Ageing Large Dams and Future Water Crisis

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Ageing large dams are the blind spots of India's water policies. More than 4,000 large dams reach the minimum age of 50 by 2050, preparing the ground for a future water crisis. The consequences and probable remedies of such a crisis are analysed.

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India's current and future water crisis is well-documented in India's policies and water management discourse. Large parts of India are already water-stressed. Meanwhile, rapid growth in demand for water due to population growth, increasing urbanisation, changing lifestyle and consumption patterns, inefficient use of water and climate change (together termed as "visible knowns" in this article) pose serious challenges to water security (MoWR 1987, 2002, 2012; Garg and Hassan 2007; Gupta and Deshpande 2004). Apart from these "visible knowns," Garg and Hassan (2007) express alarm over water scarcity from the point of view of double counting of regenerated groundwater and deteriorating water quality, thereby calling for an urgent review of water policies.

The large dams are projected as water security to tackle the water crisis emanating from "visible knowns," and their advantages get highlighted in plans and policies (for example, CWC 2009; MoWR 1987, 2002, 2012). But, a very crucial and grave water crisis is emanating from over 5,000 large dams in India, due to their ageing and structural deterioration of service life, which has been found to be either missing, omitted, or ignored in various policies of union and state governments, and India's water management discourse. If this impending water crisis continues to be ignored in India's water planning, then the crisis will get compounded beyond what is currently estimated or anticipated in the future.

It is therefore important to identify the downsides of the large dams of India—that is, the factors that turn the advantages of large dams into liabilities or sources of water insecurity—the undercurrent of the water crisis emanating from such downsides, and policy lapses in order to devise a comprehensive strategy to avert a monumental water crisis awaiting the country in the future. The questions posed in this article, thus, are: What are the downsides of large dams that have turned out to be blind spots in India's water policies and water management discourse? What are the consequences and cascading effects of such blind spots on future water crisis? And, what are the probable remedies to overcome the future water crisis emanating from India's ageing large dams?

Downsides of Large Dams

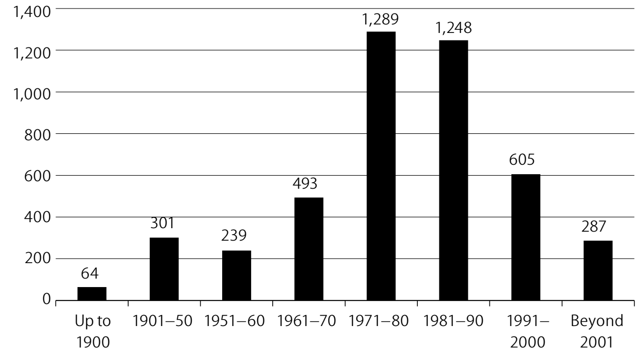
India possesses over 5,000 large dams (CWC 2009), which are considered as a bulwark of India's water security by the government. The Central Water Commission (CWC 2016) and Ministry of Water Resources, River Development and Ganga Rejuvenation (MoWR, RD & GR 2019) have declared that

> There are about 5,264 large dams in India and about 437 are under construction. In addition, there are several thousand smaller dams. These dams are vital for ensuring the water security of the country.

Large dams in India have been acknowledged for their contribution in overcoming temporal variability of precipitation (that is, the variation of rainfall occurrence over time), thereby providing water security directly, and food and energy security indirectly (Shah 1993). But, contrary to these benefits, concerns are expressed that India's large dams get justified due to scientism (Molle et al 2009), despite the several limits that they suffer from.

Spatial limit: The scope of building large storage structures in India has a spatial limit. This has not been reflected in any of the water policies so far. The National Commission on Integrated Water Resources Development (NCIWRD) assesses the utilisable surface water from all storage and diversion as limited to 690 km^3 (cubic kilometres). Considering the existing 5,000+ large dams, the government and scholars have stated India's per capita storage capacity[1] as too low in

Figure 1: Number of Large Dams Built during Different Periods of Time



Source: Prepared by author on the basis of CWC (2009).

comparison with countries such as the United States (US), China, South Africa, and Australia (Briscoe and Malik 2007; PIB 2012). It is not that India possesses infinite space to match the per capita storage of these countries to tackle any water crisis that may be arising in future.

