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Are the Economic Benefits of Dam Building Worth the Environmental Costs? - An Indian Context.

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***Abstract:** India is one of the fastest-growing economies in the world. With a large and growing population, it has an insatiable and ever-increasing demand for energy and water resources. Considering India has more than 14,000 kilometres in its top eight longest rivers, the country often uses dams for both water distribution to industrial and agricultural sectors, and hydroelectric power generation. The latter has become increasingly vital amid the global shift towards renewable energy. However, researchers across the world are beginning to question the environmental viability of dams given the increasing focus on the environment. Degradation of the environment is not only risky to the health of all living things as seen by the adverse effects of global warming, but also a major economic concern. This paper weighs the economic benefits against the environmental costs and investigates the viability of dams as sustainable projects by analysing existing research on the topic.*

***Keywords:** Dams, global warming, environmental impacts, renewable energy, agriculture, economic impacts*

1. INTRODUCTION

India is a developing country with a growing population, which has been increasing at an average rate of 1.25% since 2000 (World Bank). It already is one of the most populated countries in the world with more than 1.4 billion citizens *(World Bank)*. This huge population puts undue pressure on the country's natural resources for their food, water and energy needs. India is likely to account for 35% of global energy demand growth over the next two decades *(economictimes.indiatimes.com)*. This is a huge challenge as India does not have the natural resources to generate this energy domestically. According to reports, India, became the world's third largest oil consuming and importing nation, in July 2023 as it bought $ 2.8 billion worth of crude oil from Russia, second only to China which remains the largest importer of Russian oil *(Press Trust of India- August 15, 2024)*. With India's dismal showing in the environmental index the news of the India becoming a large importer of coal ad crude oil is not a positive sign at all. India was reported to be precariously poised at a disappointing at 176 among 180 countries in Environment Performance Index 2024, with its high emissions red flagged again *(The Print 2024)*.

India has a good network of perennial river systems and ideal topography with mountain areas where water falls from a height, making them ideal for generating hydroelectricity, which besides being a renewable source, is relatively cheap and requires lesser maintenance than other sources. This makes it even more important for India to focus on renewable energy options.

Length of some important Indian Rivers

Sl. No.	River	Length (km)
1.	Indus	2,900
2.	Brahmaputra	2,900
3.	Ganga	2,510
4.	Godavari	1,450
5.	Narmada	1,290
6.	Krishna	1,290
7.	Mahanadi	890
8.	Kaveri	760

Source: India Book 2020 - A Reference Annual

The table above shows India has close to 14,000 kilometres of length of rivers, and that is just considering some of the "most important" ones *(India Book, 2020)*. As a result, Indians have always looked to harness the power of rivers to store and collect water for various uses. Kautilya, an ancient polymath and the first Prime Minister of the Mauryan Empire (321 B.C.E. to 185 B.C.E.) wrote about building dams and reservoirs to store water in times of scarcity of rain in his book *Arthashastra (Archana, 2017)*. In fact, the British set up India's first maiden hydropower generation plant in India in 1897 with an electricity generating station of 130 kW capacity, named Sidrapong *(Gopalakrishnan, Mukuteswara. (2015)*. Even back then, they had realised the significance of harnessing the power of the perennial river systems of India. Post Independence, significant strides were made in hydroelectricity with Prime Minister Pandit Nehru proudly proclaiming that the impressive dams and hydro were "the modern temples of India"

In recent times, dams have been built to supply water for domestic, industrial and agricultural use and to produce hydropower electricity. India now ranks third in the world, right after China and the United States of America, in terms of the number of dams present. As of 2021, India had 5334 large dams that are operational with 411 more in construction *(Kanjlia, 2021)*. The table flow indicates how these investments have contributed to the total energy pool in the last dew decades:

Non-Fossil Fuel		
RES (Incl. Hydro)	**173,619**	**41.4%**
Hydro	**46,850**	**11.2 %**
Wind, Solar & Other RE	125,692	30.2 %
Wind	42,868	10.3 %
Solar	67,078	16.1 %
BM Power/Cogen	10,248	2.5 %
Waste to Energy	554	0.1 %
Small Hydro Power	4,944	1.2 %
Nuclear	6,780	**1.6%**
Total Non-Fossil Fuel	**179,322**	43.0%

Source: Minister of Power, Government of India, 2024

The table above shows non-fossil fuel sources in India. Hydropower has the second-highest generation capacity, with 12.4% out of the total pool which makes it a very significant source. The Central Electricity Authority (CEA) estimates that India's hydroelectric potential is 145,320 MW, but only 32% of it has been tapped, so there is enough scope for expansion and growth. To promote the sector, several policy measures have been implemented recently, including the waiver of interstate transmission system (ISTS) charges for hydroelectric plants (HEPs) and the issuance of guidelines for pumped storage plants (PSPs) to simplify clearance processes *(powerline.net.in/2024)*.

While hydroelectric power comes with its share of advantages, expediting capacity addition in this sector, also comes with its fair share of challenges. Fully developing India's hydroelectric potential is technically viable but faces various hurdles. These include issues regarding water rights, environmental considerations, the lack of financially robust civil contractors, challenges linked to resettlement and rehabilitation, and unforeseen geological conditions. These factors frequently lead to significant delays and cost overruns for HEPs *(https://renewablewatch.in/2024)*.

Thus, it is apparent that while India has untapped potential in this sector that could be worked on, it cannot be done without addressing crucial challenges such as environmental concerns, water rights issues and infrastructural bottlenecks which are all essential for sustainable growth. This paper examines the benefits and challenges, specifically those in terms of the environmental cost that India might have to bear and crucially factor in before it embarks upon an ambitious expansion in construction of dams to empower India's hydropower segment in making a significant contribution to the country's renewable energy landscape, aligned with its national goals for energy security and environmental sustainability.

2. RESEARCH METHOD

Sources for this literature review included other literature reviews; case studies of dams; papers summarising experimental results; government websites; United Nations portals; and academic websites.

3. ECONOMIC BENEFITS

Dams have documented economic benefits that can help a country grow and provide citizens with a better quality of life. Firstly, dams can provide jobs during the construction and maintenance of dams and by aiding industries to function smoothly. Other economic benefits are summarised below.

