INDIAN JOURNAL OF APPLIED ECONOMICS AND FINANCE
Vol. 1 - Issue 1 - (Jan-June 2025); pp 1-28

Ecological and Human Costs of Large-Scale Irrigation Projects

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Abstract

Large-scale irrigation and dam projects to enhance agricultural productivity and economic growth yield significant ecological and social costs undermining sustainability. Siltation from deforestation reduces reservoir capacity while waterlogging, salinization, and waterborne diseases degrade ecosystems and livelihoods. The Narmada Valley project exemplifies these challenges, displacing over one million people- mostly tribal- and submerging 350,000 hectares of forest and farmland with contested economic benefits. Inadequate rehabilitation policies exacerbate displacement impacts, leaving landless and marginalized groups without support.

Human costs are equally severe, with Displacement being a primary concern. The WCD estimates that 40-80 million people have been uprooted globally by dam projects, often disproportionately affecting marginalized groups. The Akosombo Dam in Ghana displaced 80,000 people, forming Lake Volta but stripping communities of livelihoods. China's Three Gorges Dam relocated 1.2 million, facing massive resettlement challenges. Brazil's Belo Monte Dam displaced up to 40,000, with compensation efforts yielding uneven outcomes. These cases spotlight the social upheaval and economic instability inflicted on vulnerable populations. Health risks compound these human tolls. Irrigation systems create breeding grounds for disease vectors.

Despite benefits like improved water access and crop production, projects like Sardar Sarovar highlight systemic neglect of ecological mitigation and equitable resettlement. Sustainable dam development requires strong rehabilitation, environmental management, and inclusive planning to balance economic gains with social and ecological integrity.

Keywords: Dam-induced Displacement, Ecological degradation, Resettlement policy, Sustainable irrigation

JEL classification: Q25, Q56, Q57, R23

Introduction:

Large-scale irrigation projects, including dams, have been pivotal in advancing agricultural productivity, economic development, and poverty alleviation by providing reliable water supply, electricity, and enhanced crop production. Initiatives like India's Command Area Development Program, launched during the Fifth Five-Year Plan (1974-1979), sought to maximize irrigation potential and improve rural livelihoods. However, their sustainability is increasingly questioned due to significant ecological and human costs (Tripathy, 2003, 2020). Siltation, driven by deforestation in catchment areas, reduces reservoir capacity and impairs water and soil conservation, as evident in the Narmada Valley project (Scudder, 2005). According to World Bank evaluations, cost overruns, slow implementation, and underutilization of irrigation potential- compounded by inadequate funding, poor maintenance, and weak monitoring further challenge these efforts.

Large-scale irrigation projects, often knotted to dam construction, promise agricultural productivity and economic growth but carry significant ecological and human costs. These initiatives reshape landscapes, disrupt ecosystems, and displace communities, with immediate and long-lasting consequences.

Though designated as a national project, the Polavaram irrigation project in Andhra Pradesh has sparked significant controversy due to its potential to submerge numerous villages. The Union Cabinet's approval to transfer 130 villages to Seemandhra has intensified debates, particularly concerning the Bhadrachalam sub-division in Khammam district, where several villages face inundation. According to estimates, the project will displace over 200,000 people by submerging 276 predominantly tribal settlements across approximately 100,000 acres, including forest land (South Asia Network on Dams, Rivers and People (SANDRP), 2005). The displaced population, largely unaccustomed to urban life, risks being forced into migrant labour or urban slums, potentially leading to lifelong social and economic challenges and fueling political unrest.

The project's impact extends beyond Andhra Pradesh, affecting villages along the Sabari River in Konta taluka, Dantewada district, Chhattisgarh, and along the Sabari and Sileru Rivers in Motu taluka, Malkangiri district, Odisha. However, the Environmental Impact Assessment (EIA) lacks detailed information on these interstate impacts. Moreover, no public hearings have been conducted in Chhattisgarh or Odisha, nor have affected communities been adequately informed or offered resettlement and rehabilitation (R&R) plans (SANDRP, 2005).

The Polavaram project has faced further setbacks, with environmental activist Medha Patkar, leader of the Narmada Bachao Andolan (NBA), launching a campaign against it. Patkar has argued that a public hearing held in October 2005 was invalid due to the absence of tribal participation and lack of consent from affected communities (Times of India, October 25, 2005). Her stance echoes broader political scepticism about the Rs. 9,000-crore project, which is projected to displace approximately 145,000 people across Andhra Pradesh, Chhattisgarh, and Odisha. Critics argue that the state government's urgency to implement the project overlooks these concerns, exacerbating tensions.

Opposition to Polavaram has gained momentum, with various organizations in Andhra Pradesh and beyond launching agitations. These protests are likely to intensify, given the project's extensive impacts and the perceived undemocratic approach of both central and state governments. Proposed on the Godavari River near Polavaram town in West Godavari district, the dam is designed to rise 150 feet (47 meters) and cost Rs. 9,265 crores-though revised estimates suggest costs could reach Rs. 20,000 crores. Its submergence zone will extend along the Sabari River, a Godavari tributary, up to the borders of Odisha and Chhattisgarh (India Water Portal, 2015, September 20, SANDRP, 2018).

The project includes two main canals. The Right Main Canal will supply 80 TMC (thousand million cubic feet) of water to the Budameru in Vijayawada, linking the Godavari and Krishna rivers over a 174-km stretch, with potential for freight navigation. The Left Main Canal aims to irrigate 1.2 million acres in north coastal districts, support industrial needs (e.g., Vizag Steel Plant), and provide drinking water to urban and rural areas in Visakhapatnam, Vizianagaram, and Srikakulam. Despite these benefits, the human and environmental costs continue to overshadow the project's promise, placing tribal identity and livelihoods at risk-ranging from total assimilation into mainstream society to complete isolation.

Dam Building and Displacement: A Global and Indian Perspective:

Dam construction is a significant driver of development-induced Displacement worldwide, often disproportionately affecting vulnerable populations such as indigenous and tribal communities (Tripathy, 2003, 2009, 2010, 2013, 2014, 2024a, 2024b). In India, large-scale dam projects have displaced millions over decades, with tribal groups bearing a substantial burden. According to the World Commission on Dams (WCD) report (2000), large dams globally have displaced between 40 and 80 million people. India is one of the most affected countries due to its extensive dam-building history.

