International Journal of Creative and Open Research in Engineering and Management
ISSN: **3108-1754 (Online)**
Volume 02 Issue 07 Jul-2026 | Impact Factor: 3.5

Dams in Decay: A Call for Deep-System Reform

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How to Cite this Article:

Jagannath, D. N. (2026). Dams in Decay: A Call for Deep-System Reform. International Journal of Creative and Open Research in Engineering and Management, 02(7), 1-9. https://doi.org/10.55041/ijcope.v2i7.204

https://doi.org/10.55041/ijcope.v2i7.204

AN ABSTRACT

India's irrigation sector faces systemic challenges addressed through Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), with government reports highlighting transformative progress. India's Dam Safety Act, 2021, establishes tiered protocols and audits to safeguard over 5,000 aging dams through surveillance, risk assessments, and emergency plans, mitigating failures from seepage or erosion. Analysis reveals implementation gaps like resource shortages and manual inspections, necessitating digital monitoring and capacity-building for climate resilience. Discussions highlight audit strengths in accountability but critique inconsistencies, inferring a robust yet imperfect system. Conclusions urge digitized upgrades and third-party audits, with recommendations prioritizing funding and training to ensure water security. India's irrigation infrastructure covers 45-48% of arable land but achieves only 35-40% efficiency, per ICRIER and NITI Aayog. Challenges include groundwater depletion (Shah/IWMI), canal losses, and low productivity. PMKSY and state initiatives promise modernization, yet adoption lags. Reforms via precision tech and IMT are urged for equity by 2030 (TISS, World Bank). Press Information Bureau (PIB, Government of India, 2025) documents Rs 1,600 crore for Modernization of Command Area Development & Water Management (M-CADWM), deploying SCADA/IoT for pressurized pipes up to 1 ha, boosting Water Use Efficiency (WUE). Ministry of Jal Shakti's PMKSY Dashboard (2025) confirms Accelerated Irrigation Benefits Programme (AIBP)'s 62 projects creating 354,000 ha potential and Har Khet Ko Pani (HKKP)'s 55,290 km pipelines across 21 states. Central Water Commission (CWC, 2025) reveals 155 major reservoirs at 64% storage (114.914/180.852 BCM), with Punjab-Haryana at 17% risking rabi shortages versus Tamil Nadu's 84% stability. Indian Infrastructure Magazine (May 7, 2025) notes 309,811 ha drip and 148,420 ha sprinkler coverage under PMKSY, elevating irrigation intensity to 154.5%, while its November 7 edition emphasizes 0.7 million solar pumps conserving ~50 BCM, exemplified by Gujarat's 120,000 ha micro-irrigation amid 38% national efficiency. India Water Portal (2023) projects 26% reservoir loss by 2050 due to Ganges-Brahmaputra sedimentation, exceeding global 13-19%, urging 10-20 MCM/site dredging and afforestation. IJIRSET (2014) quantifies lining gains: 0.376 Mm³ savings per command, lifting unlined 35-52% efficiency to 75-90% despite Rs 1-2 crore/km costs. CWC's Canal Lining Manual (2000) and FAO (2009) advocate geomembranes, warabandi, and SCADA for 20-30% downtime cuts. IAS Point (January 31, 2025) links 86% deficient districts to food volatility, countered by PMKSY's irrigated area rise from 49% to 55%. Science Magazine (February 10, 2026) warns on Salal's 95% siltation desilting risks; Mordor Intelligence (January 20, 2026) validates Per Drop More Crop (PDMC) for 20% WUE. Vikaspedia/MyScheme.gov.in/IndiaStat/AgEcon Search (2025) affirm 347 MT food grains (2024-25). Key Result Areas (KRAs)—modernization, reservoirs, efficiency, productivity, technology, resilience—interlink under PMKSY, targeting 75% lining, 10 BCM desilting, 50% micro-coverage by 2030. Challenges like land hurdles persist, but holistic execution promises agricultural resilience against

Key Words: Irrigation Crisis-Sedimentation-Unlined Canals-Conveyance Efficiency-Infrastructure Modernization-Reservoir capacity-PMKSY-Water use efficiency (WUE)-Micro-irrigation-SCADA/IoT-Agricultural Productivity-Climate Resilience-Canal lining