3.1 Efficient, cost effective and reliable:

Dams and reservoirs generate hydroelectric power. Hydroelectric power, also known as hydropower, uses water to generate electricity. Hydropower is a source of renewable energy as the energy generated is due to the water cycle, which is driven by the sun *(US Department of Energy).* It is a source of clean energy as it does not produce greenhouse gases during the generation of electricity (Enel Green Power). In addition, hydropower plants are extremely flexible as the systems require a small amount of energy to start working and can reach full power within minutes *(Enel Green Power).* Hydropower plants can also be a method to store energy as excess electricity generated by other renewable sources, such as wind and solar, can be used to pump water into the upper reservoirs. Later, when the weather conditions are not favourable, the water can be used to generate electricity *(Enel Green Power).* Moreover, Hydropower is affordable. Hydropower provides low-cost electricity and durability over time compared to other sources of energy *(https://www.energy.gov).*

One of the main benefits of hydropower energy is the fact that it can be generated by any country that has a river and a dam, this makes India with a large number of perennial rivers ideal for their use. This can be expedited and expanded to make India less dependent on international fuel sources, most of which are derived from fossils. This dependence comes at a huge cost to the national exchequer and reduction in imports could save India precious financial resources and make it less affected by the increasing fluctuations in the oil and coal prices that one has come to witness. It will also make India less affected by geopolitical tensions that could impact this stable and cost-effective supply.

Compared to other electricity sources, hydropower also has relatively low costs throughout the duration of a full project lifetime in terms of maintenance, operations, and fuel. Like any major energy source, significant upfront costs are unavoidable, but hydropower's longer lifespan spreads these costs out over time. Additionally, the equipment used at hydropower facilities often operates for longer periods of time without needing replacements or repairs, saving money in the long term *(U.S. Department of Energy).* They are durable investments as hydropower developments have an average life of 50 to 100 years (Water Science School, 2018). Additionally, Hydropower plants have the ability to run at zero load and thus, no outside source of power is needed to start the plants. This allows system operators to provide auxiliary power to other generation sources (e.g. thermal). Furthermore, hydropower provides transient stability to the grid. The quick start capability of hydropower plants helps quickly change the output to serve peak demand. The hydropower peak load factor is at 50% as against 16–20% in the case of solar and wind energy *(www.pwc.in).* this quick start ability helps to power the grid immediately, making it a flexible and reliable form of backup power during major electricity outages or disruptions.

3.2 Water Storage to meet shortage:

According to the rating agency Moody's , India's worsening water shortage crisis can adversely impact the nation's credit health while sparking social unrest and exacerbating the volatility in its economic growth. India is one of the sovereigns that are the most vulnerable to risks associated with water management, the report suggests. *(Economic Times – June 2024).* India's unprecedented disruption in the monsoon cycle has already begun to disrupt agricultural production and can also begin to impact industrial operations if the shortage is not addressed. This water shortage not only impacts the economy but also could have an adverse effect on water-intensive sectors like coal power generation and steelmaking creating a bigger energy crisis alongside.

Significantly, India is a home to about 18% of the world's population but has only about 4% of utilisable water and about 2% of the land resources of world. Factors such as increasing population, inefficient irrigation system in agriculture and an unregulated domestic and industrial water use has further aggravated the crises. Even more than the quantum, the country suffers from uneven spatial and temporal distribution of water and land.

Dams have been used by all major economies as a major infrastructure investment. Currently, top 7 countries in the world having maximum number of large dams along with their size of economy in descending order are China (23821, US$ 14.1 trillion), USA (9261, US$ 21.4 trillion), India (5745, US$ 2.9 trillion), Japan (3112, US$ 5.2 trillion), Brazil (1411, US$ 1.8 trillion), Canada (1170, US$ 1.7 trillion), South Africa (1114, US$ 0.4 trillion) and Spain (1063, US$ 1.4 trillion), which indicates that out of these 7 countries, USA, China and Japan hold the top three ranks *(Narayan, Pramod & Bueno, (2024).*

Dams store water in times of surplus and dispense it in times of scarcity (US Department of Energy). As the climate is changing in every corner of the world, there can be longer periods with less rain. This can hamper multiple industries like manufacturing and agriculture. Dams prevent this as they hoard water in the reservoirs, which can be strategically distributed between industries, ultimately safeguarding a country's economy *(US Department of Energy).*

Furthermore, dams also aid in flood control and protect downstream areas from getting flooded during heavy rain *(Enel Green Power).* This is not only beneficial for the welfare of people, as floods can risk countless lives and also spread diseases, but also safeguards the economy as floods can damage infrastructure.

Thus, Dams are major components of a comprehensive strategy to address water resource challenges posed by drought, flooding, depleted aquifers, environmental needs, energy demands, and population increase and movement in India. Dams provide a key intervention to manage the supply as per needs throughout the hydrological year. These water bodies in true sense act as balancing reservoirs vis-a-vis demand and supply. Dams are, therefore, kingpins of water security to the country*(Ignacio Escuder-Bueno & Eric Halpin (2018).*

3.3 Agriculture supply

Agriculture is an important sector of Indian economy as it contributes about 17% to the total GDP and provides employment to over 60% of the population. Over the past 50 years, policies have allowed what amounts to a free-for-all in groundwater development and now the crisis has grown to become an alarming threat. Estimates put India's groundwater use at roughly one-quarter of the global usage with total usage surpassing that of China and the United States combined. With farmers provided electricity subsidies to help power the groundwater pumping, the water table has seen a drop of up to 4 meters in some parts of the country. This unfettered draining of groundwater sources has accelerated over the past two decades. With aggressive pumping, particularly in rural areas and over reliance on monsoon rains without proper irrigation or water management techniques, Indian Agriculture is getting increasingly threatened by water shortage *(Stockholm International Water Institute).*

Agriculture consumes almost 90 percent of the country's groundwater, largely because of the easy availability of largely free power to pump it out with. The challenge – known as the energy-water-agriculture nexus – has led to a crisis in all the three sectors involved. While groundwater levels have fallen dramatically, agriculture continues to follow unsustainable practices and farmer incomes remain low and stagnating. In peninsular India, the sustainability of groundwater-based agriculture itself is in question. At the same time, the power subsidy is burgeoning, draining scarce resources and depriving essential sectors such as education, health, and other social programs. To add to the challenge, climate change is disrupting agrarian ecosystems and livelihoods in adverse and unpredictable ways *(Michael Foley, World Bank India)*. This puts undue pressure on maintaining supplies for domestic and industrial use. It is significant to note that China uses a quarter less freshwater.