According to such a comparison, India's per capita storage capacity, estimated on the basis of the 253 km³ storage capacity (as on 2012), is 209 m³, whereas the per capita storage created by the US is 2,192 m³ and that created by South Africa is 609 m³ (PIB 2012). Even in a hypothetical case, if 690 km³ of storage space is created in India, the per capita storage for 1.21 billion population (in 2011) will come to about 400–450 m³, which is nowhere close to the per capita storage of either the US, Australia or South Africa. There is no space at all in India even for creating 500 m³ for every person and, therefore, any plan to tackle future crises—originating from rising population, climate change, etc, or other "visible knowns"—with the assumption of higher per capita storage has a spatial limit: a fact blinded in various water policies and water management discourse of India.

Temporal limit: Just like large storage structures possess a spatial limit, they also possess a temporal limit, which has not been addressed in any of the water policies of India. The CWC declares that the over 5,000 completed and ongoing large dam projects are vital for ensuring India's water security. But, a substantial number of India's large dams were built half a century ago. This factor is not accounted for while assessing water security in relation to these large storage structures. Figure 1 shows the number of large dams built during different periods of time. From the figure, it is clear that about 64 large dams were built in the 19th century, 301 large dams were built in the first half of the 20th century, and about 237 large dams were built during 1951–60 in the second half of 20th century. Hence, as on 2015, the age of these dams is as follows: about 64 dams are more than 115 years of age, 301 large dams are between age 65 years and 115 years, and 237 large dams are more than 55 years, of age. Cumulatively, about 619 large dams have already crossed the age of 50 years as of 2015.

The scenario will turn alarming as India approaches the years 2025 and 2050: 64 large dams will turn minimum 125 years of age, 301 will turn minimum 75 years of age, 237 large dams will turn 65 years and an additional 496 large dams will cross a minimum age of 50. In all, about 1,115 large dams would have aged at least 54 years by 2025. By the year 2050, as many as 4,264 large dams would have aged at least 50 years, with 64 large dams being 150 years old, 302 large dams turning minimum 100 years old and about 3,880 large dams with ages varying between 50 years and 100 years.

Structural vulnerability: Any large storage structure, be it concrete, masonry, or earth, becomes structurally weak as time progresses. Hence, their ability to overcome the temporal variability of precipitation declines. This is because construction material, such as concrete, steel, etc, deteriorates due to abrasion of waves, silt, sand, and gravel, thermal expansion, and cavitation. According to Portland Cement Association, corrosion of reinforced steel over time is the leading cause of concrete deterioration which occurs due to contact with chloride ions, carbonation, sulphate attack, acids, moisture, and expansion of aggregates (PCA 2002).

Large dams are an assembly of different components much like a computer system or an automobile. The components of large dams are built with different construction materials. For example, spillways are built with concrete and steel reinforcement; the flanks of the dam are predominantly built with earth or rockfill; earth dam core is built with impervious material like clay; the dam slopes are protected with rip-rap; energy dissipation arrangements with concrete; and concrete key walls bonding with earth component and wing walls/training walls are all built with concrete. These different components of a dam are designed to withstand different loading combinations, and therefore they are subjected to differential levels of stresses depending on their load combinations.

Dams that span decades, therefore, experience differential settlement of foundation, clog of filters, increase of uplift

Table 1: Reservoirs with Loss of Live Storage Capacity

Sl No	Dam	State	River	Year of Construction	Live Storage Loss (%)	Loss of Storage as on Year
1	Hirakud	Odisha	Mahanadi	1957	24	1989
2	Bhakra	Himachal Pradesh	Sutlej	1963	9	1997
3	Tungabhadra	Karnataka	Tungabhadra	1953	15	2003
4	Srisailam	Andhra Pradesh	Krishna	1984	24	2004
5	Maithon	Jharkhand	Damodar	1955	25	2001
6	Matatila	Madhya Pradesh	Betwa	1956	38	1999
7	Khodiyar*	Gujarat	Shetrunji	1967	36	2008
8	Sriram sagar	Andhra Pradesh	Godavari	1970	50	1999
9	Nizam sagar	Andhra Pradesh	Manjira	1930	50	1960
10	Lower Bhawani	Tamil Nadu	Bhavani	1953	28	2005
11	Linganamakki	Karnataka	Sharavati	1957	3	2002
12	Nagarjuna sagar	Andhra Pradesh	Krishna	1966–67	25#	2011