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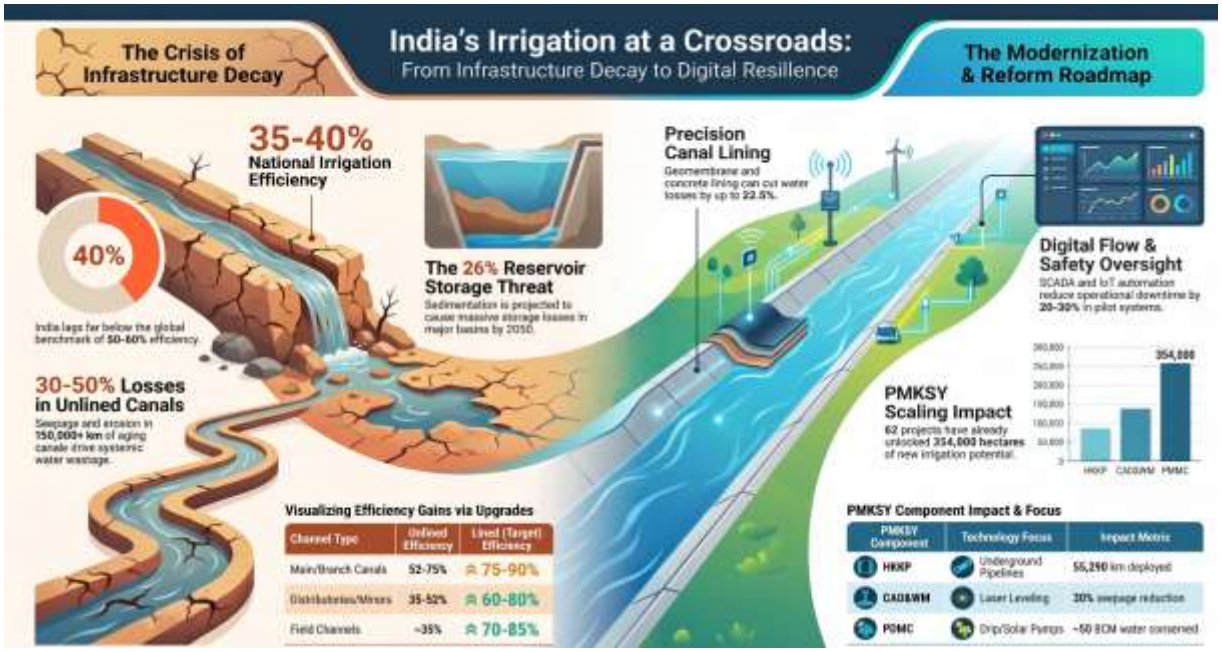
I-INTRODUCTION

Across the globe, aging industrial-era dams stand as crumbling reminders of a different age—once hailed as triumphs over nature and engines of growth, many have become environmental and safety liabilities. Superficial fixes like patching cracks or dredging silt no longer suffice; the problem is systemic, rooted in outdated policy, inadequate maintenance, and a lack of long-term ecological planning. Rather than continuing reactive, short-term measures, we need deep, holistic reforms that redefine how we manage rivers and their infrastructure. India exemplifies this paradox: agricultural potential that could feed billions is undermined by deteriorating irrigation systems—silted reservoirs, breached canals, leaky unlined channels, and conveyance/field efficiencies as low as 30–40 percent. Water is lost to evaporation and seepage, groundwater is depleted, monsoons grow more erratic, and flood–drought cycles intensify, all while sediment, formerly a nutrient, clogs the system. Northern states such as Punjab and Haryana face falling reservoir levels that increase crop risks and market volatility. Yet this crisis also opens pathways for transformation. Technologies like solar-powered drip irrigation, SCADA/IoT automation, and canal lining (which can raise efficiency to 75–90 percent) boost resilience. Community-led water-sharing, farmer cooperatives using data, and programs such as PMKSY—focusing on pipelines, micro-irrigation, and desilting—can recover vast water value. Complementary measures—wastewater reuse, precision water management, catchment afforestation, dredging, and equitable warabandi—can address sedimentation and restore functioning networks. With coordinated policy, local stewardship, and appropriate technology, India can turn vulnerability into strength and align agricultural productivity with sustainable river management.