Over 3,300 large dams have been constructed in India in the past fifty years (Singh,1997). A significant portion of those displaced is estimated at 40 to 50 per cent from tribal communities, who often lose their land, livelihoods, and cultural heritage (Singh, 1997; WCD, 2000). Two prominent examples, the Sardar Sarovar Dam on the Narmada River and the Tehri Dam on the Bhagirathi River, illustrate such projects' scale and human cost.

The Sardar Sarovar Dam: India's Most Controversial Project:

The Sardar Sarovar Dam, part of the Narmada Valley Development Project (NVDP), has been dubbed India's most contentious dam due to its social and environmental impacts. Initiated in the 1980s, the dam aims to provide irrigation, drinking water, and hydropower, primarily benefiting large landowners and urban centres in Gujarat. However, it has come at a steep cost to tribal populations in Madhya Pradesh, Maharashtra, and Gujarat.

The Narmada Bachao Andolan (NBA), led by activist Medha Patkar, emerged in the late 1980s as a powerful resistance movement against the dam. The NBA highlighted how the project submerged over 37,000 hectares of land, including forests and farmland, displacing entire tribal communities (Dreze et al., 1997). Official estimates from the Government of India suggest that approximately 42,000 families (around 200,000) were displaced. However, the NBA contends that the figure is closer to 85,000 families, or roughly 500,000 individuals, when accounting for indirect impacts of the NBA. The NVDP, spanning 30 large dams, affects an estimated 25 million people living in the Narmada Valley and alters the ecology of the entire river basin (WCD, 2000).

The Tehri Dam: Displacement in the Himalayas:

Located 250 km north of Delhi in Uttarakhand's Tehri Garhwal district, the Tehri Dam is a multipurpose project designed for irrigation, hydropower, and flood control in the Ganges Valley. Construction began in 1978, and by its completion in 2006, it had submerged the historic town of Tehri and numerous villages. A 1979 working group for the Environmental Appraisal of the Tehri Dam, commissioned by the Government of India, projected that 85,600 people would be displaced. This figure includes both fully and partially affected families, with tribal and rural communities again bearing the brunt (India Spend. (2014).

Economically, these projects often underperform. Irrigation dams frequently miss physical targets and deliver low returns due to over-optimistic projections (WCD, 2000). Hydropower generation varies with hydrological accuracy, while flood control dams, despite benefits, can heighten vulnerability through mismanagement and floodplain settlement (Postel, 1999). These shortcomings question the cost-benefit rationale behind such megaprojects.

Ecologically, these projects degrade biodiversity and water systems. The World Commission on Dams (WCD) report, Dams and Development (2000), highlights how habitat submersion and altered river flows diminish fisheries and wetlands. For instance, siltation-exacerbated by deforestation in catchment areas-reduces reservoir capacity and impairs water and soil conservation (Scudder, 2005, The Future of Large Dams, Earthscan). The Food and Agriculture Organization (FAO) notes in its 2011 report, The State of World's Land and Water Resources, that waterlogging and salinization affect 10-48% of irrigated land globally, with 2-3 million hectares lost annually to salinity, degrading soil productivity. Nutrient enrichment from irrigation runoff also triggers algal blooms and eutrophication, compromising water quality and ecosystems (Postel,1999).

Scudder (2005) highlights that waterlogging and salinization affect millions of hectares globally, alongside increased waterborne diseases like malaria due to altered ecosystems. In India, the Narmada Valley project, one of the world's largest river valley schemes, is projected to submerge 350,000 hectares of forest and farmland, disrupting biodiversity and natural food productivity (Agarwal & Narain, 1997). Socially, it threatens to displace over one million people-predominantly tribal communities whose livelihoods depend on these ecosystems.

Affected populations often face impoverishment, landlessness, and food insecurity, with rural and tribal communities hit hardest due to limited resources to resist (Tripathy, 2009, 2010, 2012, 2013, 2014, 2024a, 2024b). They reside among the crushed bricks, shattered plaster, and broken ceramic tiles left behind by the demolished homes of former neighbours, relatives, and long-time friends. These structures were razed after their owners accepted compensation packages offered by the project authorities. Amid this debris, they navigate a fragile existence, surrounded by the memories of a once-thriving community.

Swaminathan et al. (2018) spotlight the absence of a comprehensive rehabilitation framework, leaving displaced groups vulnerable. For instance, the Sardar Sarovar project in Gujarat offered landholders debt-encumbered compensation lands, while landless families received no support, reflecting systemic neglect. Women, primary collectors of water and forest produce, suffer disproportionately as livelihoods vanish without alternatives, exacerbating gender disparities. Despite these drawbacks, dam projects deliver tangible benefits. The Bhakra Nangal Dam transformed wastelands into fertile fields via the Indira Gandhi Canal, curbing desertification in Rajasthan, Punjab, and Haryana (Rangachari, 2005).

Environmental and ecological considerations must be given due importance; however, with the proper channelization of developmental activities, ecology and the environment can be significantly enhanced. For example, the Periyar Dam Reservoir has eliminated recurring famines in Madurai district, Tamil Nadu, and developed into an elephant sanctuary surrounded by dense green forests. Similarly, the Krishnarajasagar Dam transformed the Mandya district in Karnataka from a wild, shrub-covered terrain into a prosperous area with thriving paddy and sugarcane fields (Shelton, Anton, 2011). Communities displaced by these projects often report improved living standards compared to undeveloped villages, with Gujarat's R&R packages offering oustees better conditions than their tribal hamlets (Bhatia,1997).

However, the costs of ecological degradation and social disruption cannot be ignored. Proponents argue that rivers are resources for all, not just local inhabitants, justifying development for the greater good. However, this necessitates robust Resettlement and Rehabilitation (R&R) programs, activated at the outset of displacement planning. Effective R&R must equitably resolve the needs of all rich or poor, tribal or non-tribal, through well-funded compensation, land allocation, and livelihood support. The lack of such measures in projects like Narmada Valley underscores the urgency of reform.

Sustainable dam development hinges on balancing economic gains with ecological and social integrity. Environmental renewal, like converting barren lands to farmland, is possible with proper management, as seen in Bhakra Nangal's success. However, submergence-induced forest loss and biodiversity decline demand mitigation strategies (Balooni, & Venkatachalam, 2016).

