

# Water and Carrying Capacity of a City: Delhi

*Depending on natural and strategic location the expansion of a city will be bound by some limits, which may be termed the carrying capacity of the city. A report of a study estimating available water resources for Delhi and the population that it can support.*

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Limiting scales exist for all natural features on the planet. For example, the size of mountains is limited by gravity and the strength of materials. The height of a tree is limited, apart from its genetic composition, by gravity in terms of the weight it can bear, the ambient soil and water, resistance to wind, etc. Similarly, populations of wild animals are limited by the size and feeding capacity of the habitat. So is the population of human beings on the planet, as suggested by the limits to growth argument.

Human ingenuity or technology has managed to transcend some of these limits. For example, consider the height of buildings which defying all expectation continue to rise. However, here too we are limited by the strength of materials, pressures of wind, fire hazards and resilience to tremors.

Such an argument also applies to the size of human settlements. This size clearly depends on such basics as the available resource of water and the quality of air, which keeps deteriorating as the quantum of human activity goes up. For large cities survival depends on the import of produce from far away. This means a very considerable activity depends on transport – not only for people going to and back from work but in bringing in the goods that they need. As size increases, so will the cost in time and money of transporting goods and people. If a city grows to be large enough so that it takes more than a couple of hours to commute to work, the productivity of such work activity is called into question. All this also has an impact on the health of the inhabitants. Human activity generates huge amounts of effluents, which have to be either dispersed far away or stored in safe disposal – a problem in all big cities today. High density and high volume can strain infrastructure beyond manageable limits.

This is a prosaic summary of some of the problems that plague ever increasing sizes of human settlements. They indicate that depending on its natural and strategic location the expansion of a city will be bound by some limits. This, we call its carrying capacity. Although many of these problems are essentially interlinked, we shall henceforth be concerned with the carrying capacity of a city with respect to water. This study concentrates more on understanding issues fundamental to the problem and making order of magnitude estimates rather than more exact quantitative estimates. Though, for specific purposes, it has been carried out for Delhi it may be readily used, on substitution of the relevant data, for any city.

In the 1960s the population of Delhi was about 3 million. There was no water problem and there were almost no shanties. This is exactly the time the first master plan was launched. It is remarkable that as the first master plan has given onto the second, the first Ring Road has given onto the second. The Ring Road, like the Peripherique, was meant to be a girdle around the city. Now that the third masterplan is looming we have nightmare of a third Ring Road to tighten the population noose around the city. The master plans have simply resulted in concentric expansion of the city and a high increase in the disaffected or shanty population (it is now almost 50 per cent of the total) and a breakdown in the essential services, health, water, sanitation and a forbidding increase in pollution. The present population of Greater Delhi is about 14 million. All these issues need to be discussed but we shall concentrate on water.

There are two local sources of water in Delhi, the river and groundwater reserves. Whereas the river was adequate till three decades ago, today, there is no river for most of the year and the groundwater level in most parts of Delhi has receded from

about 2-5 metres to 8-12 metres. This indicates that both these sources are finite and now almost exhausted by the city's growth. It is clear that we have exceeded the local limit, since the river and the ground water have been grossly over-exploited, which is surely heading us into an environmental problem. Water is now imported from far afield, the Ganga and the Beas, to the detriment of their catchment areas and basin ecologies.

In what follows, we estimate, at an approximate level, what are the available water resources and the population it can support. We consider, first, the water resource from the Yamuna and that which is extracted from other catchments. We then present an approximate way of estimating the groundwater recharge. For Delhi the sum of these constitutes the water resource for Delhi. We then look at ways of augmenting water availability by water harvesting or recycling. For a city of the size of Delhi, while the former can contribute only a small fraction of the requirement, the latter is prohibitive in cost and, further, inadequate in its quantum.

The river Yamuna flows past Delhi. From Mughal times it has been used to supply water to the city. There are two distinct sources of Yamuna water: (i) The river, as it enters Delhi, is forded in the north of Delhi by the Wazirabad waterworks (water treatment capacity: 0.546 mcmd – million cubic metres per day) and at Chandrawal (water treatment capacity: 0.409 mcmd), from where water is pumped to the city; (ii) The Tajewala barrage, the seat of the Western Yamuna Canal, from which water is fed to Delhi through the Haiderpur water works (water treatment capacity: 0.910 mcmd); and (iii) ranney wells on the Yamuna bed contribute about 75 mcm a year [Rohilla, Bansal and Datta 1999].