The infographic outlies the critical need for systemic reform in India's deteriorating irrigation and dam infrastructure to ensure long-term water security. They highlight a significant gap between existing agricultural potential and the low efficiency of aging canal networks, which suffer from severe seepage and heavy sedimentation.



II-CURRENT STATUS OF IRRIGATION INFRASTRUCTURE IN INDIA

India's irrigation infrastructure remains a cornerstone of its agricultural economy, supporting nearly 50% of the net sown area despite covering only about 45-48% of arable land as of recent assessments. While gross irrigated area has expanded to around 70 million hectares through canals, tanks, wells, and tube wells, the system's overall efficiency hovers at a low 35-40%, far below global benchmarks of 50-60%. This gap underscores underutilization of created potential, with states like Punjab and Haryana showing high coverage but Punjab exemplifies over-irrigation leading to ecological distress. Critical appraisal reveals progress in coverage but persistent systemic inefficiencies.

Major challenges plague the infrastructure, including rapid groundwater depletion—India extracts over 250 cubic kilometres annually, the world's highest—driven by free electricity and subsidized power in northern states. Aging canals suffer from siltation, leakages, and poor maintenance, causing 30-50% conveyance losses, while inadequate drainage fosters waterlogging and salinization in Indo-Gangetic plains. Climate variability exacerbates unreliability, with erratic monsoons reducing surface water availability, and fragmented governance across 20+ ministries hampers coordinated reforms. These issues result in low water productivity, at $0.2-0.5 per cubic meter versus $1-2 in advanced systems.

Government initiatives show promise but face implementation hurdles. Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) and its sub-schemes like M-CADWM, approved with Rs 1,600 crore for 2025-26, promote micro-irrigation, SCADA, and IoT for better water use efficiency up to farm level. Accelerated Irrigation Benefit Programme (AIBP) has completed 62 priority projects by 2024, creating potential for millions of hectares. State-level efforts, such as Maharashtra's Rs 15,000 crore NABARD loan for 57 projects and canal repairs in February 2026, aim to irrigate 8 lakh hectares efficiently. Yet, fragmented policy execution and low farmer adoption limit impact.

Sustainability concerns demand urgent shifts toward precision technologies like drip and sprinkler systems, which cover only 12-15% of irrigated areas despite proven 40-60% water savings. Institutional reforms, including Irrigation Management Transfer to Water User Associations, are gaining traction but require capacity building. Integrated watershed management and conjunctive use of surface-subsurface water could boost resilience, alongside regulatory measures like groundwater metering in overexploited blocks. Without these, food security risks loom amid population pressures and climate change.

In appraisal, India's irrigation infrastructure scores moderately on expansion (7/10) but poorly on efficiency and equity (4/10), with groundwater dominance posing long-term threats. Modernization under PMKSY offers hope, but success hinges on enforcement, technology diffusion, and federal convergence by 2030 to align with sustainable development goals. Prioritizing maintenance over new builds could yield quicker gains, ensuring equitable access for rainfed regions housing 60% of farmers.

III-METHODLOGY

The methodology employs a comprehensive literature review as its foundational step to map existing knowledge on the subject. This involves systematically searching academic databases, journals, and grey literature using predefined keywords and inclusion criteria, followed by screening for relevance and quality assessment of sources. Data extraction then captures key themes, methodologies, and gaps, enabling a synthesis that identifies trends, contradictions, and opportunities for further inquiry. Complementing this, document analysis provides rigorous scrutiny of primary and secondary materials such as policy reports, project evaluations, and institutional records. Applying a structured approach like READ—readying materials, extracting data, analyzing content through thematic coding, and distilling findings—ensures nuanced insights into contextual factors and implementation dynamics. Together, these methods triangulate evidence for robust, evidence-based conclusion

IV-KEY INSIGHTS FROM LITERATURE REVIEW

Key insights from Gulati and Banerjee's ICRIER report (2023) highlight India's irrigation coverage at 45-48% of arable land, supporting half the net sown area through 70 million hectares of canals, tanks, and wells, yet efficiency lags at 35-40%—well below global 50-60% standards. The authors underscore underutilization in high-coverage states like Punjab and Haryana, where over-irrigation causes ecological distress, signalling progress in expansion but systemic inefficiencies. Planning Commission's mid-term appraisal (updated by NITI Aayog, 2024) reinforces this, noting fragmented infrastructure limits agricultural productivity despite expanded gross irrigated areas.