Objectives:

1) To assess how large dams in India have influenced economic development, social welfare, and ecological health, focusing on benefits like irrigation and power generation versus costs such as Displacement and biodiversity loss.
2) To analyze the effectiveness of existing policies and decision-making processes, like those proposed by the WCD, in ensuring sustainable outcomes for future dam projects.

Methodology:

This study relies primarily on secondary sources to synthesize a comprehensive analysis. Key texts include the World Commission on Dams (WCD) Report (2000), which provides a global framework for evaluating dam performance, and Singh's Dams and Development (2012), offering an India-specific perspective on project outcomes. Gupta's River Ecosystems and Development Projects in India (2019) supply ecological insights, while government reports and World Bank evaluations supplement data on economic and social impacts. Peer-reviewed journals, books, and policy documents are reviewed to ensure a strong evidence base.

The methodology involves qualitatively synthesizing these sources, focusing on case studies like Bhakra Nangal and Narmada Valley to compare projected versus actual outcomes. The thematic analysis identifies recurring issues-displacement, ecological degradation, and benefit inequity-while cross-referencing WCD findings with Indian experiences tests the applicability of global sustainability principles locally. Limitations include reliance on existing data and potentially missing real-time field nuances, though the breadth of secondary sources mitigates this by capturing diverse perspectives.

Impacts and Sustainability of Large River Valley Projects in India:

The Displacement caused by dams like Sardar Sarovar and Tehri reveals a pattern: benefits accrue to wealthier, urban populations, while marginalized groups pay the price. The World Bank, which initially funded the Sardar Sarovar Project but withdrew in 1993 due to protests, acknowledged that resettlement efforts often fail to restore livelihoods (World Bank, 1994). Moreover, ecological damage, such as biodiversity loss and altered river flows, compounds the human toll.

The Tehri Dam, located on the Bhagirathi River in Uttarakhand, India, is the tallest dam in the country at 260.5 meters. It serves multiple purposes, including power generation, irrigation, and flood control. Though it displaced around 85,600 rural and tribal people and faced some local opposition, it was not widely contested at the national level. The construction of the Tehri Dam was completed in 2006, followed by the Koteshwar Dam in 2012, and the pumped storage house was commissioned in February 2016, which faced severe criticism (Asian Research Consortium, 2017). The submergence of Old Tehri town's forest area led to the decomposition of flora and fauna, releasing greenhouse gases. This contributed significantly to rising summer temperatures in the region. The area also faces monsoon-related issues such as frequent landslides, minor earthquakes, and the looming threat of hill collapse, posing risks to downstream populations.

Large river valley projects in India, such as the Bhakra Nangal and Narmada Valley initiatives, have been championed as regional development, water security, job creation, and industrial growth engines. Proponents assert that these dams have avoided overarching negative environmental impacts and have often enhanced ecological conditions while delivering substantial socioeconomic benefits (Tripathy, 2020). Irrigation, flood control, and hydroelectric power generation bolster agriculture, energy supply, and export potential, positioning dams as critical tools for national progress. However, these projects have revealed significant ecological and social costs over the past five decades, prompting debates about their sustainability.

Despite claims of environmental improvement, large dams fragment river ecosystems, disrupt hydrological cycles and degrade biodiversity (Bhatt et al., 2017). Globally, an estimated 40 to 80 million people have been displaced by dam reservoirs, with India contributing heavily to this figure (World Commission on Dams (WCD), 2000). The Narmada Valley project alone threatens over one million displacements, mostly tribal communities, intensifying scrutiny of human and ecological tolls (Tripathy, 2003, 2009, 2010, 2013, 2014, 2024a, 2024b). Critics highlight escalating debt, cost overruns, ecosystem destruction, and inequitable benefit distribution, challenging the narrative of unmitigated progress.

The Dual Edge of Irrigation: Benefits and Sustainability Challenges:

Irrigation has been a cornerstone in reducing poverty, enhancing food security, and improving the quality of life for rural communities worldwide. Enabling consistent agricultural production has bolstered livelihoods and economic stability. However, the sustainability of irrigated agriculture faces growing scrutiny due to its economic and environmental implications. While the benefits are clear, the environmental challenges it introduces demand urgent attention.

Large-scale irrigation and drainage projects in Africa have often stumbled due to overemphasizing technical engineering and projected economic gains, neglecting broader environmental and social factors. Decisions to launch these costly ventures frequently lack thorough assessments of their ecological and human impacts, relying instead on incomplete cost-benefit analyses (Adams, 1992). This oversight has undermined the long-term viability of capital-intensive water schemes, leading to unforeseen difficulties.

The sustainability of irrigation depends on two aspects: resolving environmental consequences and ensuring adequate maintenance funding. Adverse ecological effects can erode investments, necessitating sufficient resources for implementing agencies to manage routine and emergency upkeep. Effective irrigation planning must integrate with river basin and regional development strategies, considering upstream and downstream ecosystems.

The agricultural expansion fueled by irrigation brings a suite of adverse effects: increased erosion, pollution of surface and groundwater with biocides, declining water quality, and nutrient enrichment causing algal blooms, aquatic weed growth, and eutrophication in canals and waterways (Postel, 1999). Downstream, poor water quality disrupts other uses, harms aquatic life, and fosters weed proliferation that clogs navigation routes and poses health risks. Moreover, altered microclimates marked by reduced dry-season dieback and higher humidity can intensify crop pest and disease pressures.

Large irrigation projects that impound or divert river water disrupt basin hydrology and limnology. Reduced flows alter floodplain ecology, risking saltwater intrusion into rivers and groundwater, while diversions limit water for downstream municipalities, industries, and farms. Lower base flows diminish the dilution of downstream waste, heightening pollution and health hazards (Postel, 1999). Over-extraction of groundwater, which exceeds recharge rates and lowers water tables, causes subsidence, degrades quality, and invites coastal saltwater intrusion. Upstream activities, like erosion or pollution, further complicate water quality with high sediment loads that clog canals.

Key environmental impacts include waterlogging, salinization, heightened disease prevalence, and social disruptions from Displacement. Globally, salinity claims 2 to 3 million hectares of farmland yearly, with 10 to 48% of irrigated land affected, especially in arid zones (FAO, 2011). Waterlogging and salinization, driven by poor drainage and over-irrigation, concentrate salts in the rooting zone, with alkalization posing a persistent challenge. In arid regions, scarce rainfall and high irrigation volumes exacerbate salt buildup as evapotranspiration leaves residues behind.