According to new *Stanford University research Analysis,* dammed reservoirs could store more than 50% of the water needed to irrigate crops without depleting water stocks or encroaching on nature. The study, published the week of Nov. 14 in *PNAS*, quantifies for the first time how much water storage would be required to maximize crop irrigation without depleting water stocks or encroaching on nature, and how many people this approach could feed. While the researchers find that dammed reservoirs could be used to store more than 50% of the water needed for such irrigation, they emphasize that large reservoirs are only part of the solution and recommend evaluating alternatives and encourage a more cautious approach. The researchers analyzed the amount of freshwater in surface and groundwater bodies generated and renewed by natural hydrological cycles, as well as water demands of current crop mixes on irrigated and rainfed lands. They estimated that the full potential of storage-fed irrigation could feed about 1.15 billion people. If all 3,700 potential dam sites that have been mapped for their hydropower potential were built and partially used for irrigation, the world's dams could supply enough water storage to irrigate crops for about 641 million people or 55% of the total *(Rafael J. P. Schmitt and Gretchen C. Daily 2022, Liyin He, Lorenzo Rosa 2023)*

Moreover, Dams protect arable land from being ruined and prevent soil erosion, by thwarting floods, saving the nutrients that help the crops to grow (Zhang, 1999). Dams protect the crops from being flooded during heavy rain, which can potentially ruin the yield. The flow of the river can be regulated, and stored water can be released in times of need when there is less rainfall *(Zhang, 1999)*. Dams can adjust the local climate and improve environmental conditions which benefits farmers for irrigation. All dams and reservoirs become a part of the local environment which they influence and transform. In arid regions, it was observed by L. Zhang that a new dam and or reservoir project could alter the local humidity of the surrounding areas, due to the large store of water at a single location. This further influences rains which are good for the crops in certain seasons *(Zhang, 1999)*.

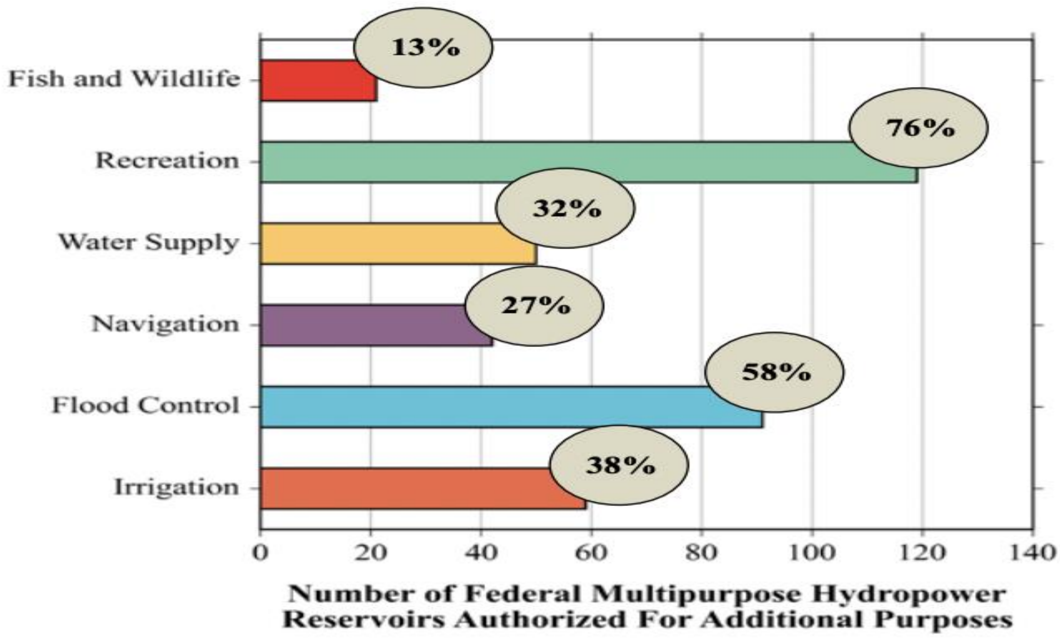
3.4 Recreational Activities

Reservoirs are a popular destination for a variety of recreational activities like fishing, boating, camping, swimming, watersports and wildlife observation *(Bonnet, 2015)*. These activities can provide jobs to the local people of the area and have proven to assist the tourism industry. Tourists are often attracted to recreational areas, especially in places where natural surface water is scarce *(Zhang, 1999)*.

3.5 Navigation

Dams help in inland navigation in a country and can be used in the transportation of goods. In the United States, 500 million tons of cargo is transported every year through the inland waterway system *(Bonnet 2015)*. The dams are used in tracking the cargo and can be used as lock sites and chambers (Bonnet 2015). Locks are devices used for raising and lowering watercraft between expanses of water of different levels on a river *(PANI)*.

The following data was recorded by researchers in the Oak Ridge National Laboratory, in the United States of America, in the year 2015. It shows the economic benefits of dams and their contribution as a whole.



4. CHALLENGES POSED BY DAMS

Despite the listed benefits if hydroelectric power and Dam construction and India's huge potential for it, all research studies caution against relying on them as a significant part of the sustainable irrigation solution, citing dams' socio-environmental consequences, such as fragmentation of rivers, with impacts on fish migration and sediment transport, and displacement of people. Dams are also less appealing for irrigation storage because of water loss, expense, and ecological damage related to the need for conveyance to distant agricultural fields, as well as higher levels of evaporation across large reservoirs' large water surfaces. Some of the key challenges are:

4.1 Human displacement and Livelihoods:

Globally, between 40 and 80 million people have been displaced as a consequence of reservoir inundation. Historically, resettlement programs have been inadequate and most of these people are worse off than they were prior to being resettled. In addition, the livelihoods of an estimated 472 million people living downstream of dams have been adversely affected by changes in flow regimes (*McCartney, M.P.; Smakhtin, V. 2010).* It has been found that the benefits associated with dams such as regular supplies of electricity and water, do not translate into improved incomes or direct benefits for local people.