The Dam Safety Act, 2021, provides key insights into a comprehensive regulatory framework, featuring four-tier institutions like NCDS and NDSA to enforce surveillance, audits, and emergency plans for India's aging dams. It emphasizes hazard-based protocols targeting structural risks such as cracks and seepage, mandating periodic evaluations and cost projections to ensure accountability and proactive maintenance across water-critical infrastructure. Insights on India's 2023 analysis reveals implementation challenges, including state-level disparities in resource allocation and overreliance on manual inspections that overlook climate vulnerabilities. It highlights audits' role in compliance but critiques inconsistent enforcement, underscoring the need for digital monitoring and capacity-building to strengthen the Act's

Shah's IWMI study (2022) and CGWB's 2024 compilation reveal groundwater depletion as India's top challenge, with over 250 cubic km extracted yearly—the global highest—fuelled by subsidized power in northern states. Aging canals incur 30-50% losses from siltation and leakages, while poor drainage breeds waterlogging and salinization in Indo-Gangetic plains; erratic monsoons and 20+ ministries' fragmented governance further slash water productivity to $0.2-0.5 per cubic meter against $1-2 elsewhere.

Ministry of Jal Shakti's PMKSY report (2026) and NWDA's AIBP progress (2024) detail Rs 1,600 crore approvals for micro-irrigation, SCADA, and IoT, alongside 62 completed projects creating millions of hectares' potential; Maharashtra's NABARD-backed plan (2026) targets 8 lakh hectares via 57 projects. Yet, these face hurdles like policy fragmentation and low farmer uptake, as noted.

Narayanamoorthy and Bhattarai's TISS-IWMI analysis (2023), World Bank's IMT review (2022), and NITI Aayog's 2030 Vision (2025) advocate precision tech expansion from 12-15% coverage for 40-60% savings, Irrigation Management Transfer to Water User Associations, and conjunctive water use. They score infrastructure 7/10 on expansion but 4/10 on efficiency-equity, urging maintenance prioritization, enforcement, and SDG-aligned convergence by 2030 for rainfed farmers' equity

The review of government reports reveals PMKSY's transformative impact, with Press Information Bureau (PIB), Government of India (2025) documenting Cabinet approval for Rs 1,600 crore M-CADWM scheme, emphasizing SCADA/IoT for water accounting

to boost farm-level WUE up to 1 ha through pressurized pipes. Ministry of Jal Shakti's PMKSY Dashboard (2025) confirms AIBP's completion of 62 projects creating 354,000 ha potential, while HKKP deployed 55,290 km pipelines, highlighting measurable progress in surface minor irrigation across 21 states by 2023-24.

Central Water Commission's Reservoir Storage Bulletin (2025) exposes critical 64% storage (114.914 BCM of 180.852 BCM) across 155 major reservoirs, with northern Punjab-Haryana at dire 17%, underscoring sedimentation's seasonal rabi/kharif risks. Indian Infrastructure Magazine (May 7, 2025) analyses PMKSY's role in digital integration—IoT/GIS/SCADA—alongside Rs 16 billion 2025 command upgrades, noting 309,811 ha drip and 148,420 ha sprinkler coverage, driving irrigation intensity to 154.5%. The same publication (November 7, 2025) stresses technology convergence, with solar pumps (0.7M installed) conserving ~50 BCM, positioning Gujarat's 120,000 ha micro-irrigation as scalable model amid 38% national efficiency vs. global 55%.