Salinity stifles plant growth by raising water extraction energy, with sensitive crops like clover and rice suffering more than barley or wheat. Studies indicate that salinity cuts paddy and wheat yields by 50% on degraded soils, slashing incomes by 85% compared to unaffected areas (FAO, 2011). Downstream rivers grow saltier, and saline aquifers impair water quality for agriculture and wildlife.

Mitigation is possible with proper drainage. In Egypt, drainage systems reduced salinity, lifting wheat yields from 1 ton/ha to 2.4 tons/ha and maize from 2.4 tons/ha to 3.6 tons/ha (Adams, 1992). However, drainage remains poorly managed in many projects. Micro-irrigation, delivering precise water amounts, offers another solution to curb waterlogging and salinization.

Table 1: Environmental Degradation from Large-Scale Irrigation Projects

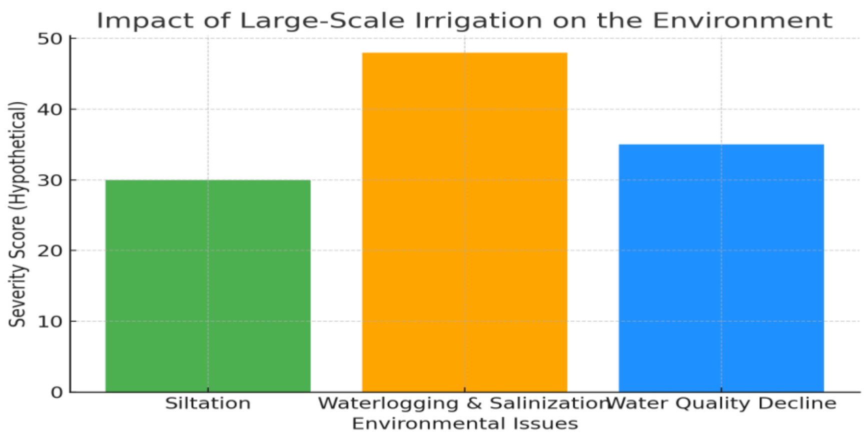
Issue	Description	Detail	Source
Siltation	Reduces reservoir capacity and impairs water/soil conservation	Driven by deforestation in catchment areas	Scudder, T. (2005). *The Future of Large Dams*. Earthscan.
Waterlogging & Salinization	Affects 10-48% of irrigated land globally, degrading soil productivity	2-3 million ha lost annually to salinity	FAO. (2011). *The State of World's Land and Water Resources*. Rome: FAO.

Issue	Description	Detail	Source
Water Quality Decline	Nutrient enrichment leads to algal blooms and eutrophication	Impacts downstream ecosystems and usability	Postel, S. (1999). *Pillar of Sand: Can the Irrigation Miracle Last?*

Source: Compiled by the author

Notes: Table 1 highlights the ecological toll of irrigation projects. Scudder (2005) discusses siltation's role in reducing dam efficacy, while FAO (2011) quantifies salinization's global impact. Postel (1999) details water quality degradation, emphasizing downstream consequences.

Siltation, worsened by deforestation, reduces reservoir capacity and hampers water and soil conservation. Waterlogging and salinization degrade 10-48% of irrigated land, with 2-3 million hectares lost yearly to salinity, lowering productivity. Water quality declines from nutrient enrichment, causing algal blooms and eutrophication, which harm downstream ecosystems and usability.



The bar chart visualizing the environmental impact of large-scale irrigation projects.

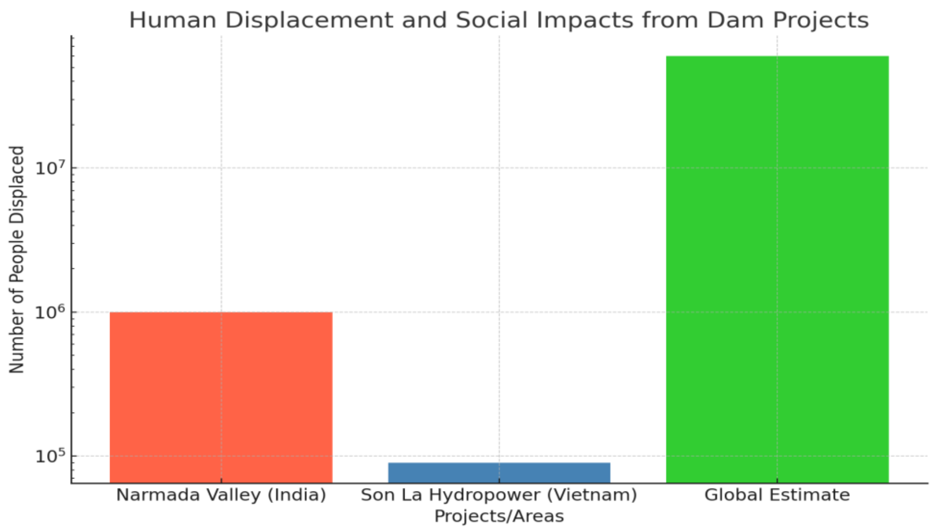
Table 2: Human Displacement and Social Impacts from Dam Projects

Project/Area	Impact	Detail	Source
Narmada Valley (India)	Displaces over 1 million people	Mostly tribal, losing forest/farmland	Agarwal, A., & Narain, S. (1997). *Dying Wisdom*. Centre for Science and Environment.

Project/Area	Impact	Detail	Source
Son La Hydropower (Vietnam)	65% income decline post-resettlement	90,000 displaced to remote, impoverished areas	Nguyen, et al. (2017)
Global Estimate	40-80 million displaced by dams	Often without adequate compensation	World Commission on Dams (WCD). (2000). *Dams and Development*. Earthscan.

Source: Compiled by the author

Agarwal and Narain (1997) highlight how over a million mostly tribal people in India's Narmada Valley lost forests and farmland due to dam construction. Similarly, Nguyen et al. (2017) and the WCD (2000) emphasize widespread Displacement, impoverishment, and inadequate compensation globally.



The bar chart visualizing human displacement and social impacts from dam projects.