The combined flow from first two sources is as follows:

Period	Flow	Total In Mcm
November to February	231 cusec	68
March to June	255 cusec	76
June-October		580

Source: Rohilla, Datta and Bansal 1999.

Of these, from November to June, almost all the flow is extracted and used for the NCR water supply. During this period the river is practically non-existent. During the monsoon, the Yamuna resumes its identity as a river and the present capacity

of the treatment plants permits about 40 per cent of the flow to be used for the water supply [Rohilla, Datta and Bansal 1999].

Therefore, the total Yamuna water available annually is about 376 mcm per year. Of this, there are large evaporation and other minor losses, that may be estimated to be at least of the order 30 per cent, thus the actual water use from the Yamuna is around 264 mcm per year.

### Other River Sources

Delhi imports water from: (i) The Upper Ganga Canal via a pipeline from Murad Nagar. This amounts to 200 cusec or 180 mcm per year. Since the water comes via a pipeline there are negligible evaporation losses. The installed treatment capacity is for about 0.450 mcmd or 160 mcm per year and (ii) lately, Delhi has received water from as far afield as the Beas via an open canal which joins the Western Yamuna Canal. This amounts to about 290 mcm. On writing off 30 per cent as evaporation and other losses, the actual water use figure from this source is about 190 mcm. Further, because of limited processing capacity the utilisation of this source is possible only for about 8 months a year, leaving a net utilisation figure of about 130 mcm per year (Affidavit filed by Union of India and States of HP and Haryana in Supreme Court case, Sureshwar Sinha vs Union of India and others (WPC 537/92).

The total actual water use from all these sources, then, is about 630 mcm per year. It must be noted that a large fraction of this water is not local but imported from other river basins.

### Groundwater Reserve

We present a simple way to estimate the groundwater reserves of the city using rainfall and pan evaporation data. Germane to this exercise are the following facts:

– Precipitation is lost to evaporation unless it occurs in bulk. This is because rainfall up to 0.25 cm a day serves merely to wet the surface of the earth, evaporating subsequently to simply add to the humidity in the atmosphere. Water recharge thus occurs only on days when rainfall exceeds 0.25 cm.

– Precipitation in excess of 0.25 cm a day occurs in Delhi mainly during the monsoon, i.e., July, August and September. According to climatological atlas this is 15 cm in July, 15 cm in August and 12 cm

in September. The rest of the year accounts for the balance of roughly 13 cm but does not figure in the groundwater budget.

– The number of days it rains more than 0.25 cm is 8, 8 and 4 for July, August and September respectively. (Data from Climatological Atlas and Met Data, meteorology department.)

– Pan evaporation data for these months is

(a) July	0.69 cm/day
(b) August	0.5 cm/day
(c) September	0.6 cm/day

– Evaporation from a pan is different from that from soil. Typically, monsoon wet soil is known to have an evaporation rate of 70 per cent of the pan rate. Since soil retains moisture, a similar evaporation rate obtains the following day. During the monsoon the soil is wet, so even when there is no rainfall evaporation occurs.

– The rule of thumb is that for twice the number of rainy days we allow for evaporation at 70 per cent of the pan rate – this is the so-called ‘potential rate’ of evaporation. For the remaining days during the monsoon the evaporation rate, on the average, is found to be approximately 50 per cent of the potential rate.