Among the negative outcomes, displacement *(WCD, 2000),* deteriorating physical and mental health *(Richter et al., 2013),* loss of farmland, and overall changes in livelihood *(M. Cernea 1997, A.K. Biswas)* have been highlighted time and again. Hydropower dam construction has several positive outcomes; however, it always has drawbacks with far-reaching consequences for local communities *(Cernea, 2004; Dachaga & Chigbu, 2020),* especially for the rural population that lives around where the project is undertaken. Reservoir dam constructions usually result in the inundation of significant land which ends up being covered by water. Dam construction has resulted in the displacement of millions of people worldwide, resulting in the loss of over a million people's homes, valuable cultivated lands, and significant ecological change (*Jansen et al., 2019).*Beside this, Dam construction may lead to loss of access to river water, drying up of natural spring, loss of fields, and submergence of croplands during floods *(DoIW-GoWB, 2016),* causing a reduction in the income of farmers, creating unemployment and food insecurity which is in line with long term social insecurity *(M.W. Beck et al).* For example, in China, more than 1.13 million people lost their livelihoods due to the construction of the Three Gorges Dam *(Wilmsen, 2016).*

India has been no different in terms of consequences. The recent example of protests demanding the decommissioning of the Ithai dam in Manipur, and the Gumti Dam in Tripura where significant tribal lands were inundated, devastating their livelihood base is testimony to the fallout on the livelihoods that needs to be considered. Most of the displaced people do not receive more than minimal compensation. For example, the Loktak Lake, the largest freshwater lake in northeastern India in Manipur is the world's one-of-a-kind wetland ecosystem that has earned the designation of a Ramsar Protected Site of International Importance. The lake holds an immense economic, cultural, and social significance for the people of Manipur. The construction of the Ithai Hydropower Dam in 1983 elevated the water level of the Loktak wetland. It initiated the destruction of this unique wetland ecosystem. The dam permanently flooded over 83,000 hectares of farmland and pastures around the wetland, resulting in the loss of livelihoods and severely impacting the wetland's biodiversity. More than 100,000 people through 55 communities directly or indirectly depend on this ecosystem for their food and livelihood. Over the decades, the dam has altered the hydrology and ecology of the Loktak wetland, while continuing to pose threats to the food security of the indigenous community *(Neeta Satam 2017)*

4.2 Disruption of natural ecosystem:

Studies conducted on large hydroelectric dams on American rivers found that they were destroying native ecosystems in rivers and streams. They revealed that hydroelectric dams can collect large amounts of mercury behind the dam, contaminating the fish and eventually impacting the entire food chain. Additionally, when the water current is slowed behind the dam, the entire native ecosystem is altered. Certain fish can only survive in certain types of water, whether it's fast or slow moving. This can also cause sedimentation, which destroys native habitat above and below the dam. Instead of sediments being evenly distributed throughout the course of the river it is dumped in a single location above the dam. Hydroelectric dams block migrating fish from getting to their spawning grounds.

Open free-flowing rivers are used all over the world by migratory fish coming from the ocean to spawn in freshwater streams and rivers. Obstructing them affect the aquatic life. in America Wild New York Salmon have virtually become extinct because of hydroelectric dams. The construction of two dams on Sacramento River have isolated Salmon from large portions of their spawning grounds. There once were thousands of Salmon that would spawn in the Sacramento River annually, but 95% of the past two generations have died *(wildlifeleadershipacademy.org)*

Dams can also alter the timing of flows. Some hydropower dams, for example, withhold and then release water to generate power for peak demand periods. These irregular releases destroy natural seasonal flow variations that trigger natural growth and reproduction cycles in many species. Slow-moving or still reservoirs can heat up, resulting in abnormal temperature fluctuations which can affect sensitive species. This can lead to algal blooms and decreased oxygen levels(www.americanrivers.org). Due to decreased water discharges, water temperature will rise in daytime and decline sharply at night. Rooted plants will grow in the riverbed due to the decrease in water volume. Fish such as snow trout, catfish and loaches may be pulled into the intakes and get killed *(www.fao.org).* In Reduced oxygen content and release of gases like methane, sulphuretted hydrogen in Dam reservoirs is also a detrimental factor. Moreover, Anaerobic decomposition of inundated vegetation consumes large amounts of oxygen and produces noxious gases that are toxic to aquatic life. The slowing down of the water flow can lead to thermal stratification, with warm water on top and cold-water underneath. Since the cold water is not exposed to the surface, it loses oxygen and becomes uninhabitable for fish *(Chen, Qiuwen & Li, Qinyuan & Lin, Yuqing & Zhang, Jian-yun & Xia, Jun & Ni, Jinren & Cooke, Steven & Best, James & He, Shufeng & Feng, Tao & Chen, Yuchen & Tonina, Daniele & Benjankar, Rohan & Birk, Sebastian & Fleischmann, Ayan & Yan, Hanlu & Tang, Lei. (2023).* Dams also ruin the habitats for fish that feed / spawn in the river bottom. Their natural habitat is destroyed by intense flooding and depletion of riverbed gravel. This specially impacts the invertebrates such as insects, mollusks and crustaceans *(Kim, S. K., & Choi, S. U. (2019).* The reservoir is generally much more species poor than the riverine environments it replaces. Fluctuations in water level are often extensive and are temporally controlled by human water needs rather than by natural conditions. The riparian zones are often impoverished of species. Riparian vegetation along storage reservoirs in Sweden and Canada has, on average, decreased by 84 per cent in degree of coverage and by 34 per cent in species numbers compared with unregulated riverbanks. Owing to the unnatural water level fluctuations, benthic fauna is more or less absent within the zone that is periodically drowned and exposed. In the long term, the productivity of the reservoir greatly diminishes, since the only photosynthesising organisms that can cope with the water level fluctuations are pelagic phytoplankton that move up and down with the changing water levels. The fauna is mainly confined to pelagic zooplankton and the fish that live on these *(R. Jansson, C. Nilsson and B. Renöfält (2000), Birgitta Johansson and Björn Sellberg Planning group 2006)* .