Table 3: Mitigation Strategies and Outcomes in Irrigation Projects

Strategy	Description	Outcome	Source
Drainage Systems (Egypt)	Reduces soil salinity through improved drainage	Wheat yields rose from 1 to 2.4 tons/ha	Adams, W. M. (1992). *Wasting the Rain: Rivers, People and Planning in Africa*. Earthscan.

Strategy	Description	Outcome	Source
Micro-Irrigation	Precise water delivery to limit excess application	Minimizes waterlogging and salinization	FAO. (2011). *The State of World's Land and Water Resources*. Rome: FAO.
Environmental Flows	Maintains downstream ecosystems via controlled releases	Mitigates altered streamflow impacts	Postel, S. (1999). *Pillar of Sand: Can the Irrigation Miracle Last?*

Source: Compiled by the author

Table 3 showcases practical solutions. Adams (1992) documents Egypt's drainage success, FAO (2011) endorses micro-irrigation's efficiency, and Postel (1999) advocates environmental flows to balance ecological needs with irrigation demands.

Sustainable Water and Energy Development:

The World Commission on Dams (WCD) Knowledge Base underlines the dual nature of large dams: vital for water and energy supply yet laden with significant environmental and social costs. While these projects have historically driven development, their sustainability hinges on integrating ecological considerations, ensuring equitable benefit-sharing, and exploring alternatives to minimize harm. Improved governance, scientific research, and community participation are critical to achieving a balanced approach to water and energy management (WCD, 2000).

Better development outcomes demand a comprehensive, inclusive framework for planning and decision-making. This involves weighing large dams against alternatives and prioritizing equity, efficiency, participation, sustainability, and accountability. A rights-and-risks approach is foundational, recognizing stakeholders' entitlements-especially those of Indigenous groups, women, and vulnerable populations-while assessing broader social, environmental, and economic risks beyond mere financial considerations (Postel, 1999).

Public acceptance is pivotal, requiring informed participation, transparent negotiations, and respect for Indigenous consent. Access to information, legal support, and negotiation platforms enhances legitimacy. A thorough options assessment is equally essential, exploring smaller-scale systems, improved irrigation, and renewables like solar and wind over defaulting to dams. Efficiency in existing infrastructure must precede new projects (FAO, 2011).

Sustaining rivers and livelihoods is non-negotiable. Large dams disrupt biodiversity, fisheries, and water quality, necessitating impact avoidance, harm reduction, and ecosystem restoration through measures like environmental flows and strategic site selection. Benefit-sharing goes beyond compensation, aiming to enhance livelihoods via fair resettlement and long-term opportunities secured through binding agreements between developers, governments, and communities.

Sustainability must guide planning, balancing short-term gains with long-term resilience. Strong environmental and social impact assessments are vital to prevent harm, while accountability strong institutions, oversight, and transparent reporting-ensures alignment with public interests. Shifting from top-down to participatory approaches fosters collaboration among governments, developers, and communities, creating socially just and environmentally sound outcomes.

The World Commission on Dams (WCD, 2000) highlights the varied performance of large dams across sectors. Irrigation dams frequently fall short of projected targets, facing cost recovery failures and low returns due to overly optimistic estimates. Though financially viable, hydropower dams often suffer from inconsistent generation caused by hydrological miscalculations. Municipal and industrial dams struggle with delays and poor cost recovery, undermining their economic feasibility. While flood control dams mitigate risks, they inadvertently increase vulnerability by encouraging settlements in floodplains and mismanagement of flood control measures. Multipurpose dams amplify these shortcomings, reflecting unrealistic expectations. Persistent cost overruns and project delays have fueled scepticism, prompting a shift toward integrated flood management that combines structural and non-structural approaches (Postel, 1999).

Beyond economic concerns, physical and ecological challenges threaten the long-term sustainability of dams. Ageing infrastructure and climate change necessitate continuous investment in dam safety. High erosion rates lead to sedimentation, reducing storage capacity over time (WCD, 2000). Waterlogging and salinity affect nearly 20% of irrigated land, posing severe risks to agricultural productivity without proper drainage systems (FAO, 2011). Moreover, large reservoirs contribute to habitat loss, biodiversity decline, and greenhouse gas emissions, particularly in tropical regions. Efforts to mitigate these issues often suffer from inadequate forecasting and implementation, though emerging strategies such as environmental flow management and selective dam decommissioning offer potential solutions. While large dams have historically driven development in India's irrigation and hydropower expansion, their social and environmental costs remain excessive and frequently avoidable. The Bhakra Nangal project showcases agricultural transformation, yet the Narmada dam crisis highlights the Displacement of marginalized communities (Rangachari, 2005). Resolving these concerns requires transparent decision-making, improved resettlement and rehabilitation (R&R) policies, and a broader embrace of sustainable alternatives, such as decentralized water management and renewable energy solutions (Bhatt et al., 2017).

Table 4: Performance Trends of Large Dams

Dam Type	Key Performance Issue	Detail	Source
Irrigation	Missed physical targets, low economic returns	Over-optimistic projections	WCD (2000). *Dams and Development.*
Hydropower	Inconsistent power generation	Varies by hydrological accuracy	WCD (2000). *Dams and Development.*
Flood Control	Increased vulnerability despite benefits	Floodplain settlement, mismanagement	Postel, S. (1999). *Pillar of Sand.*

Source: Compiled by the author

Notes: This section highlights performance variability, with WCD (2000) and Postel (1999) detailing economic and operational shortfalls.

Irrigation dams miss physical targets and yield low economic returns due to overly optimistic projections. Hydropower dams suffer inconsistent power generation tied to hydrological accuracy. Despite the benefits, flood control dams increase vulnerability through floodplain settlement and mismanagement, exacerbating risks rather than fully mitigating them. Irrigation dams miss physical targets and yield low economic returns due to overly optimistic projections. Hydropower dams suffer inconsistent power generation, tied to hydrological accuracy. Flood control dams, despite benefits, increase vulnerability through floodplain settlement and mismanagement, exacerbating risks rather than fully mitigating them.