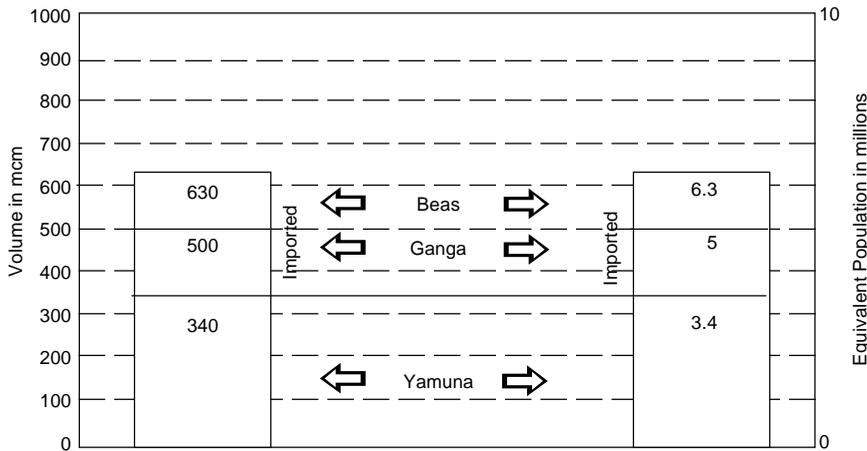
This is explained by the table. Thus as shown in the table, we have 14 cm of balance useable rainfall for the year which can be absorbed by an aquifer or run-off. With an aquifer potential of 50 per cent we have a recharge in groundwater of 7 cm a year. This is probably higher than the actual recharge of groundwater for Delhi.

Water harvesting is a very useful conservation measure, particularly for rural areas and small towns. However, for large cities it will make only a marginal impact as we see below:

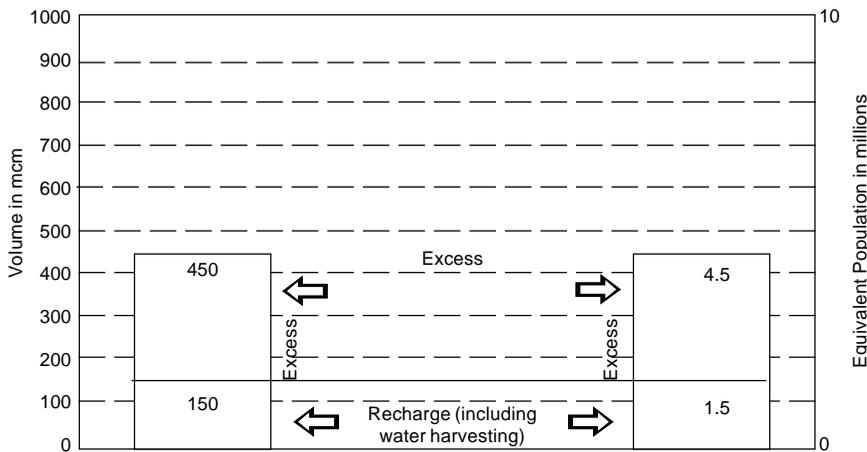
(i) Rooftop water harvesting is being zealously pursued in Delhi. The total area of the NCR is approximately 1,400 sq km, of which about half is urban. Roughly, 10-15 per cent of the urban area is rooftop that can be farmed for water. Again simple wetting (< 0.25 cm per day) will not contribute to gathering. Of the 42 cm of monsoon rain, on leaving out evaporation and line losses, a maximum of 30 cm may be recovered. This works out to an upper limit of 2 cm of groundwater recharge per year for the entire area of the NCR. Besides, rooftop water harvesting is cost-intensive as it requires roof waterproofing and piping to a safe underground storage.

(ii) Roughly, an equivalent amount of water can, perhaps, be collected through catchment water harvesting by trapping some of the runoff in reservoirs.

**Figure 1: Annual Volume of River Water**



**Figure 2: Annual Groundwater Withdrawal**



The total water harvesting potential can thus add about 4 cm per year to groundwater recharge.

It is now extremely simple to put limits on groundwater recharge simply from the total area of the the NCR of Delhi, which is about 1,400 sq km. The total groundwater recharge per year by rain then comes to, 1,400sq km × 11 cm. This includes the potential for water harvesting – it is clear that for a huge city like Delhi this makes only a marginal contribution. The total groundwater recharge then amounts to about 150 MCM per year. (We have not included here the deeper underground lateral flow from external sources.)

ished. This provides an explanation of the decline in the water table. If we withdraw the amount that is replenished 150 mcm per year, it leaves a shortfall of 300 mcm or the equivalent of three million in population. One likely cause of this is that agricultural land around South Delhi has been transformed into high profile hacienda suburbia. This segment of farmhouse owners is not shy to state their opulence by having grand gardens and swimming pools which consume rather a lot of water.