One rapid EIA study reported only one fish species in a Ravi River stretch of 18.5 km (3.5 km submergence + 15 km downstream). This looks highly improbable and might be due to the "rapid" nature of the study. The local villagers reportedly have claim that they last saw otters in 1992-93 and that they are extinct now. A more systemic analysis would have ascertained the reasons for local extinction viz. is it due to pre-dam construction activities that altered the habitat characteristics. *(Source: EIA technical report no. 23 (1998) (Dr. Tata L. Raghu Ram 2019).*

A current study, conducted on India that has one of the most fragmented fish habitats in the world, studied the fish species occurring in the 167 hydropower dams in the country. In the Western Ghats, a study led by Dr Vidyadhar Atkore showed that fish populations are severely affected just downstream of dams and barrages in the Malaprabha basin. Yet another study in the Godavari basin also shows that dams lead to habitat fragmentation *(researchmatters.in, Gulab Dattarao Khedkar, Sigal Lutzky, Sandeep Rathod, Amol Kalyankar, Lior David 2014).* Not just large dams, overfishing, pollution and the introduction of invasive species also affect the fish population. Considering that many dams in India are constructed and planned in biodiversity hotspots, the impacts are likely huge.

Vijay Taram, an anti-dam activist with the Forum for Siang Dialogue protesting the large dams planned over the Brahmaputra claims that "big dams will spoil our lives and livelihood. If completed they will flood all fertile agricultural lands, destroying the flora and fauna of entire Siang belt and displace thousands of people of Siang valley. Tribal men will lose their traditional hunting grounds as well as the link to their culture." it is important to note that the Siang districts belong to the indigenous communities of the Adi and Galo tribes. Twenty-three of their villages are on the banks of the Siang River and will be directly affected by the project. Rice is a staple food of Adi and Galo people, and wet rice fields are situated just above the Siang River. The planned dam will submerge these fields, threatening the very survival of these tribes *(the Wire.in).*

When reservoirs are created, large areas of forests and land, including agricultural lands, are flooded. Such areas often include wetlands, which are important wildlife habitats, and low-lying flood plains, which are often fertile croplands. Flooding of forestland also means the loss of species and habitat diversity *(Maudgal, S (1988).*

India has a total of 89,451 animal species accounting for 7.31% of the faunal species in the world *(MoEF 1997)* and the flora accounts for 10.78% of the global total. The endemism of Indian biodiversity is high - about 33% of the country's recorded flora are endemic to the country and are concentrated mainly in the North-East, Western Ghats, North-West Himalayas and the Andaman and Nicobar Islands. These delicate eco systems have been severely impacted by dam construction.

If all dams are constructed as proposed, in 28 of 32 major river valleys, the Indian Himalaya would have one of the highest average dam densities in the world, with one dam for every 32 km of river channel. Proposed locations of dams correlate with zones of species richness for angiosperms, birds, fishes, and butterflies. In the Indian Himalaya, subtropical and temperate forests are most vulnerable to species losses driven by land-use changes. Dams impact terrestrial biodiversity through Habitat loss, Habitat fragmentation and the cumulative impact of development that comes in the form of human settlements, industry and associated infrastructure that forces the indigenous species out or marginalises them *(R. Edward Grumbine and Maharaj K. Pandit 2013)*

The major proximate causes of species extinction are habitat loss and degradation affecting 89 percent of all threatened birds, 83 percent of mammals and 91 percent of all threatened plants assessed globally *(IUCN 2000).* A report commissioned by the Central Water Commission noted that, "Siang Lower hydroelectric project (2,700 MW), Siang Upper Stage II (3,750 MW) and Siang Upper Stage I (6,000 MW) are planned to cover almost the entire length of the Siang in India. More than 200km of the river will be converted into one continuous reservoir as all three projects are planned back-to-back without any free-flowing intermediate river stretch. Once the dams are built, the Siang basin will never be the same again. Studies by the Central Water Commission point out that the 44 planned dams within India will change the natural flow of the water in 29 rivers and streams. As of now, these rivers and streams stretch out over 514 km. Once the dams are built, all of it would be altered — 353 km will turn into reservoirs, and close to 161 km will be converted into tunnels. This would inevitably change the basin's 15,000 square km of forest. The Siang basin is home to 11 different kinds of forests, 1,349 plant species and 1,197 animal and fish species. The official assessment of the dams' cumulative impact predicts that much of this wildlife will migrate, some perhaps forever. Fish species too would find life more difficult once the natural flow of water changes *(www.cwc.nic.in).*

Of the 1.4 million hectares of forest cleared since 1990, the largest proportion of land went to mining, followed by defence projects and hydroelectric dam projects *(Ghosh, H. (2016).* Besides Dams cause large scale inundation of fertile land that is good for agriculture. According to estimates by Wetlands International South Asia, nearly 30% of the natural wetlands in India have been lost in the last three decades. This loss I primarily attributed to Illegal construction, unsustainable urbanization, agricultural expansion and pollution, Inefficient waste management and Damming and water abstraction. Keoladeo Ghana Sanctuary, Loktak Lake, Chilika Lake, Vembanad Kole are among those severely impacted by dams that affect water and silt flows *(https://forumias.com).* These wetlands are crucial as they in flood control by acting as natural sponges. They temporarily store and gradually release stormwater. Also, roots of wetland vegetation hold soils in place, thus stabilizing the banks of rivers and streams. They are also play an important role in maintaining the quality of water in deep-water ecosystems, host a large number of species of microbes, plants, insects, amphibians, reptiles, birds, fish and mammals, act as carbon sinks and wetland soil contains a high amount of carbon, help in natural groundwater recharge and discharge, and in regulating local climatic conditions, particularly temperature and climate. They are also a great source of timber and medicinal plants *(https://bluenorth.co.za)*.