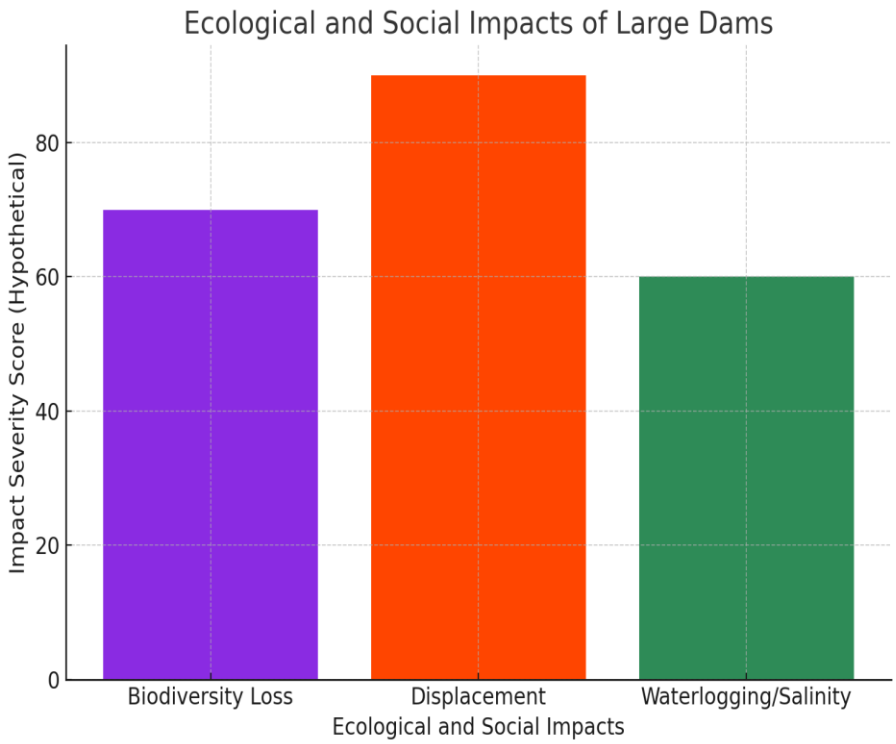
Table 5: Ecological and Social Impacts of Large Dams

Impact	Description	Detail	Source
Biodiversity Loss	Habitat submersion and flow alteration	Affects fisheries, wetlands	WCD (2000). *Dams and Development*.
Displacement	40-80 million people globally displaced	Often excludes marginalized groups	WCD (2000). *Dams and Development*.
Waterlogging/Salinity	Affects 20% of irrigated land	Irreversible without drainage	FAO (2011). *State of World's Resources*.

Source: Compiled by the author

Notes**:** Quantifies ecological and human costs, supported by WCD (2000) and FAO (2011).

Large dams cause biodiversity loss by submerging habitats and altering flows, impacting fisheries and wetlands. They displace 40-80 million people, often marginalizing vulnerable groups, and lead to waterlogging and salinity, irreversibly affecting 20% of irrigated land without drainage.



Water-Related Diseases: Risks and Sustainability Pathways:

Large dams and irrigation systems have transformed water management, delivering benefits like food security, energy, and flood control. However, these projects introduce significant risks, notably waterborne diseases and Displacement, which challenge their sustainability. This analysis examines the health and social impacts of irrigation and dams, explores strategies for equitable resettlement, and evaluates hydropower's role amidst climate change and renewable alternatives, drawing on global and regional evidence.

Irrigation systems often foster waterborne diseases such as malaria, schistosomiasis (bilharzia), and onchocerciasis (river blindness), whose vectors, mosquitoes and snails, thrive in irrigation waters. Other risks include agrochemical exposure, water quality decline, and diseases from wastewater reuse, affecting farm workers, consumers, and nearby residents (Scudder, 2005). Sprinkler irrigation heightens pathogen spread via air dispersal. High-risk scenarios include poor drainage, rice or sugarcane cultivation, night storage reservoirs, stagnant borrow pits, and unlined, vegetated canals (Agarwal & Narain, 1997).

Globally, irrigation-related malaria affects millions, with sub-Saharan Africa bearing a heavy burden. According to WHO estimates, Schistosomiasis, linked to snail habitats in irrigation channels, impacts over 200 million people annually. These health risks underscore the need for integrated water management to mitigate disease vectors.

The Impacts of Dam-Induced Displacement:

The Kaptai Dam, built in the 1960s in Southeast Bangladesh with U.S. support, displaced over 100,000 Indigenous Jumma Peoples and submerged vital lands, homes, and cultural heritage. It remains a stark example of development without consent, leading to environmental loss, forced migration, and marginalization. Despite producing 5% of Bangladesh's electricity, the Jumma Peoples received no compensation (Rahman, 2011).

The Hirakud dam project, though envisioned as a transformative initiative for flood control, irrigation, hydropower, and navigation, resulted in the Displacement of nearly one lakh people in Odisha alone, with inadequate rehabilitation and compensation. Despite early resistance, affected communities were relocated under promises that remain largely unfulfilled even after 70 years. The rehabilitation process was marred by negligence and systemic failures, leading to recurring protests by groups like the Hirakud Budi Anchal Sangram Samiti. The submerged villages and lost livelihoods reflect a legacy of developmental injustice and unresolved human costs (Dansana, 2021).

Dams have displaced 40-80 million people worldwide, submerging fertile river valleys where communities rely on agriculture, fisheries, and trade (Scudder, 2005). The Akosombo Dam in Ghana (1960s) displaced 80,000, forming Lake Volta, while China's Three Gorges Dam (2000s) uprooted 1.2 million, and Brazil's Belo Monte Dam (2019) displaced up to 40,000 (Randell, 2016). Displacement often leads to impoverishment, landlessness, food insecurity, and psychological distress, disproportionately hitting marginalized groups (Cernea, 2000). Development-induced Displacement from dams, mines, and infrastructure often harms livelihoods. However, well-resourced, compensation-based resettlement programs can help align national goals with short-term socioeconomic gains for displaced communities (Randell, 2016).

Post-resettlement, households struggle with fragmented communities, smaller or infertile land, and lost river access. Compensation rarely offsets losses, and cultural heritage-cemeteries, temples, and Indigenous sites-vanishes underwater. The Son La Hydropower Project, Vietnam's largest and most complex dam, will displace up to 100,000 ethnic minority people, primarily Thai, requiring the nation's largest resettlement. These river-dependent communities, mainly practising wet rice cultivation, face relocation 50-100 kilometres away, with limited access to arable land and the Da River slashing incomes by 65% due to isolation and inadequate land (Nga Dao, 2010). Resettlement programs are often underfunded and exclude affected voices, exacerbating inequities (Scudder, 2005). India's Narmada Valley project, set to displace over one million, lacks robust rehabilitation, leaving tribal populations vulnerable.