*Medium project and the loss is gross storage; # the loss is gross storage.
The data for respective dams has been taken from Rathore et al (2006); Jain et al (2012); Durbude (2014); Narasayya (2012); Thakkar and Bhattacharya (2006); Majumdar (2015); Mahabaleshwara and Nagabhushan (2014); Durbude (2014); Lok Sabha Debates 2011.

pressures, reduction in freeboard, cracks in the dam core, loss of bond between the concrete structure and embankment, reduction in slope stability in earthen and rockfill dams, erosion of earthen slopes, and deformation of dam body itself (USSD 2010). Thus, dam components lose strength differently during their lifetime and every component within a large dam ages at a different rate (McCully 2001). Hence, as a dam ages, the impact of the erosion of earthen components, seepage of water through the dam body and foundations, and sedimentation occur at a rate different (or adverse) than what has been assumed by the policymakers and planners.

Different generations: According to Bowles et al (1999), the fact that the dams are products of different generations adopting different design standards and construction practices, is in itself a greater concern than the dam ageing process. Table 1 (p 38) shows that India's large dams were constructed during different periods of time. Therefore, the design standards and construction practices differ widely amongst the 5,000 large dams. During the British rule in the 19th century, India's dams were built with rubble masonry (Chrimes 2009). According to Tappin (2002), the adoption of British standards of concrete technology in India was improper, given the climatic differences between Britain and India, poor skilled Indian workers, and poor maintenance mechanisms.

After India's independence, the Bureau of Indian Standard's (BIS) design codes have been revised from time to time, updating the latest technology (Table 2). According to the BIS (2010), design codes are revised to reflect the latest practices based on experience gained from the past. For example, Indian Standard IS: 456: 1978 (Plain and Reinforced Concrete) was first published in 1953, revised in 1964 and 1978 and then in 2000 (22 years later). The IS: 456–2000 inter alia was an improvement over its 1978 version with respect to the durability concerns of concrete in line with trends of concrete technology of the 21st century (BIS 2000). From Figure 1, it is clear that during 1981–2000, about 1,861 large dams were built in India, when IS: 456–1978 was in force. It was not possible for these dams built between 1981 and 2000 to incorporate the durability concerns of concrete updated 22 years later by IS 456: 2000 such as permeability to ingress of water, oxygen, carbon dioxide, chloride, sulphate and other deleterious substances (Prasad 2000).

Similarly, IS: 6512–1984 (criteria of the design of solid gravity dams) was first published in 1972 and was first revised in 1984. In the first revision, modifications were made to the (i) methods and formula for computing wave height and freeboard; (ii) modification of minimum freeboard; and (iii) permissible factor of safety related to the partial factor of safety. During 1971–81, about 1,289 large dams were built in India with the IS: 6512–1972 based on the past practices and less experience. The second revision has been underway since 2010 (BIS 2010).

Almost every code of the BIS is being revised from time to time with the updation of latest and better technology from what was available at any time in the past; whereas the time of construction of large dams has spanned over several decades overlapping with different periods of several revisions of dam design codes and standards. So, when India's dams weaken with age, the assumptions about their ability in addressing future water crisis also become weaker (as these assumptions are based on present and past design standards), with the outcome that India's water crisis will be worse than that estimated currently by planners and policymakers.

Fuzzy Spot

The loss of storage capacity of large dams over time is part of the dam ageing process. It has been documented sporadically in India, but not for every dam. Therefore, it is a semi-blind spot or a fuzzy spot of India's water crisis. In 1999, the Ministry of Water Resources (MoWR)-constituted NCIWRD estimated the total loss of live storage capacity by 2050 from all existing, under construction and contemplated projects as 65 km³. The source is attributed to computation by CWC of 46 reservoirs. But, no information of these 46 reservoirs, the particular studies, methods, or their locations is available in the NCIWRD report.