A recent report indicates that due to fertiliser use and effluent discharge, the pollution of groundwater in and around Delhi is beyond health limits insofar as

fluorides, sulphates and nitrates are concerned [Datta 1999].

We use the figure declared by the Delhi Development Authority for the total per capita requirement of water – about 300 litres per day (as per the master plan for Delhi, which indicates, 225 litres for domestic use and the rest from public use, including industrial, fire service, parks and gardens and hotels, etc). The carrying capacity from the total river water resource for Delhi then works out to about 6.3 million people. The carrying capacity from the total groundwater reserve (including water harvesting) works out to about 1.5 million people. This yields a total carrying capacity of about 7.8 million people (see Figures 1, 2).

Let us now consider the two main fixes for adding to the water reserve.

Recycling of sewage water is an idea now integrated into the water management plans for modern cities. This requires an extensive investment and infrastructure in terms of sewage grid and stations that can carry out primary, secondary and tertiary water treatment depending on the level and nature of the pollution. Full treatment is required for industrial effluents that contain heavy metal or chemical toxins. Even after treatment, this water is not fit for irrigation as it can cause a cumulative contamination of groundwater. The only sewage source that may be recycled is domestic sewage which has largely organic pollutants.

The total sewage discharge for Delhi is estimated at about 600 mcm a year. Of this, perhaps, domestic recyclable waste could be maximally 400 mcm a year. Of this about 50 per cent may be recovered – i e, 200 mcm. Some pilot projects on recycling water in the city of Mumbai,<sup>1</sup> estimate the cost of converting domestic waste to useable water to be between Rs 20 and Rs 80 per kilolitre, depending on the quality of water being fit only for irrigation or non-potable domestic use. This means a running expenditure ranging from Rs 400 to Rs 1,600 crore for 200 MCM per year. A water recycling system thus means a huge investment in the city. Let us see what investments have done to the city.

### Sounding an Alert

In the absence of official figures, according to a study by INTACH [Rohilla, Datta and Bansal 1999], the figure for private withdrawal of water from tubewells amounts to 450 MCM a year! This is more than three times the amount that is replen-

**Table: Rainfall and 'Potential Rates' of Evaporation**

Month	Rainfall (cm)	Rainy Days > 0.25 (cm)	Potential Rate (cm)	Evaporation Loss (cm)	Balance Total (cm)
July	15	8	0.49	11.5	3.5
August	15	8	0.35	8.2	6.8
September	12	4	0.42	8.0	4.0

Note: Evaporation Loss for the month = No of rainy days × potential rate × 2 + (Days in the month – no of rainy days × 2) × (50 per cent potential rate).

The irony of planning in Delhi however is that all development in Delhi has taken place without the most elementary regulation in terms of providing for transient housing for the influx of migrant labour working on sites. This discrepancy is obviously deliberate – it is designed to bring great profit to the nexus between the DDA and the developers, at the cost of reducing labour to a subhuman existence and the city to a slum.

It is for this reason we have seen such huge lopsided investment in Delhi in the last few decades. The consequence is: (i) over 50 per cent of the population of Delhi is in semiformal shanties or 'jhuggies'. This has happened in the last 40 years, since the first Master Plan (1962); (ii) the migrant labour has settled on the green areas. Once this has happened, the areas are declared non green by the DDA and opened for development; and (iii) the landscape of Delhi, including the roadside, is perennially a series of dumps as developers take over public space and sometimes do not even clear it after.

Any investment simply adds to the jhuggies. It is to be considered that a huge investment like a water recycling project could well add more population under these circumstances.

The cost of recycling 200 mcm per year of water, if the end use is not only for irrigation, is of the order of Rs 1,600 crore and will service 2 million people. This means, effectively, an expenditure of Rs 8,000 per person per year for water alone. This is severalfold more than the charges for water anywhere in the country – it is close to the per capita income. In the present lawless planning scenario, it will add much migrant labour as additional population. Finally, recycling waste water is a good idea, but it can only increase the carrying capacity of Delhi by a couple of million, which still leaves us with an overpopulation of at least over 5 million today, and thus it really cannot solve the problem.