Supplementary Social and Ecological Risks:

Successful cases, like Belo Monte, show potential: well-funded compensation enabled farmers to rebuild, though urban moves caused distress (Randell, 2016). Minimizing Displacement via strategic siting is ideal; resettlement must enhance livelihoods through ample funding, pre-displacement research, and post-relocation monitoring when unavoidable. Involving communities ensures tailored solutions while benefit-sharing-e.g., energy revenues or infrastructure-offers sustained support.

Globally, 40-80 million people have been displaced, with millions losing downstream livelihoods. Marginalized groups, especially women, bear disproportionate costs, often without compensation or cultural restoration (Postel, 1999). Benefit-sharing models offer hope for equity through

alternative demand-side management, system upgrades, basin management, and renewables-reduce dam reliance (FAO, 2011). Historically, centralized decisions have shifted toward participatory governance, filtering out unviable projects early.

Beyond Displacement, dams disrupt downstream livelihoods. Floodplain agriculture declines with restricted floods and fisheries collapse, as seen with Mekong dams (Cernea, 2000). Health risks include methylmercury poisoning from reservoirs and increased malaria from altered flows (Hong et al., 2012). As dams shift water temperature, oxygen, and nutrients, ecosystems suffer, slashing biodiversity (Fearnside, 2015). Hydropower's renewable label is challenged by ecological and social costs, climate-induced uncertainties, and regional feasibility of alternatives, demanding sustainability through careful trade-off assessments, resilience planning, and prioritization of low-impact, context-appropriate energy solutions.

Table 6: Water-Borne Diseases Linked to Irrigation

Disease	Vector/Mechanism	Detail	Source
Malaria	Mosquitoes in irrigation waters	Millions affected globally	Scudder, T. (2005). *The Future of Large Dams*. Earthscan.

Disease	Vector/Mechanism	Detail	Source
Schistosomiasis	Snails in canals	Over 200M cases annually (WHO)	Agarwal, A., & Narain, S. (1997). *Dying Wisdom*. CSE.
Agrochemical Risks	Increased pesticide use	Impacts workers and consumers	Calder et al. (2016).

Source: Compiled by the author

Irrigation waters breed mosquitoes, spreading malaria to millions globally. Canals harbour snails, causing over 200 million annual schistosomiasis cases. Increased pesticide uses from agrochemicals tied to dams affects workers and consumers, posing health risks and highlighting the disease burden linked to large dam projects.

Table 7: Major Dams and Their Human Displacement Impacts

Dam Name	Country	Completion Year	River	Displacement Impact	Notes
Akosombo Dam	Ghana	1960s	Volta River	Displaced 80,000 people	Created Lake Volta, the world's largest artificial lake by surface area
Three Gorges Dam	China	Mid-2000s	Yangtze River	Displaced over 1.2 million people	One of the largest hydropower projects in the world
Belo Monte Dam	Brazil	2019	Xingu River	Displaced up to 40,000 farmers, fishers, and urban residents	Built in the Amazon region, highly controversial
(General Impact)	Worldwide	20th century onward	Various	Estimated 40 to 80 million people displaced globally	Dams flood fertile, populated areas and disrupt communities

Source: Compiled by the author

Large dam projects, while enabling hydropower and water management, have caused massive Displacement of up to 80 million people globally, disrupting livelihoods, ecosystems, and communities, especially in densely populated and ecologically sensitive regions. A perusal of the above analysis highlighted the conclusions presented in Table 8.

Table 8: Multidimensional Impacts of Large-Scale Dam Projects in India

Impact Area	Metric	Value/Range
Displacement	People displaced (Narmada)	250,000–320,000
	% facing landlessness	60%
	% receiving adequate R&R	20–30%
Ecological	Biodiversity loss	20–30%
	Soil degradation	15–20%
	Ecosystem degradation	40%
Economic	% facing impoverishment	40–60%
	Income drops	30–50%
Social	% with weakened community networks	70%
	% with kin group dispersal	50%
Health	Increased morbidity	15–20%
Sustainability	Small-scale project cost reduction	~50%
	WCD guideline alignment	10–15%
	Risk reduction via participatory planning	30–40%

The costs of large-scale dam projects in India, as evidenced by the Narmada project, are substantial and multi-dimensional. Displacement affects hundreds of thousands, with ~60% facing landlessness and 70–80% receiving inadequate R&R, leading to widespread impoverishment (40–60%) and income drops (30–50%). Ecologically, biodiversity loss (20–30%), soil degradation (15–20%), and ecosystem damage (40%) threaten long-term environmental sustainability. Socially, weakened community networks (70%) and kin dispersal (50%) erode cultural and support systems, while health impacts include a 15–20% rise in morbidity (Table 8).

Approximately 285,000 people are displaced by the Narmada project, with estimates varying by ±35,000, indicating moderate uncertainty in the total number affected, equivalent to a medium-sized city's population. About 60% of displaced individuals lose their land, consistently across projects, with a variability of ±5%, severely impacting their ability to earn a living. Only 25% of displaced people receive adequate resettlement and rehabilitation, with a high variability of ±5%, showing inconsistent and often poor support for rebuilding lives.

Biodiversity loss averages 25%, with a high variability of ±5%, indicating that plant and animal species decline significantly but vary by project location. Soil degradation affects 17.5% of the land, with a moderate variability of ±2.5%, reducing fertility and impacting farming across different areas. Ecosystem degradation damages 40% of the natural regions, with a moderate variability of ±5%, causing widespread harm to water systems and wildlife in most projects.

Around 50% of affected people face poverty, with a high variability of ±10%, showing that economic hardship differs greatly across communities impacted by dam projects. Incomes drop by an average of 40%, with very high variability of ±10%, indicating significant financial disruption that affects some groups more than others.

About 70% of communities experience weakened social ties, with a low variability of ±5%, demonstrating a consistent and widespread loss of community cohesion across projects. Approximately 50% of families are separated, with a moderate variability of ±5%, reflecting significant but variable disruption to family structures. Morbidity increases by 17.5%, with moderate variability of ±2.5%. This means more people get sick due to poor living conditions or water quality issues, with slight variations across projects.