India Water Portal's analysis (2023) warns of 26% dam storage loss by 2050, far exceeding global 13-19% averages, attributing trap efficiency in Ganges-Brahmaputra basins to deforestation, demanding catchment afforestation and 10-20 MCM/site dredging. IJIRSET researchers (2014) quantify canal lining benefits—0.376 Mm^3 savings per command (0.263 Mm^3 mains, 0.113 Mm^3 fields)—elevating 35-52% unlined efficiency to 75-90%, with 22.5% loss cuts, though Rs 1-2 crore/km costs hinder minors/fields.

Central Water Commission's Canal Lining Manual (2000) provides technical foundation for geomembranes/RCC, recommending pari-passu warabandi under CAD&WM to combat 200-500 mm/day seepage in sandy soils across 150,000+ km networks.

FAO experts (2009) advocate canal automation via SCADA, reducing 20-30% downtime in pilot systems, aligning with PMKSY's AIBP for equitable distribution while addressing fragmented landholdings through micro-systems. IAS Point analysts (January 31, 2025) link 86% rainfall-deficient districts to northern storage crises (17%) vs. Tamil Nadu's 84% stability, amplifying food grain volatility despite PMKSY lifting irrigated area from 49% to 55% (2016-2021). Science Magazine reporters (February 10, 2026) caution against aggressive desilting like Salal's 95% siltation crisis, while Mordor Intelligence (January 20, 2026) projects micro-irrigation market growth, validating PDMC subsidies for 20% WUE gains. Vikaspedia and MyScheme.gov.in (2025) outline PMKSY's "Har Khet Ko Pani" convergence with Jal Shakti Abhiyan, while IndiaStat (March 10, 2025) and AgEcon Search researchers confirm 347 MT food grains (2024-25), positioning KRAs for 2030 resilience amid urban Bengaluru

V-KEY RESULT AREAS

Infrastructure modernization and reservoir capacity management are foundational to revitalizing India's irrigation systems, while conveyance efficiency gains directly translate to water savings and agricultural resilience. These areas, drawn from prior analysis, highlight actionable priorities amid aging infrastructure and environmental pressures.

Infrastructure Modernization: India's extensive canal network—totalling over 150,000 km across main canals, branches, distributaries (discharge >2.5 cumecs), minors (<2.5 cumecs), and field channels—remains plagued by unlined sections that cause excessive seepage (up to 200-500 mm/day in sandy soils) and erosion, leading to structural degradation and water wastage. Prioritizing repairs involves structural reinforcement, seepage control through geomembranes or concrete lining, and upgrades like automated gates for equitable distribution. PMKSY exemplifies progress via its Accelerated Irrigation Benefits Programme (AIBP), completing 62 major projects by 2024, which unlocked 354,000 hectares of additional irrigation potential through renovated distribution networks and interlinking efforts. This not only expands cultivable area but also integrates digital tools like SCADA for remote control, reducing manual interventions and operational downtime by 20-30% in pilot systems.

Dam safety protocols & Audit: Dam safety protocols are standardized procedures designed to prevent structural failures and mitigate risks associated with dams, particularly large ones critical for water management and hydropower. These protocols typically include regular surveillance, inspections, and maintenance to monitor key components like spillways, foundations, and embankments for signs of distress such as cracks, seepage, or erosion. In India, the Dam Safety Act of 2021 establishes a robust framework with four-tier institutions—National Committee on Dam Safety (NCDS), National Dam Safety Authority (NDSA), State Committees, and State Dam Safety Organizations—to enforce uniform standards, emergency action plans, and operational guidelines across specified dams. Dam safety audits involve systematic, independent evaluations to assess compliance with protocols, identify deficiencies, and recommend remedial actions, often conducted at varying frequencies based on hazard classification (e.g., high-hazard dams require annual or intermediate checks).