4.3 Soil Erosion, sedimentation and siltation:

Dams hold back the sediment load normally found in a river flow, depriving the downstream of this and increases the speed and the pressure of the downstream water which erodes its channels and banks. Sedimentation in dam reservoirs happens when the larger sediments in water entering a reservoir are deposited as its upper end forming a delta and steadily raising the level of the upper reaches of the reservoir *(Leichao Bai, Nan Wang, Juying Jiao, Yixian Chen, Bingzhe Tang, Haolin Wang, Yulan Chen, Xiqin Yan, Zhijie Wang 2020)*. This causes flooding due to its bank water effect as has been witnessed in the Sardar Sarovar Dam, the fine sediments settle at the bottom of the reservoir which erodes the base and the walls reducing the utility of the dam *(Berger, T. R. (1994).* This Siltation reduces the water storage capacity of the reservoir, undermines its effectiveness for power-generation, irrigation and flood control and renders it usefulness in the long term.

The water logging caused by dams is another major drawback. The Indian Institute of science estimates that 40 percent of the command area for Sardar Sarovar Dam will become waterlogged. This area contains black cotton soils which are particularly prove to water logging under perennial irrigation due to high water retention capacity. Once Soils become waterlogged, the crop yields fall *(Talib N. Ellison 2005)*.

4.4 Water Quality

The water pollution begins right from the onset of the construction of the dam. During the construction of a dam, all work is done in or close to the riverbed- such as diversion channel construction, excavation works at the dam site, construction of protection dikes and coffer-dams, quarrying works, sand borrowing in the river bed. This creation of spoil areas too close to the riverbank with unstable slopes and creation of flood plains- result in a sediment load. All this load is usually discharged into the river which can result in polluted water downstream. Pollution caused by hazardous substances at the construction site is another major issue *(Alla, 2021)*. Large amounts of gasoline, lubricant products, explosives and chemicals are stored and processed at the construction sites which creates a risk of leakage *(Alla, 2021)*.

Once the dam becomes functional, water quality degradation is one of the major concerns associated with it. There are several different ways that the use of water to produce electricity pollutes the water, either as a direct result of the action of the dam itself or as a by-product of the creation of a reservoir or the redirection of water systems. The diagram below is an illustration of the principal causes of deterioration in the water quality:

Oxygen Stratification

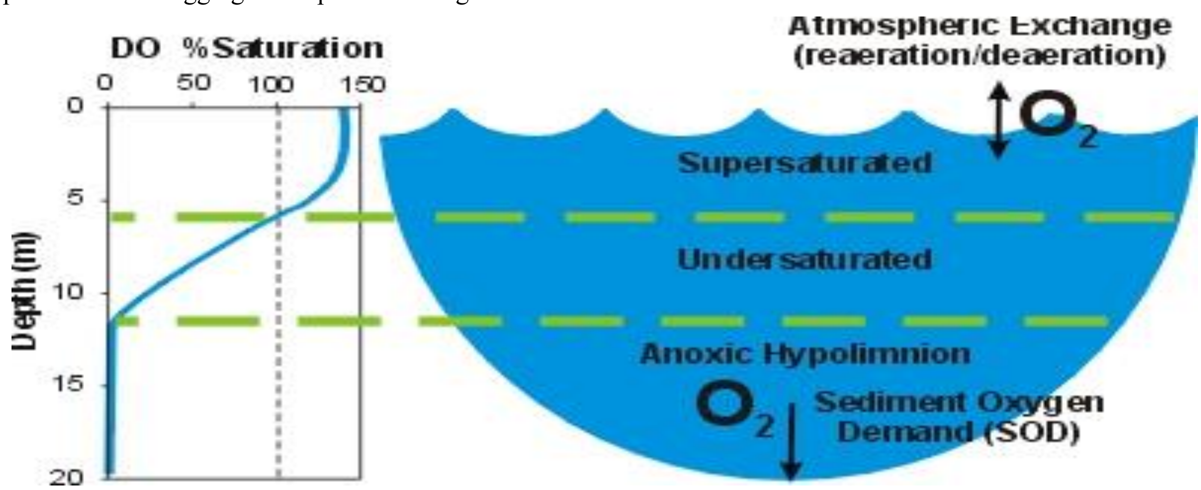


Figure 1. A diagram showing how dissolved oxygen content decreases rapidly with water depth. Areas at the top of the reservoir are oxygen-rich, but depth leads to oxygen depletion. Note that such depths are not reached in rivers, which is part of why rivers do not suffer from oxygen stratification. Source: Upstate Freshwater Institute. (September 1, 2015).

The water in the reservoir, which remains much more still than the river that existed before it, results in the formation of layers within the water. These layers have discrete levels of oxygen, with higher concentrations at the top and lower concentrations at the bottom. These parts of the reservoir that are lacking in water are known as hypoxic areas. Concentrations of oxygen in the water can even become almost zero if the reservoir is deep enough, these areas are known as anoxic areas. This is largely due to organic sediments in the bottom of the reservoir being decomposed by micro-organisms, which uses oxygen. This reduced oxygen area is not healthy for any aquatic life living in the reservoir area *(J.Knight 2015)*. This water is then drawn into the turbine from the bottom, and this is how the oxygen-poor layer of the reservoir flows downstream. This reduces the overall oxygen content of the stream or river beyond the dam as well *(F.Bunea, D. Bucur, G. Dumitran, G.Ciocan. (2015)*.

Eutrophication is another big issue. Due to lack of movement of water, reservoirs frequently are sites of algal blooms. When algae population explodes, water quality suffers. Excess of algae by photosynthesis, ultimately choking a body of water of oxygen, creating an anoxic environment and killing the algae and other organisms present. After the death of the algae, bacteria form and eats it. This phenomenon creates a marsh. The dead algae are decomposed by micro-organisms in the water. When the algae decompose, oxygen is used and oxygen-poor or hypoxic environments form. In addition to poor oxygen conditions, the taste, colour, and odour of water are all negatively impacted by the presence of algae, making the water unsuitable for human consumption. Furthermore, some types of algae are poisonous and can negatively impact human health if consumed. Increased algal concentrations can also cause premature clogging of filters/traps due to the increased organic content, decreased biodiversity resulting from lower dissolved oxygen levels, and an increase in the concentrations of hydrogen sulphide, iron, manganese, and ammonia resulting from anaerobic decomposition of algae *(J.M.K.C. Donev et al. (2024)*.