India's differently aged 5,000 large dams are located in diverse agroclimatic regions, diverse geomorphology, and have been subjected to changes in land use and land cover for centuries. Therefore, the sedimentation rates as well as storage capacity across dams vary both spatially from one dam to another and temporally within the design life of a dam. But, the varying sedimentation rates and loss of storage capacity in each of India's large dams have never been estimated or taken into account as adding to the future water crisis.

In 2009, the erstwhile Planning Commission "invented" the new figure of 53 km³ as the loss of live storage by 2050, but without any reasonable explanation or specific dam studies to show how the loss of live storage could vary by 10 km³ in comparison to the NCIWRD figure of 65 km³ of 1999. The fact that the NCIWRD

Table 2: List of Indian Standard Codes—Changes in Design Standards after a Period of Time

BIS Code No	Name	First Published and Revisions
6512	Criteria for Design of Solid Gravity Dams	1972, 1984
6934	Hydraulic Design of High Ogee Overflow Spillways—Recommendations	1973, 1998
11155	Construction of Spillways and Similar Overflow Structures—Code of Practice	1984, 1994
7365	Criteria for Hydraulic Design of Bucket Type Energy Dissipators	1974, 1985, 2010
11527	Criteria for Structural Design for Energy Dissipators for Spillways	1985
11772	Design of Drainage Arrangements of Energy Dissipators and Training Walls of Spillways	1986, 2009
7894	Code of Practice for Stability Analysis of Earth Dams	1975, 2000
6955	Sub-surface Exploration for Earth and Rockfill Dams—Code of Practice	1973, 2008
6966 (part–1)	Hydraulic Design of Barrages and Weirs	1973, 1989
12094	Guidelines for Planning and Design of River Embankments (Levees)	1987, 2000
8826	Guidelines for Design of Large Earth and Rockfill Dams	1978, 2002 (reaffirmed)
9429	Drainage System for Earth and Rockfill Dams—Code of Practice	1980, 1999
14815	Design Flood for River Diversion Works—Guidelines	2000

or Planning Commission merely considered figures like 65 km^3 or 53 km^3, without accounting for spatial/temporal variability of sedimentation across 5,000 large dams for the past 100 years, indicates the extent of the underestimation of sedimentation science in India and overestimation of storage capacity in the future (that is, 2050). Thakkar and Bhattacharya (2006) analysed the sedimentation rates of 23 dams and found that the actual rate of sedimentation in these 23 dams is not 1.3 km^3 per annum as considered by NCIWRD (1.3 multiplied by 50 years = 65 km^3), but, instead, is 1.95 km^3 per annum.

More examples of glaring loss of live storage in India's dams are shown in Table 1. Till 1999, Matatila dam had already lost 38% of live storage capacity in 43 years of its construction (Thakkar and Bhattacharya 2006). Srisailam dam had lost 24% live storage within just 20 years span of 1984–2004 (Narasayya et al 2012). By the year 2001, Maithon dam had lost 25.29% of live storage within a span of 46 years of its operation. Similarly, the Tungabhadra dam built in 1953 has lost about 15% of its live storage as of 2003 (Durbude 2014). Ideally, India's planners should have made the estimate of a loss of live storage only after disclosing the already lost live storage due to sedimentation in each of the 4,000+ large dams as of 1999 or 2011, which they have failed to do so till date. Therefore, the actual live storage capacity available in the 21st century India is inflated, and thus, camouflages the creeping water insecurity.

A scheme by the name "Dam Rehabilitation and Improvement Project" (DRIP) for the rehabilitation of 223 large dams within four states has been initiated since 2012 by the MoWR, RD & GR in association with the World Bank (CWC 2016; MoWR, RD & GR 2019). However, the information available in the public domain does not clarify if the scheme could overcome any of the downsides of ailing large dams, such as spatial limits, temporal limits, and structural decline, and then restore the declining live storage capacity to its original capacity. Seven years since 2012, any restoration of service life or storage capacity or water crisis averted due to DRIP has not found any mention in the policies and water management plan documents of India.

The assumption seems to be that large storage structures will continue to secure the water future of India forever, which is not the case. Therefore, the water crisis emanating from the downsides of ageing large dams continues to be a blind spot in policies, planning and water management of India. The ideal way to make DRIP more effective and meaningful is through the disclosure of the type of rehabilitation undertaken in the case of each of the 223 dams and the remaining 4,777 large dams, the type of structural decline averted, and live storage capacity and extent of years of service life restored.