Audits cover structural integrity, instrumentation data review, and risk assessments, with reports detailing repair costs and future liabilities to guide owners and regulators. In practice, these audits, performed by internal teams or third parties, ensure accountability and incorporate quality management systems to verify documentation and procedural effectiveness, as seen in guidelines from bodies like the Central Water Commission

Reservoir Capacity Management: Sedimentation, driven by deforestation, poor watershed management, and monsoon silt loads, has diminished live storage in India's 5,700+ large reservoirs by 13-19% on average globally, with India facing a stark 26% projected loss by 2050 due to trap efficiency in high-sediment rivers like the Ganges and Brahmaputra basins. As of early 2025, 155 major

reservoirs stored just 64% of capacity (114.914 BCM out of 180.852 BCM), reflecting 13 weeks of decline from deficient monsoons. Regional disparities are acute: northern basins like Punjab-Haryana at 17% (risking rabi wheat shortfalls), contrasted by southern stability; extreme cases include Salal reservoir (J&K) at 95% siltation, slashing irrigation and hydropower output. Targets focus on desilting via dredging (e.g., 10-20 MCM annually per major site), catchment treatment (afforestation, check dams), and periodic surveys using hydrographic methods to restore impounding for critical rabi (winter) and kharif (monsoon) seasons, potentially reclaiming 5-10 BCM/year nationwide. Through the implementation of the PMKSY government scheme, the text illustrates how integrating IoT sensors, micro-irrigation, and precision levelling boosts crop yields and resource efficiency. Ultimately, these efforts aim to bridge regional disparities in water access while building national resilience against the escalating pressures of climate change.

Conveyance Efficiency Gains: Unlined canals suffer 35-52% conveyance efficiency for main canals/minors due to seepage (40-65% losses) and evaporation, dropping further in field channels amid porous soils and overtopping. Lining with concrete, RCC, or plastics elevates this to 75-90%, as evidenced by studies showing 0.376 Mm^3 total savings in a typical command (0.263 Mm^3 from main/branch canals, 0.113 Mm^3 from fields) via reduced infiltration. Across systems, lining achieves 22.5% loss cuts, yet lags in minors/field channels due to high costs (Rs 1-2 crore/km) and fragmented landholdings. PMKSY's CAD&WM component enforces pari-passu lining with warabandi scheduling, while Per Drop More Crop subsidizes micro-systems to bypass inefficiencies.

Channel Type	Unlined Efficiency	Target Lined Efficiency	Key Savings Metric	Adoption Barrier
Main/Branch Canals	52-75%	Up to 75-90%	0.263 Mm^3 per network	Capital investment
Distributaries/Minors	35-52%	60-80%	22.5% loss reduction	Land acquisition
Field Channels	~35%	70-85% (with drips)	0.113 Mm^3 per network	Farmer-level scaling

***Agricultural Productivity Enhancement*:** Agricultural productivity enhancement and technology integration under PMKSY are critical for bridging irrigation gaps, while regional resilience efforts address uneven water access across India. These key result areas build on prior challenges like sedimentation and seepage, emphasizing measurable outcomes in farm output and adaptive capacity. Irrigation shortages from low reservoir levels (e.g., 64% national average in early 2025) and conveyance losses exacerbate crop failures in rabi (wheat, pulses) and kharif (rice, cotton) seasons, particularly in 86% of rainfall-deficient districts, heightening food insecurity and livestock stress. Northern and eastern regions suffer deficits (e.g., Punjab at 17% storage), contrasting southern stability like Tamil Nadu's 84%, which amplifies price volatility and regional disparities in yields. PMKSY targets 20% water use efficiency gains via micro-irrigation and lining, stabilizing output—evidenced by increased irrigated area from 49% to 55% of gross cropped area (2016-2021), boosting irrigation intensity to 154.5% and food grain production to 347 million tonnes by 2024-25.

***Technology and Scheme Implementation*:** IoT sensors enable real-time flow monitoring (reducing pilferage by 15-20%), GIS maps command areas for precise planning, and SCADA automates gate operations across canals and distributaries, integrating with PMKSY's dashboard for data-driven decisions. Core components deliver tangible upgrades: AIBP completes repairs on aging networks (62 projects, 354,000 ha potential); HKKP deploys 55,290 km pipelines, restoring minor irrigation without land hurdles; CAD&WM introduces laser levelling (cutting seepage 30%) and warabandi for equitable turns; PDMC subsidizes drips/sprinklers, 0.7 million solar pumps, and micro-systems, conserving ~50 BCM. Funding milestones—Rs 16 billion for 2025 command modernization, Rs 47 billion Micro-Irrigation Fund—drive successes like Gujarat's 120,000 ha under micro-irrigation, enhancing field channel efficiency.