Thermal pollution is just as much of a problem as oxygen stratification. In a reservoir, thermal energy accumulates in the top layers closest to the Sun, while the rest of the reservoir gets progressively colder. This can alter the temperatures of the water downstream. Drastic temperature changes can cause direct casualties in marine populations, but even minor changes can alter metabolic rates, reproduction, and growth of animals *(J.John. (September 1, 2015)*.

Moreover, Mercury enters the water when elemental mercury found in the rock and soil of the reservoir interacts with bacteria released because of decomposition of submerged plant material. This interaction results in the formation of either mono-methylmercury or the more volatile di-methylmercury. Both forms of mercury are water-soluble and will begin to accumulate within the water system. Since the water does not move, mercury concentrations increase in the water system. This mercury will then begin to biomagnify within the food chain, eventually posing a health risk to people who rely on fish as a food source *(Pollution Probe. (September 3, 2015)*. This water when released makes the land around the area unsuitable for farming, wildlife habitat, or human recreation.

For a country like India which is already under tremendous water stress and had a very high density of population, this drop in water quality can have a huge health impact on large swathes of population which may not be the case in low density populated countries.

4.5 Green House gas emissions that contribute to Global Warming:

Often regarded as one of the oldest forms of renewable energy, hydroelectric dams and their reservoirs are responsible for the release the equivalent of almost one billion tonnes of carbon dioxide into the atmosphere (with much of these greenhouse gas emissions in the form of methane) as water approaches and then tumbles its way through the turbines that generate electricity *(www.bbc.com)*. Methane is a greenhouse gas that's more than 80 times more potent than carbon dioxide over a 20-year lifespan, but it also breaks down faster in the atmosphere than CO2. The *Intergovernmental Panel on Climate Change (IPCC*) has indicated a GWP for methane between 84-87 when considering its impact over a 20-year timeframe *(GWP20)* and between 28-36 when considering its impact over a 100-year timeframe *(GWP100)*. This means that one tonne of methane can considered to be equivalent to 28 to 36 tonnes of CO_2 if looking at its impact over 100 years *(ipcc.ch/report , IEA 2021, MIT Climate Portal 2021)*. These hidden emissions mean that hydroelectricity is perhaps not as clean as it has been portrayed over the years,

Artificial reservoirs created by dams are distinct from natural systems in a number of keyways that may enhance GHG emissions from these systems. First, the flooding of large stocks of terrestrial organic matter may fuel microbial decomposition, converting the organic matter stored in above and below ground biomass to carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Second, reservoirs often experience greater fluctuations in water level than natural lakes. Drops in hydrostatic pressure during water level drawdowns can enhance CH_4 bubbling (e.g., ebullition) rates at least over the short term *(Maeck et al. 2014)*. This enhanced ebullition may then decrease the fraction of CH_4 that is oxidized to CO_2, a less potent GHG, by methane oxidizing microbes *(Kiene, Rogers JE Whitman WB 1991)*. Finally, the high catchment area–to–surface area ratios and close proximity to human activities *(Thornton et al. 1990)* characteristic of many reservoirs are likely to increase the delivery of organic matter and nutrients from land to water (relative to natural lakes), potentially fuelling additional decomposition.

India, renowned for its varied climate, has been increasingly confronting the severe consequences of climate change. The last two years, the country has been experiencing one of its most intense heatwaves in recent memory. This phenomenon is not only breaking temperature records but also leading to significant socio-economic and environmental challenges *(India Today 2024)* . Extreme heat and humidity may adversely affect labour hours and up to 4.5 per cent of India's GDP could be at risk by 2030, according to the *Reserve Bank of India's latest report*. In such a scenario, India ought to be more careful as it plans its hydroelectric expansion.

4.6 Contribution to flooding and flash floods:

While dams and embankments are often touted as interventions for better flood management, they have often been accused of being at root of severe flood disasters in India. the flash floods suspected to have been precipitated by a glacial lake outburst, in Uttarakhand's Chamoli district in February 2021 was also indirectly linked to the construction of dams in the area. A *report from the Relief Commissioner's Office* said that Sharda river in Pilibhit district was in spate due to the overnight release of about three lakh cusecs of water from the Banbasa dam in Uttarakhand, with floodwater from the river entering 20 villages *(www.thehindu.com 2021)*. The situation was worsened when the Banbasa barrage on the Sharda in Uttarakhand also released water into the river, with its effects visible in Lakhimpur Kheri. Similarly, In the context of the annual flooding of the Brahmaputra River in Assam, an *EPW editorial (2017)* wrote that "although the recurrent floods are a natural phenomenon, they are also an outcome of anthropocentric interventions. It is natural that the high precipitation in the Himalayas—the catchment of most of the tributaries of the Ganga and Brahmaputra—coupled with the sudden fall in altitude results in a large volume of water gushing down river channels from the Eastern Himalayas into the floodplains. This water exceeds the carrying capacity of the river channels resulting in a spillover into adjoining areas. But with increased deforestation in the Eastern Himalayas, the surface run-off has increased at the cost of infiltration leading to tons of sediment being deposited on the riverbed as the river reaches the plains. This further reduces the carrying capacity of the river and enhances the risk of flooding. The plan to build large dams in upstream areas, largely in Arunachal Pradesh, is likely to exacerbate this process" *(EPW Engage, 2019).*

In theory, every dam can help moderate floods in the downstream areas, as long as it has space to store water, and depending on the amount of space available. In fact, by storing, holding and recharge (to groundwater aquifers), they delay the flow of rainwater from the catchment to the river which helps moderate its flow, and, in turn, moderates floods in the river. However, our catchments are fast losing this capacity, due to the continued destruction of natural forests, wetlands, local waterbodies, and the soil's capacity to hold water. When the catchment is not planned properly, the reservoir gets access water and is forced to release it as there is no space left to store more water. Due to this, in downstream areas, which are already facing floods due to local rainfall or other reasons, must face what we now call flash floods as the dams end up increasing the magnitude of the flood disaster *(Himanshu Thakkar (2018).*

There are numerous instances of this kind, including the floods in Uttarakhand (June 2013), Tehri (September 2010), Hirakud (2009, 2011, 2014), Damodar dams (multiple years), Krishna basin dams (2006, October 2009), Ukai (August 2006), Chennai floods (December 2015), Bansagar dam (August 2016), Kurichu dam in Bhutan (2004, 2016, others), and Ranganadi (2017) and Doyang (2018), among other dams, where flawed operation of the dams created or worsened flood disasters in the downstream areas.

