A new scheme for large-scale natural water storage in the floodplains: the Delhi Yamuna floodplains as a case study

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The top layer of accumulated sand washed down by floods over millions of years, makes river floodplains into giant aquifers. We propose a scheme for the natural storage of excess monsoon river-water discharge in the extensive and deep sand top layer of the floodplain of the river. The excess monsoon discharge can be used for a regulated inundation of an embanked area of the floodplain – to soak in and store the water. This storage can then be used for the withdrawal of water during the dry months. We illustrate this by an evaluation of the potential of the Yamuna floodplains in the National Capital Territory of Delhi and show that there can be an annual yield of 600–900 MCM of water, which is three-fourths the total water supply to Delhi. This makes it an invaluable natural resource potentially worth about Rs 6000–9000 crores a year of non-invasive use.

Keywords: Aquifers, floodplains, monsoon discharge, sand top layer.

WITH the shrinking of forest cover, siltation of river systems and melting of glaciers, the natural water recharge and storage capacity of large tracts of the planet are seriously diminishing. The climate change debate often clouds over a much more serious problem – the loss of natural resources, which, unlike climate change, is irreversible.

Furthermore, in India, the population has increased by more than three times since 1947, to one billion. Thus, the annual per capita availability of water resource has gone down from over 3000 m^3 per person in 1947 to less than 800 m^3 per person today. This is closing in on the water use per person, which is about 500 m^3 – a matter of concern.

And we are developing at a fast pace to catch up with the US, where energy consumption is over 20 times ours. The area of the US is three times that of India and the US population is a quarter of that in India. So the amount of natural resource per person available with the US is 12 times more than in India. To follow the US model of development is not even viable in India.

Delhi's water

In developing countries, cities are urbanizing at an unsustainable pace, way beyond their carrying capacity. In a study on the sustainable carrying capacity of Delhi based on its water resources[1], it was found that Delhi's population is already twice its carrying capacity.

For these mega cities in the developing world it is no longer a question of importing an essential resource like water; the water is just not there. New York gets its water from the Catskills forest, which is 150 km away. Delhi does not have such an option.

Delhi's water requirement may be easily estimated. At a conservative 250 litres per day per person, we find that Delhi's present population of 18 million requires 1650 million cubic metres (MCM) of water per year. About 300 MCM comes from the Yamuna, over 500 MCM is derived from other river basins[1] and the rest comes from groundwater.

Are there any other viable options for Delhi? Further import of water from other river basins, like the Beas, Sutlej and Ganga is not an option[1]. Being heavily agricultured, these hinterlands require between 30 and 60 cm of water for a wheat, sugarcane or rice crop. Since the recharge of groundwater in these areas is less than this requirement[1], they are deficit in water, resulting in depleting water tables. Intense conflicts may lie ahead and signs of things to come are visible already. Furthermore, in Delhi, for the last 20 years we are over drafting groundwater by more than three times the rate at which it is replenished by rain[1], resulting in a serious resource and ecology crisis. Recycling (secondary) of water is unrealistic, as the cost per person per year comes to Rs 9000, almost one-third of the per capita income of the country, and rainwater harvesting can provide not more than 5% of Delhi's annual water demand (see Appendix 1).

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A local solution

The only water resource we have is the surplus monsoon flow in the river Yamuna, which goes to the Bay of Bengal. According to the data[2] from Flood and Irrigation Department of Delhi (2003), we have ~4000 MCM of unused monsoon discharge flowing out of the Wazirabad barrage. This is almost four times the annual Delhi Jal Board (DJB) supply for Delhi, which is ~1100 MCM.

The river floodplains are a natural storage for large quantities of water. For millions of years, during the monsoon, the river has been bringing sand from the mountains and depositing it along its basin, forming the floodplains. This accumulated sandy layer[3–5] exists to an average depth of 40 m. Sand is a highly permeable and porous aquifer soil. A simple experiment shows that a glass of floodplain top layer dry sand can store up to 50% of its volume of water and, thus, is an ideal water-recharge zone and reservoir for storing freshwater[3]. Unlike for a lake, no water is lost to evaporation.