PMKSY Component	Tech/Infra Focus	Productivity Impact Example
AIBP	Canal repairs	354k ha new potential
HKKP	Pipelines (55k km)	68k ha surface minor irrigation
CAD&WM	Laser levelling, warabandi	30% seepage reduction

PMKSY Component	Tech/Infra Focus	Productivity Impact Example
PDMC	Drips, solar pumps	~50 BCM conserved; 20% efficiency

Regional and Climate Resilience: North-south disparities (e.g., Punjab's 17% vs. Tamil Nadu's 84% storage) demand tailored watershed interventions like check dams and afforestation to trap silt upstream, alongside aquifer recharge via rooftop harvesting in rainfed areas (42% of net sown area). Real-time dashboards from SCADA/IoT forecast deficits, enabling adaptive releases amid climate shifts like erratic monsoons. Success metrics include scaled desilting (reclaiming 5-10 BCM/year), universal canal lining (target 75% efficiency), and private investment via funds, converging with schemes like Jal Shakti Abhiyan for holistic resilience against projected 26% storage loss by 2050.

VI-AN ANALYSIS OF THE RESULT AREAS

India's irrigation infrastructure demands urgent modernization to counter the vulnerabilities of its 150,000+ km canal network, where unlined sections drive seepage losses of 200-500 mm/day in sandy soils, eroding structural integrity and wasting precious water. This foundational Key Result Area (KRA) prioritizes repairs through geomembranes, concrete lining, and automated gates, as demonstrated by PMKSY's AIBP completing 62 projects by 2024 to unlock 354,000 hectares of potential. By integrating SCADA for 20-30% reduced downtime, modernization not only expands cultivable land but also sets the stage for equitable distribution, directly addressing aging systems that undermine national food security.

Dam safety protocols and audits form a critical bulwark against catastrophic failures, with their analysis revealing both strengths and persistent gaps in implementation. The tiered institutional structure under India's Dam Safety Act, 2021—spanning national to state levels—provides a comprehensive oversight mechanism that standardizes surveillance, inspections, and emergency planning, effectively reducing risks from structural distress like seepage or erosion. However, analysis highlights uneven adoption across states, where resource constraints and aging infrastructure (over 5,000 large dams) often delay remedial actions, underscoring the need for better funding and real-time instrumentation integration. Audits, as independent verifications of protocol adherence, excel in identifying high-hazard vulnerabilities through risk-based assessments and cost projections, fostering accountability via periodic reviews. Yet, their effectiveness is hampered by inconsistent frequencies, reliance on manual inspections, and limited third-party involvement, which can overlook subtle instrumentation anomalies or climate-induced stresses. Overall, while protocols and audits mitigate liabilities, a deeper analysis calls for digitized monitoring, capacity-building, and stricter enforcement to align with global best practices amid rising climate threats.

Reservoir capacity management emerges as a critical KRA amid sedimentation's toll—13-19% global average loss escalating to 26% in India by 2050—exacerbated by deforestation and silt-heavy rivers like the Ganges. Early 2025 data reveals 155 major reservoirs at 64% storage (114.914 BCM of 180.852 BCM), with Punjab-Haryana at a dire 17% risking rabi shortfalls and Salal at 95% siltation crippling output. Strategic desilting (10-20 MCM/site annually), catchment afforestation, and hydrographic surveys could reclaim 5-10 BCM yearly, ensuring reliable impounding for kharif and rabi cycles and mitigating monsoon deficits.

Conveyance efficiency gains represent a high-impact KRA, transforming unlined canals' dismal 35-52% delivery rates—plagued by 40-65% seepage—to 75-90% via lining, yielding 0.376 Mm^3 savings per command (e.g., 0.263 Mm^3 in main canals). While lining slashes losses by 22.5%, barriers like Rs 1-2 crore/km costs hinder minors and fields; PMKSY's CAD&WM enforces synchronized upgrades with warabandi, complemented by PDMC subsidies. This efficiency leap is pivotal for resilience, curbing evaporation and overtopping in fragmented holdings.

