Cultural landscapes and their links to conservation of biological diversity, are now recognized under the 1972 UNESCO Convention concerning the Protection of the World Cultural and Natural Heritage - The World Heritage Convention<sup>1</sup>.

In a cultural landscape we find two broad component systems - ecological and social. Both these systems are interlinked in such a way that the 'humans-in-nature' situation is sustainable, wherein, the local social system develops management practices, based on ecological knowledge, for dealing with the dynamics of the ecosystem with which it interacts<sup>2</sup>.

Ecosystems nevertheless undergo irreversible changes in structure and function under regimes of human-induced disturbances. Ecological 'resilience' has been identified as an effective tool in assessing robustness of ecosystems. The magnitude or scale of disturbance that can be absorbed before the ecosystem permanently changes in structure and function is an important measure of ecological resilience. When there is a permanent change in the ecosystem's structure and function, it is considered as a 'flip' from one equilibrium state to another<sup>2</sup>.

In cultural landscapes, our concern therefore is about the 'sustainable system' which comes into existence after an appropriate blending of social system with ecological system, in a limited

geographical space that has already flipped. Although we do not expect this to happen immediately or within a short span of a few generations, it has to emerge and stabilize after long years of trials and errors, and be compatible with systems of conservation of biological diversity (= biodiversity), at least locally.

India has had a long history of human-in-nature situation resulting in the evolution of several types of cultural landscapes. The history of landscape transformations in India is fairly well known (eg. see Gadgil and Guha<sup>3</sup>). And certain cultural landscapes have been preserved till date. The different stages in the transformation of a geographical area from its pre-human state to a cultural landscape may include the following:

- Transformation of the landscape elements, especially vegetation, into a state that offers more scope for hunting and gathering of food, minimizes risks of injuries and death caused by accidents or wild animals, that provides greater opportunity to domesticate and cultivate wild animals and plants, and that which minimizes the risk of crop/livestock losses.
- Direct conflicts and resultant adaptive strategies which lead to the reduction of 'harmful' animals in the landscape.
- A newly created 'soft landscape' wherein certain habitats and species (especially plants) are favoured after the elimination or displacement of

others and which is actively managed by an organized social system. Such a system will show a shift in the values placed on biodiversity - favouring some and disregarding others as dictated by inherent biophilias (and biophobia)<sup>4</sup> and the rapidly-changing human needs.

In tropical countries, this could mean a transformation of landscapes from dense forests to grass and scrub, a general loss of larger carnivores and competing herbivores (especially elephants) and a gradual expansion of the human niche in that a superorganism evolves, constantly modifying the landscape, enriching it and making it hospitable and valuable to future generations.

One set of hills comprising a cultural landscape which is still relatively well preserved is the Kolli Hills in the Namakkal district of Tamil Nadu. This landscape lies, as the crow flies, 50 km southeast of Salem town and just west of the Pachchamalai Hills. It comprises a range of cool and dry hills varying in altitude from 300 to 1550 m ASL. To a large extent the nearly 300 km<sup>2</sup> area is steep and rocky, the bases being covered with fairly dense deciduous forests. The forests above 1000 m that we see on the slopes and valleys are however unique - popularly called 'sholas' - and quite resembling the high elevation and montane forests of the Western Ghats, despite the annual average rainfall of only 800-900 mm. Other major elements in the landscape are occasional perennial streams, rice cultivation in the valleys, barren and rocky fallows, mixed