Floods caused by a dam are sudden and given its intensity and the unpreparedness of people living in surrounding areas, its impact is more destructive to lives and property. This is what happened in Kerala this year. The sudden nature of floods caused by dams, together with the reluctance of authorities to share information with people, makes communities vulnerable in a two-term monsoon region like Kerala. In an undammed river, the flood water rises over a period of time, which allows people to respond. Moreover, due to the dam the contours of the riverbed, the flow of the river downstream and even the floodplains change *(Anant Phadke, 2002, Mirza Zulfiqar Rahman (2020).*

Apart from dams, another oft-touted method of flood management is embankments. But these too have been known to be ineffective. For instance, an *EPW editorial (2020)* observed that Prior to the construction of the bandhs, when the rivers were in spate, they would gently sweep across the landscape, depositing their burden of silt. As the rivers were channelised, their velocity increased, thus allowing the waters to carry, in addition to silt, sand and gravel and rocks. Initially, this burden was deposited in the river channels. Gradually, the mean level of the rivers rose, as the original riverbed was filled with debris. Soon, the mean levels of the rivers were higher than the original floodplains. In some areas, the river levels increased to heights of three to four metres above their floodplains, requiring that the levees be further strengthened and elevated. Before the embankments, the sand, gravel and stone that the rivers carried was released soon after the rivers entered Bihar. Farther downstream, the waters carried only silt. Now, sand, gravel, stone and silt are carried much farther downstream. The sand, gravel and stone, in addition to filling the old riverbeds, damage the face of the embankments. In time, the scouring action eats away at the embankments and creates holes or breaches in the levees. "It was man-made floods that wreaked havoc on them [farmers] all these years" *(Karunakaran 2004:3).* The floods that come through the unrepaired breaches rise slowly, not like bulldozers smashing everything in their path, as happened when the levees breach suddenly and without warning *(www.downtoearth.org.in).*

5. CONCLUSION

Propelled by sustained economic growth and rise in income levels, India is poised to face significant increase in energy demand in the next few decades which also translates into higher demand for electricity. Considering an energy elasticity of 0.82, India is projected to require around 7% annual growth in electricity supply to sustain a GDP growth of around 8.5% p.a. over the next few years *(PwC.in).*

Fossil fuel consumption in India rose 8 per cent in 2023, accounting for almost all demand growth, while its share of overall consumption stood at 89 per cent, according to a report. According to an Energy Institute (EI) report, for the first time, more coal was used in India than Europe and North America combined which when studied with reference to India's dismal showing on the Environmental index is a cause of worry *(economictimes.indiatimes.com)*. Over 80%of India's energy needs are met by three fuels: coal, oil and solid biomass. Coal has underpinned the expansion of electricity generation and industry and remains the largest single fuel in the energy mix. Oil consumption and imports have grown rapidly on account of rising vehicle ownership and road transport use *(IEA 2024).*

This makes it imperative for India to look at more renewable sources of energy. India is endowed with significant hydroelectric potential and ranks fifth in the world in terms of usable potential. As per the latest available data, India has around 36 GW of installed hydropower capacity whereas an additional 13 GW is under construction. This puts the total capacity which is yet to be tapped at around 67% of the potential. Countries such as Canada and Brazil had harnessed around 69 and 48% of the economically feasible potential back in 2009. From a regional perspective, over 93% of the total potential in the northeastern region is yet to be tapped, primarily in parts of the Brahmaputra River basin. The scenario is in sharp contrast to the southern and the western regions where more than 65% of the potential has already been harnessed *(PwC.in).*

While the government of India has, over the years, taken several initiatives to prioritise hydropower development and to attract investments in the sector, challenges in implementation has led to its declining share of hydropower in India's energy mix since 1966. Though reservoir-based hydropower projects have come under criticism due to CO2 and methane emissions beyond acceptable limits, most hydro-rich countries have followed an integrated full life-cycle approach for the assessment of the benefits and impacts to ensure sustainability.

Various factors such as environmental concerns, R&R issues, land acquisition problems, long clearance and approval procedures, capability of developers, etc. have contributed to the slow pace of hydropower development in the past. These issues have been compounded as hydropower development has largely remained under the ambit of state governments (water being a state-specific subject) with varying policies (e.g. upfront premium, royalty power, land acquisition policy, etc.) adopted by the states. To accelerate growth in the hydropower sector and to bridge the gap between the actual and planned capacity addition, the private sector is being seen as an important stakeholder. The government of India needs to ensure that inter-state agreements for water sharing must be in place to avoid disputes. A National River Authority of India may be constituted to improve river management, address inter-state disputes and for integrated river basin development.

A centralised *Central Electricity Authority (CEA)/Central Water Commission (CWC)* could go a long way in ensuring that interstate disputes and clash of interest are resolved amicably. The government should incest a great deal in R&D and ensure that all checks are made before launching the project while ensuring the settlement of those displaced. The process needs to be participatory and transparent, and all fallouts discussed and covered to win the confidence of the people. The overarching principle for socially and environmentally responsible hydropower development needs to be that the project affected population be the first beneficiary of the project.

The government must tread this line very cautiously taking putting advice from the scientists and other key stakeholders rather than be taken over by political hubris and one upmanship. The implementation of effective water management practices, along with the development of appropriate environmental safeguards, can help in mitigating the environmental impacts of hydroelectric power projects. And just giving up on it would be a loss for India. The cause would be better served if the Government could put in place highly accountable mechanisms to ensure that the implementation is done for the benefit of the people and not for harming them. The government should make stringent policies and laws regarding waste disposal, proper clearance of areas, etc. Such laws should be actively enforced through monitoring. Dams should be maintained properly, and the water quality should be monitored regularly to prevent the challenges discussed above.

India does not have too many options. Hence it is imperative that the scientific community begins to invest greater time and resources for researching solutions. Use of AI can also help collect data that would be crucial to streamline the operations to mitigate the environmental risk.

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