Hydrological profile of the Yamuna floodplains in Delhi

The Yamuna enters Delhi at Palla and runs about 25 km to Wazirabad and from there traverses a similar distance to the Okhla barrage, where it exits to Haryana. The floodplains is an area about 2 km wide, contiguous to the banks of the river. A simple calculation gives us an idea of its immense potential to store water.

To evaluate the floodplains for the water security of Delhi, we need to know the area of the floodplains[6], the depth of the water-absorbing sand top layer and its ability to yield water on demand. This is worked out as shown in Table 1.

Specific yield indicates the volumetric fraction of the bulk aquifer volume that a given aquifer will yield when all the water is allowed to drain out of it under the forces of gravity. According to Wikipedia[7], the specific yield (%) of medium sand is: 15 (minimum), 26 (average) and 32 (maximum).

Table 1. Potential of the floodplains to store water

(i) Total area of the floodplains[6]: 97 km^2
(ii) Soil composition of top layer[4]: Sand
(iii) Depth of sandy layer freshwater line[4]: 35 m (average)

Below the sand layer is an impervious layer of clay and kankar, and below that is bedrock (see Figure 1)[4].

(iv) Bulk volume of the sandy floodplains aquifers: (i) × (iii) ~3400 MCM (MCM = million cubic meters)

(v) Water-holding capacity in relation to its volume (50%): ~1700 MCM

(vi) Specific yield of the Yamuna floodplains (MCM/yr):

Minimum	Average	Maximum
510	883	1086

The annual water supply of Delhi is ~1100 MCM (according to DJB). The floodplains, thus, have a potential to meet more than two-thirds the annual supply of the city. The Central Ground Water Board (CGWB) (S. Shekhar and P. N. Singh, pers. commun.) claims that the recorded maximum specific yield from the Yamuna is 20%. This would work out to be 680 MCM/yr for the entire floodplains.

The proposed scheme

Over the last few decades the river waters have been diverted into many canals for irrigation. This has markedly reduced the flow of water in the river, so much so, that instead of annual floods we now have only decadal floods. Floods that inundated the entire floodplains of the Yamuna in Delhi have been recorded in 1978, 1988 and 1995, in the recent past. This has adversely affected the recharge of the floodplains. The scheme we give below is to restore the annual recharge of the floodplains.

We need to create several barrages with embankments from the entry point of the Yamuna river into Delhi, at Palla, through Wazirabad till Okhla, the exit point. We may need a 30–40 m deep underground bund at Okhla across the river. Such a natural bund already exists at Wazirabad, where the bedrock rises, almost touching the riverbed. These bunds help store water underground and prevent it from flowing downstream through underground flows. The area of the floodplains needs to be lined with appropriate embankments. The existing one, the Pushta, may need modification. We then need to have a controlled or regulated flood on the entire embanked floodplains in Delhi, by allowing excess monsoon flow successfully from an upstream barrage, to cover the embanked plain to a depth of 2 ft for a few days, by closing the next downstream barrage. Recharge wells may be dug where the sandy layer is interspersed with less pervious clayey or kankar layers.

A few days of regulated floods will be enough to saturate the floodplains sand with water. At one site in Kalindi Kunj near Okhla, it was found that 8 m of water in a dug well was absorbed in the sand below in less than half a day (M. Bhatnagar, INTACH, pers. commun.). The total requirement of captured monsoon discharge is less than 1 billion m^3, or a quarter of the total monsoon discharge. After this, the river will flow its course as usual. The water gathered by the sand layer of the floodplains can be used for the rest of the year, particularly in times of scarcity – the summer months. The cycle can then be repeated the following year. The reason we are presenting this scheme is that we badly need this local water resource. Since the frequency of natural floods has gone down from annual to decadal, due to diversion of river waters into many canals, we have to arrange for a regulated flood in the floodplains.