Future Water Crisis

Declining storage capacity and utilisable surface water: The blind spots of large dams further make invisible the reality of India's ultimate storage capacity (USC) of all of India's major and medium projects (consisting of large dams), utilisable surface water (USW), and ultimate gross irrigation potential (UGIP), based on which the current policies are devised to address future water challenges. India's USC has been assessed as 385 km^3 (MoWR 2008; Garg and Hassan 2007). The erstwhile Planning Commission estimates the USC as 397 km^3 without deduction for the loss of live storage in the last 100 years (PC 2009) and the CWC Annual Report 2013–14 has further enhanced it to 408 km^3, but without any substantiation for this enhancement in the USC.

India's ever-constant figures of USC, USW, or UGIP in its water management discourse do not consider the impact of differential age (such as 64 large dams built 115 years ago, 302 large dams built 65 years ago, and 237 large dams built 55 years ago), different generations of dams built with different design codes, and their declining service life and storage capacity due to sedimentation. As a matter of fact, there has not been a single instance in India to show that sediment in a large dam has been dredged completely and reservoir capacity restored. Engineers of Hirakud dam have admitted that it would be next to impossible to even locate the highly silted places in a reservoir, leave alone conceiving of any scope for dredging sediment successfully (Mishra 2014). Then, dams cannot be reconstructed at the same site once the reservoir is filled with sediment; either sediment has to be removed or the site abandoned (Thakkar and Bhattacharya 2006).

In such a scenario, the storage capacity of 5,000 large dams has to decline with age, and correspondingly the USC and USW should also decline instead of remaining constant at 385 km^3 and 690 km^3, respectively; a fact ignored in the water management discourse of India. Otherwise, these constant figures indicate that the live storage capacities of a number of large dams shown in Figure 1 have undergone zero loss of live storage till date, which is not the case as observed in Table 1. The consequence of this static figure of 385 km^3 of USC and 690 km^3, of USW is the creation of an illusion that India is in possession of assured water security in the 21st century and beyond, which is nothing but gross underestimation of the future water crisis.

Declining ultimate gross irrigation potential: Another consequence of this deceptive static of USC and USW is on the estimate of the UGIP, which has been assessed as 139.9 million hectare (mha), out of which 58.47 mha of potential is from major and medium storage projects (MoWR 2006). These figures remain astonishingly constant in government documents. This ever-constant figure of 58.47 mha is misleading because while India's live storage capacity continues to decline, the gross ultimate irrigation potential of the country cannot remain static at the level of 58.47 mha.

This is because when the USCs from all reservoirs of large dams decline, concomitantly the irrigation potential and the intensity of the irrigation should also reduce. And, unless the lost storage capacity is restored to its full capacity, there is no way the reservoir can irrigate the entire command area with the planned irrigation intensity. The continuance and projection of the static gross irrigation potential of India at 139.9 mha is a fallacy of India's water management that is a direct consequence of having a blind spot for water crisis emanating from deteriorating large storage structures. Therefore, with USC, USW, and UGIP being interconnected, dynamic, and declining in time, a perilous water future beckons India, albeit subtly, as more dams age by 2025 and 2050.

Water Management Scenario

In light of the above discussion of the blind spots pertaining to large dams in India, it can be concluded that any plan to tackle growing challenges of the water sector in the 21st century, ignoring the downsides of its over 5,000 large dams, is seriously flawed and bound to fail. The visible challenges, such as rising population, change in consumption pattern, urbanisation, increase in demand for water for agriculture, industries and energy, and the phenomenon of climate change, cannot be tackled with the false sense of water security attributed to large dams or the fallacious statistics of the USC, USW, or UGIP.

While the demand for water and, therefore, the conflicts continue to rise in the 21st century, the dwindling supply of water due to the dams' declining ability to overcome temporal variability will accentuate the crisis in the future. For example, as the Tungabhadra dam has lost 25% of its live storage capacity as on date due to siltation, the irrigation activities in the command area have already been severely disrupted (*Hindu* 2016). Similarly, the ultimate irrigation potential of the command area envisaged, based on the initial storage capacity, will shrink owing to the loss of live storage shortage in the reservoir, thereby crippling the capability of the reservoirs to irrigate the entire command area.