Smaller-scale projects could reduce costs by 50%, with moderate variability of ±5%, offering a cost-effective alternative with some variation in savings. Only 12.5% of projects align with global World Commission on Dams standards, with a high variability of ±2.5%, indicating poor and inconsistent adoption of best practices. Community involvement could reduce risks by 35%, with moderate variability of ±5%, highlighting a reliable strategy to improve project outcomes.

Key Takeaways:

Displacement affects 285,000 people, with 60% losing land and only 25% receiving proper resettlement. Ecologically, 25% biodiversity loss, 17.5% soil degradation, and 40% ecosystem damage occur. Economically, 50% face poverty, and incomes drop 40%. Socially, 70% lose community ties, and 50% of families split. Health worsens with 17.5% more illness. Sustainability options include 50% cost savings, 12.5% global standard alignment, and 35% risk reduction through community input.

High variability affects income loss (50%), poverty (40%), biodiversity loss (40%), resettlement quality (40%), and global standards (40%). Moderate variability impacted displacement (24.6%), ecosystem damage (25%), soil degradation (28.6%), illness (28.6%), risk reduction (28.6%), cost savings (20%), and family separation (20%). Low variability occurs in community ties (14.3%) and landlessness (16.7%). Social (70% weakened ties) and ecological (40% ecosystem damage) impacts are severe, while economic effects (50% poverty, 40% income drops) vary widely.

The displacement of 285,000 people, with 60% losing land and only 25% getting help, highlights a failure to support affected communities adequately. Ecosystem damage (40%) and biodiversity loss (25%) threaten nature and farming in the long term. Poverty (50%) and income drops (40%) show benefits like power often bypass locals, worsening inequality. Increased illness (17.5%) adds health burdens. Smaller projects (50% cheaper) and community input (35% less risk) are promising, but low global standard adherence (12.5%) shows systemic gaps.

Conclusion:

Large dam projects' social, economic, and ecological costs currently outweigh their benefits for affected communities. Transitioning to smaller-scale projects and adopting participatory planning and WCD guidelines could mitigate risks and enhance sustainability. Still, systemic reforms are needed to prioritize equitable benefit distribution and minimize harm.

While benefits like hydropower, irrigation, and flood control can drive economic growth, they often disproportionately favor urban or elite groups, marginalizing local communities. Sustainability metrics suggest potential for improvement: small-scale projects could halve costs, and participatory planning could reduce risks by 30–40%. However, current alignment with WCD guidelines remains low (10–15%), indicating poor adherence to global best practices.

Large dam projects' social, economic, and ecological costs currently outweigh their benefits for affected communities. Transitioning to smaller-scale projects and adopting participatory planning and WCD guidelines could mitigate risks and enhance sustainability. Still, systemic reforms are needed to prioritize equitable benefit distribution and minimize harm.

Dam building in India exemplifies the tension between development goals and human rights. At the same time, these projects deliver undeniable benefits; their costs-displacement, ecological harm and cultural loss are disproportionately borne by tribal and rural populations (Tripathy, 2024a, 2024b). Movements like the NBA have brought global attention to these issues, however, challenges in equitable resettlement persist. Tackling this requires better planning and amplifying the voices of those most affected.

Large-scale irrigation projects take a steep toll on ecosystems and human lives. Biodiversity loss, soil degradation, and water quality decline parallel the Displacement, health crises, and economic disappointments faced by affected communities (Tripathy, 2003, 2009, 2010, 2012). Resolving these costs requires rethinking project design, prioritizing sustainable alternatives, and ensuring equitable compensation and mitigation measures. The evidence from diverse global sources (2000), FAO (2011), Scudder (2005), and others demands a critical reassessment of such developments to balance progress with preservation.

Prof Tripathy aptly remarked, 'Displacement and involuntary resettlement induced by policy decision of the Government, often germinates to severe economic, social and environmental risks: productive systems are dismantled; people face impoverishment when their productive assets or income sources are lost; people are relocated to environments where their productive skills may be less applicable and the competition for resources greater; community institutions and social networks are weakened; kin groups are dispersed; and cultural identity, traditional authority, and the potential for mutual help are diminished or lost, violation of human rights (Tripathy 2020, 2024a, 2024b).

Cernea's impoverishment risk and reconstruction model proposes that "the onset of impoverishment can be represented through a model of eight interlinked potential risks intrinsic to displacement." These are: i) Landlessness, ii) Joblessness, iii) Homelessness, iv) Marginalization, v) Food Insecurity, vi) Increased Morbidity and Mortality, vii) Loss of Access to Common Property, viii) Social Disintegration, ix) Loss of Access to Community, x) Violation of Human Rights (Cernea, 1988).

While dams drive economic progress and improve livelihoods, their sustainability requires acknowledging and mitigating their ecological and human tolls. Projects like Narmada Valley illustrate the stakes: vast Displacement and environmental loss against contested benefits. Dam development can evolve into a responsible endeavour by prioritizing comprehensive R&R, sustainable environmental strategies, and participatory planning, harmonizing growth with equity and ecological health.

Large river valley projects in India deliver undeniable benefits but at a steep cost to ecosystems and communities. Attaining sustainability demands rigorous impact assessments, inclusive planning, and viable alternatives aligning with WCD principles. Future projects must prioritize equitable outcomes to harmonize development with environmental and social integrity. Inclusive decision-making, integrating affected communities, can ensure equitable benefit-sharing and minimize costs.

India's debate on large dams reveals three perspectives: some defend them, others highlight unequal costs and benefits, and a third group advocates smaller, eco-friendly alternatives. However, ecological, economic, and social calculations increasingly question the viability of big dams as a sustainable development strategy (Aravinda, 2000).

Dams and irrigation deliver critical benefits but exact heavy tolls via diseases and Displacement. Sustainable development demands integrated planning, equitable resettlement, and renewable diversification supported by transdisciplinary research to balance trade-offs and enhance co-benefits.

While irrigation drives rural progress, its sustainability demands a balanced approach. Resolving environmental degradation through integrated planning, robust maintenance, and innovative techniques is critical to preserving its benefits without compromising ecosystems or livelihoods.

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