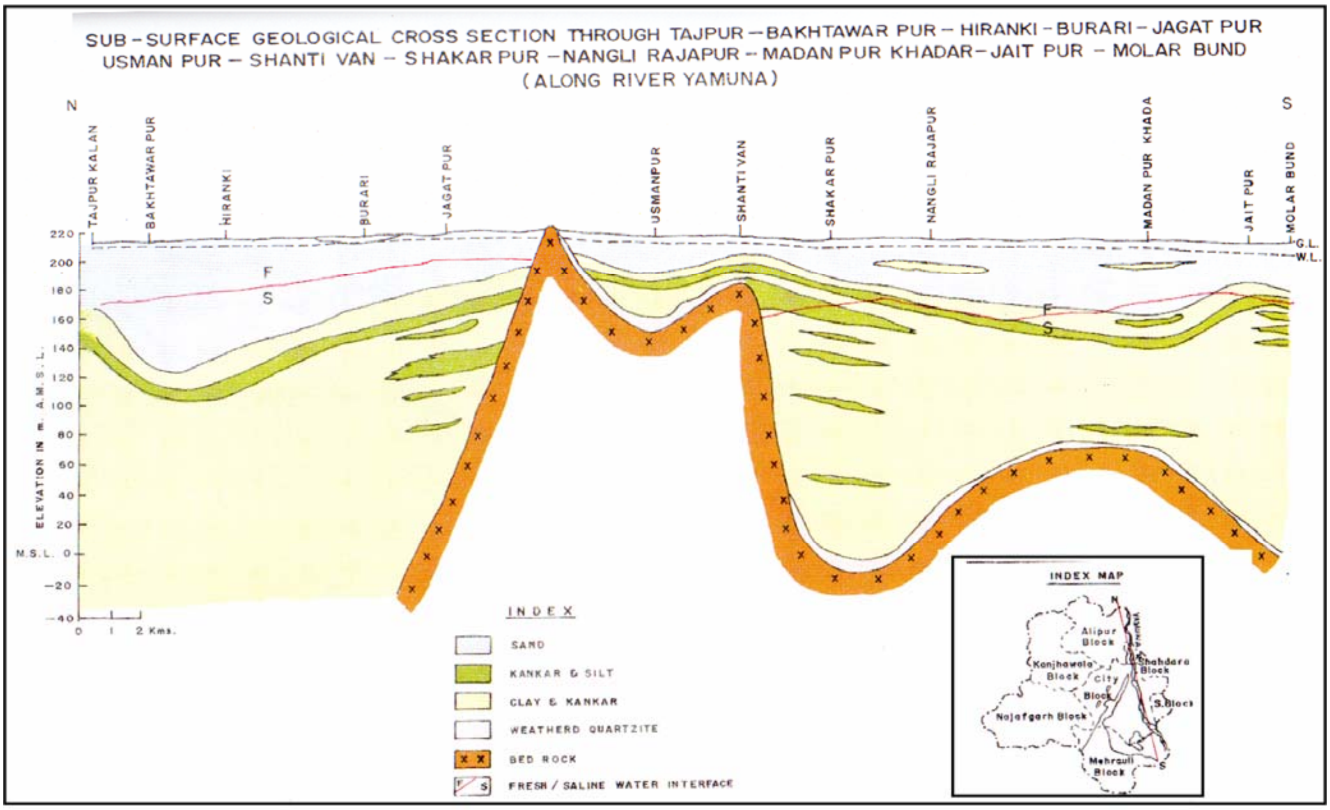

Figure 1. Central Ground Water Board Yamuna profile.

This scheme can potentially yield about 700 MCM of water non-invasively every year for Delhi's needs. This needs to be seen in the perspective of the total of ~1100 MCM that is supplied by the DJB to the city, to appreciate its import.

Supplementary remarks

1. At the moment, hydrogeology mapping of the floodplains is incomplete, especially across the river profiles. This is absolutely essential to set up a tube-well grid and also to locate isolated troughs of sandy aquifers. This is presently being completed by the CGWB.

2. Freshwater occurs till an average depth of 30–40 m below ground. The heavier saline water is found below this. When a large column of freshwater is withdrawn, a cone of depression is created below the tube-well site. Some upwelling of the saline water from 30 to 40 m below can occur after a point. At this point the drafting of water must be stopped and the water levels allowed to relax to their normal configuration, i.e. freshwater above and saline water below. Water can then be withdrawn again. CGWB has harvested (pumped) water from 8 m above the level of the freshwater, saline water boundary.