### Import of Water: A Criterion

In this part we shall evolve a criterion on the import of water from hinterland catchments to service a city. The total useable rainfall in the hinterland area is that left after evaporation, for groundwater recharge and runoff. Remember, though, that most of this runoff occurs during the monsoon so will run down unused in rivers. If it goes to a reservoir, on the plains lands,

the reservoir can at best be of limited depth and cover only a limited amount of catchment. It will also lose a large fraction of water in evaporation. Thus, it is mainly the groundwater recharge that is useable. Estimate the total population and use – mainly agricultural – in the hinterland. The difference between useable groundwater recharge and population is then crudely the surplus available for export.

Consider the case of Delhi, Delhi receives imported water from three external sources, the Tajewala canal upstream from the Yamuna, the Ganga canal and the Beas.

Some of these sources are closer to the Siwalik hills than Delhi is, so we can assume that they receive considerably more rainfall. Let us put this figure at double that for Delhi, at 100-120 cm per year. In this case, using the same method as before to estimate the amount of water left after evaporation we get about 40-50 cm for groundwater recharge and runoff.

If we allow for a 50 per cent aquifer recharge we get a figure of .2-.25 mcm/sq km/year for the recharge of groundwater. The rest runs off. In view of this runoff being during the monsoon and due to storage constraints, very little is recoverable. We shall work with a figure of 0.25 mcm/sq km/year of useable water.

However, a caveat remains. We have not included the irrigation water that streams in via canals from all the hill dams. This is a substantial component of the water requirement for the cultivation of wheat (30 cm per crop), sugar cane (40-50 cm per crop), rice (over 60 cm per crop). However, it is well known that less than half of the crop land saturates the total capacity of these canals. Therefore, over half of the cropland does not have the benefit of this canal water. We shall therefore leave this out from our accounting.

As we have indicated above, the minimum water requirement is for a wheat crop and that is 30 cm or 0.3 mcm/sq km/per year.

On this basis the difference between the water Delhi imports and the wheat crop requirements is very small. This means that the population density, the high irrigation requirement and fertility of the hinterland around Delhi does not permit the import of water to service Delhi. Only if the population density is small or the agricultural use of water less, can there be a surplus that may be imported to the city. This is not the case for Delhi.

Such simple estimates can be used to

work out the carrying capacity for any city and constitute an essential exercise in planning population limits for a city. Any excess of population beyond the limits found by such an exercise can only be to the detriment of the people who live there, and further to the detriment of the people whose catchments are being usurped to service the increasing the city's population.

Already, in the case of Delhi about 290 mcm of water is imported from the Ganga, and Beas catchments. This is over a third of the total water resources of Delhi. If we include the Tajewala barrage as a non-local catchment, this figure becomes even larger. The point is that water is scarce and people from these catchments will soon be demanding their rights. Furthermore, it is ecologically damaging to transfer water from outside river basins and catchments.

Secondly, it is ecologically disastrous to extinguish the flow of the river Yamuna for five months. This kills all life that sustains the quality of the water in the river. Further, the huge volume of the effluent discharge of Delhi, over this entire period, collects on the river bed instead of being dispersed by the flow, causing the water and the subsoil water to become dangerously toxic. This is already the case. Thus, if the flow is revived during the whole year there will be a further shortfall in water resource. Finally, groundwater overuse and pollution may put all our groundwater out of commission.

As stated earlier the groundwater being actually withdrawn for the National Capital Territory is 450 mcm per year, whereas the amount being replenished is merely 150 mcm per year. This means that if we stay within the permissible withdrawal of 150 mcm per year a shortfall of 300 mcm remains, much of which is for important agricultural use. If this is to be met from the existing resource it amounts an additional shortfall for an equivalent three million of population!

In Delhi where the population is already almost two times the carrying capacity and increasing unchecked, we are well on course to urban genocide. **[EWT]**

### Note

[I would like to thank Subash Chander for having taught us to use climate data to work out groundwater recharge and for ready inputs. Sureshwar Sinha is to be thanked for giving various relevant facts on water flows into Delhi and discussions; D Sahdev for his fellowship; and

Gautam Soni, Ravi Mehrotra and R Rajaraman are for their critical but friendly reading of the article; Poonam Bhagat for her encouragement.]

1 This information is available from, for example, Voltas, Bombay, for units of a capacity over 10 k litres per day. Some of the Canadian sources for domestic water recycling indicate the cost to be higher.

## References

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