This impact has a cascading effect on food security and the socio-economic status of the farmers, as their ability to grow crops and the contemplated yield get severely crippled. With the decline in ability to irrigate the whole command area, the area of irrigated land retreats with the concomitant advance of the rain-fed area or groundwater irrigation in the same command area. This is a paradox. The present policies, plan documents, and the management discourse in India, so far, have been blind to this escalation in the water crisis and its cascading effect on other interrelated sectors such as the economy, agriculture, society, etc.

The current solutions envisaged in various central and state policies, such as inter-basin transfer, additional large dams, traditional structures of rainwater harvesting, groundwater recharge, micro-irrigation, recycle and reuse of waste water, desalination, water audits, and virtual water trade, remain oblivious to the water crisis emanating from ageing large storage structures. These solutions, designed to tackle only the "visible knowns," will be inadequate to address the creeping water crisis as time hurtles towards 2025 and 2050.

The Way Forward

Considering the monumental underestimation of the future water crisis, the existing policies, plans, and water management discourse need urgent revision with recognition of the crisis unfolding due to ageing large dams. The comprehensive damage to the water sector and the impact of the declining storage capacity, utilisable surface water, and irrigation potential on the interrelated sectors should be recognised in the policies and plan documents. Then the estimation of such damage should be made. For this to happen, the water organisations in India have to be more transparent with respect to the dysfunctional and deteriorating large dams.

The existing status the live storage capacity of large storage structures (after deducting the loss of live storage due to sedimentation) available throughout the country should be disclosed, rather than providing a mere display of real-time water storages available in reservoirs. The latter actually blinds the loss of live storage capacity of the reservoirs over a period of time. A realistic estimate of ultimate gross irrigation potential has to be made based on the actual estimate of live storage available as on date. Similarly, the utilisable surface water should be revised deducting the live storage capacity of those dams whose service life has been completed.

Against such a background, the country's water policymakers, planners, and water managers have to discover alternatives to dysfunctional large storage structures. One way to overcome the loss of ultimate storage capacity is to find alternative sites for construction of water harvesting structures of varying capacities wherever it is feasible. Second, such a loss can be compensated with a series of small storage structures with an emphasis on medium or minor irrigation structures. A third alternative is to recharge the aquifers and store water underground so that the phenomenon of the depleting groundwater across the country is reversed.

A fourth alternative, which seems to be beyond the current level of thinking in India due to emotional connect with large dam scientism, is the decommissioning of large dams that have fulfilled their service life, then restore the flow path of rivers or streams, research the site and reconstruct fresh storage structures as per feasibility. From the Indian perspective, the research on the decommissioning of dams to clear the knick point[2] and restore the flow path is at a nascent stage and less encouraged in comparison with advanced countries.

For the loss of irrigation potential in canal command area due to loss of storage capacity, a short-term solution could be to recoup the lost irrigated lands by building more but smaller water harvesting and groundwater recharge structures in the canal command area in order to, to harness the precipitation commensurate with the loss of the storage potential. Such a solution should be a part of the integrated and sustainable plan, taking in consideration the hydrological units involving allied sectors or disciplines such as soil management, agriculture, land use, land cover, etc. In the long term, research on dam decommissioning, study of river morphology, removal of knick points, and assessment of feasibility to rebuild storage structures are the solutions to retrieve some of the lost storage capacity and lost utilisable surface water, so that the future water crisis emanating from ageing and deteriorating large dams in the 21st century can be tackled.

NOTES

1 Per capita storage capacity is estimated by dividing the cumulative storage capacity assessed from all the large dams of a country by the total population of that country. The per capita storage capacity varies with the population and decline in storage capacity over time.

2 Knick point is the point of abrupt change in the longitudinal profile of stream or its deepest point known as "thalweg," due to change in the base level. Removal of a dam lowers the base level of the stream upstream of the dam and increases the hydraulic gradient resulting in erosion and entrainment of sediments stored in the reservoir.

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