3. Unless the river is in flood, the groundwater levels in the floodplains are lower than the river. So no lateral flow into the river is expected. But since the river enters Palla at an altitude of 210 m and leaves Okhla at an altitude of 198 m, the water stored in the floodplains will move down in an oblique flow towards the river. This is the sense in which the river is influent. Otherwise, the river would be effluent or only feed the floodplains.

4. In this scheme, due to extraction of water for use by the city, the water table of floodplains will be at its lowest after extraction during the summer months (even 30 m blg). This may be potentially dangerous, as the water flowing in the river during non-monsoon months may seep into the floodplains and impede the river flow. However, it will not be so because of the following: (a) Along the river water flows much faster, as it is a free flow, than any lateral or downward movement into the floodplains, which is not a free flow but a percolation through a sand layer. This means that minimum percentage flows will be maintained. (b) As soon as the monsoon arrives, the situation reverts to normal. (c) The river flow above Palla is normal and that from Wazirabad onwards will receive treated discharge from Delhi (Najafgarh drain, etc.). So in any case only the Palla–Wazirabad part of the river will be low. (d) If we extract water in the Palla–Okhla segment, there will be some downflow from the upstream river floodplains into both the Delhi segment of the river and the floodplains. This will need an inter-state agreement.

5. An underground bund can be created at Okhla to prevent groundwater flow out of Delhi.

6. There is much more water in the Uttar Pradesh floodplains on the eastern part of the river from Palla to

Wazirabad and in the east where the Okhla Bird Sanctuary is located. Agriculture requires only 2 m depth of floodplains (equivalent to 30–50 cm of water at the specific yields given above) and this may be supplied to the farmers, while the rest 20–25 m can be used by Delhi through an inter-state agreement. Also, the Hindon river floodplains can be used after treating the discharge water in these areas.

7. There is evidence of contamination of the floodplains aquifers from human discharge. This has two origins: (i) The sewage drainage from land, from, for example, the Najafgarh drain, will have to be treated to render the sewage free of contaminants. This is a larger problem of sewage treatment that has already been contracted to Engineers India. It is clear that all sewage will have to be treated before releasing the wastewater to the river. (ii) The present practice of floodplains agriculture renders the water below the topsoil to be flushed with wasted fertilizer, which can cause ammonia contamination.

8. Periodic desiltation of the surface sand layer will be needed.

We have highlighted some of the important concerns that have to be addressed. Only after the whole mapping of the river floodplains is completed and field trials carried out can we move from the potential to the actual.

Economic value

Economists have always been at odds when evaluating the financial value of a natural resource. But in this

Appendix 1. Comparison of annual water-yielding capacity of floodplains, rainwater harvesting and water bodies

Rainwater harvesting
- Source of water: Monsoon rainfall
- Amount of rainfall during monsoons: 42 cm
- Rooftop area (10% of total area of NCT): 150 km^2
- Total recharge (@ 35 cm/yr): 52 MCM/yr

*About 20 cm falls during non-monsoon months, but most of it serves to wet the ground/rooftop and evaporate, and does not collect as run-off.

Water bodies
- Source of water: Monsoon rainfall
- Amount of rainfall during monsoons: 42 cm
- Average size of water bodies, including their catchments areas: 3 ha
- Total surface area of the water bodies: 629 × 3 = 1887 ha or 19 km^2
- Recharge potential of a water body from rainfall received in catchments: 30 cm of total 42 cm
- Total recharge potential of single water body: 30 cm × 30,000 m^2 = 9000 m^3
- Total for all 629 water bodies: 5,661,000 m^3/yr = 5.6 MCM/yr.

Pan evaporation from water bodies is of the order of 1–2 m/yr. With 30 cm = 0.3 m recharge, this means that if the ratio of the total catchment area per water body (including the water body area) to actual waterbody area is less than 3, there will be no net water sequestered by the water body! The catchment area must be much larger than three times the actual water body area for any water addition. The above calculation did not account for this loss.

There is no water addition from lateral ground flow in Delhi as now groundwater levels are below water body bottoms.

Yamuna floodplains
- Source of water: Surplus flow during monsoon months
- Amount of surplus flow available at Wazirabad Barrage (2): 4000 MCM
- Area of floodplains: 97 km^2
- Soil composition: Sand
- Water-holding capacity: 50% of total volume
- Specific yield (world average): 26% of total volume
- Depth of sand and silt layers: 35 m average
- Total water recharge potential: 1700 MCM
- Total annual yield: 883 MCM

Thus, the Yamuna floodplains is almost 160 times more potential water resource than all the other water bodies taken together in the city and almost 20 times that from water harvesting. This is primarily because of a large source of water available in the form of surplus flow during monsoons. Coupled with this is the fact that the Yamuna floodplains is highly permeable because of its sand composition and allows a quick recharge of water. This is not possible in other soils.

However, the conservation of water bodies is important as each drop is crucial for the city. At the same time, it instills a culture of conservation among the people.

instance the exercise is not at all difficult. One way is to use the commercial value of water at the market rates charged by private water vendors. In Delhi, the rate for such water is about Rs 1000 for a 10,000 litres (10 m^3) tanker full of water. The value of the water stored by our scheme in the floodplains amounts to about Rs 6000–9000 crore/yr of permanent annual non-invasive use[3].

However, many people may not like this way of pricing water. So let us look at another way – recycling the same amount of water. Enquiries with several Indian companies give a ballpark figure of Rs 100 per kl (or 1 m^3) for the cost of secondary recycling, which makes the water good enough for any use, except drinking. The cost of recycling, an amount that we can annually reclaim from the Yamuna floodplains, then works out to be the same, i.e. Rs 6000–9000 crore/yr.

Clearly, our scheme will save us ~Rs 6000–9000 crore/yr at current costs of water and preserve the resource. Note that the cost of water is likely to escalate faster than that of real estate. This underscores the importance of the scheme for the future.

Problems

However, due to the lack of knowledge about the potential and value of the floodplains, it is being destroyed by construction permitted by the authorities, in spite of being protected as a recharge zone in the Masterplan and by the Groundwater Authority[8]. This is being done against advice and directions from NEERI[5] and the MOEF Appraisal Committee[9]. An irreparable disaster is the dumping of flyash. (Recently, the Metro has dumped 13 lakh tonnes of flyash on the floodplains.) This has the effect of comprehensively and terminally killing the porosity of the aquifer.

Conclusion

Our suggestion is to secure all the floodplains which are delineated by the Pushta bunds and remove all other bunds and stop construction. We can then use the scheme of the regulated flood given above to have a local natural water resource that can non-invasively serve three-quarters of the water needs of the capital and save us Rs 6000–9000 crore of water resource in a year, at the same time preserving the ecology and flow of the river.

The regulated flood scheme we have presented here is a general one that can be implemented for any city situated on a floodplains river. There are hundreds of cities located around floodplains of various rivers and this scheme therefore has enormous potential in this era of water scarcity. In view of the uncontrolled urbanization, this would be an ideal natural water storage solution that is perennial and non-invasive.

1. Soni, V., Water and carrying capacity of a city: Delhi. *Econ. Political Wkly*., 2003.
2. Babu, C. R., Kumar, P., Prasad, L. and Rashmi, A., A Case Study of Wetland Ecosystems along the Yamuna River Corridors of Delhi Region. EERC Working Paper Series: WB-6, Theme: Wetlands and Biodiversity, see table 2.2, p. 15.
3. Soni, V., Three waters – An evaluation of urban groundwater resource in Delhi. *Curr. Sci.*, 2007, **13**, 760–761.
4. CGWB Yamuna profile.
5. Environmental Management Plan for Rejuvenating of River Yamuna in NCT of Delhi. NEERI report, October 2005.
6. Delhi Masterplan, MPD2001.
7. Wikipedia, Specific yield of aquifers.
8. The CGWA notified the Yamuna floodplains as protected for groundwater management on 2 September 2000.
9. Expert Appraisal Committee of the MOEF (1/12/06).
10. Revelle, R. and Lakshminarayan, V., Ganges water machine. *Science*, 1975, **188**.
11. Chaturvedi, M. C. and Rodgers, P. (eds), *Water Resources Systems Planning – Some Case Studies for India*, Indian Academy of Sciences, Bangalore, 1985.

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