Agricultural productivity enhancement, as a core KRA, tackles shortages fuelling crop failures in 86% deficient rainfall districts, where northern deficits contrast Tamil Nadu's 84% stability, spiking prices and livestock woes. PMKSY's 20% efficiency target via micro-irrigation has lifted irrigated area to 55% of gross cropped land, pushing irrigation intensity to 154.5% and food grains to 347 million tonnes by 2024-25. By stabilizing rabi/kharif yields, this KRA bridges regional gaps, fostering output security amid volatility.

Technology and scheme implementation under PMKSY operationalizes KRAs through IoT (15-20% pilferage cuts), GIS mapping, and SCADA automation, linked to real-time dashboards. Components like HKKP's 55,290 km pipelines (68,000 ha minors restored), CAD&WM's 30% seepage reductions via laser levelling, and PDMC's 0.7 million solar pumps (~50 BCM conserved) are funded by Rs 16 billion (2025) and Rs 47 billion Micro-Irrigation benchmarks. Gujarat's 120,000 ha success underscores scalable integration, amplifying field-level impacts.

Regional and climate resilience, the capstone KRA, confronts north-south divides (Punjab 17% vs. Tamil Nadu 84%) with watershed check dams, afforestation, and aquifer recharge in 42% rainfed areas. SCADA/IoT dashboards enable predictive releases against erratic monsoons, aligning with Jal Shakti Abhiyan. Metrics like 5-10 BCM desilting, 75% lining coverage, and private funds convergence counter 26% storage threats by 2050, ensuring adaptive equity.

Collectively, these KRAs interlink: modernization feeds efficiency gains, sustaining reservoirs and productivity, while technology bridges disparities. PMKSY's holistic push—evident in 354,000 ha created and 50 BCM saved—offers a blueprint, yet scaling demands overcoming land/cost hurdles for transformative resilience.

Challenges persist, including uneven adoption and climate intensification, but prioritizing these KRAs could reclaim billions in water value, stabilize 55% irrigated cropland, and secure India's agricultural backbone against 2050 scarcities. Success hinges on sustained funding, state convergence, and data-driven execution.

VII-KEY DISCUSSION POINTS FROM THE ANALYSIS

India's irrigation infrastructure hinges on six interconnected Key Result Areas (KRAs) that address systemic inefficiencies, from aging canals to climate vulnerabilities, offering a roadmap for sustainable agricultural growth.

1. Infrastructure Modernization as Foundation. The 150,000+ km canal network—spanning main canals, distributaries (>2.5 cumecs), minors (<2.5 cumecs), and field channels—suffers unlined sections with seepage up to 500 mm/day, fuelling erosion and wastage. PMKSY's AIBP has completed 62 projects by 2024, unlocking 354,000 ha potential via repairs and SCADA integration, cutting downtime 20-30%; yet, scaling structural reinforcements and geomembranes remains urgent to prevent further degradation.
2. Dam safety protocols and audits warrant a nuanced discussion on their role in balancing risk mitigation with practical governance challenges. The tiered framework under India's Dam Safety Act, 2021, fosters coordinated oversight from national to state levels, enabling proactive surveillance of structural vulnerabilities like embankment erosion or spillway inefficiencies. This structure not only standardizes emergency action plans but also promotes stakeholder accountability, yet discussions reveal implementation hurdles, such as varying state capacities and the aging profile of India's 5,000+ large dams, which amplify climate-related stresses like intensified monsoons. Delving into audits, their independent, risk-based evaluations provide vital insights into protocol compliance and remediation needs, bridging gaps between routine inspections and long-term sustainability. Conversations around audits highlight their strength in projecting repair costs and liabilities, but also critique overreliance on periodic manual checks, advocating for advanced instrumentation and third-party expertise. Ultimately, discussions emphasize evolving these mechanisms through capacity-building and digital integration to enhance resilience against emerging threats, ensuring dams serve as reliable assets for water security and hydropower.
3. Reservoir Capacity's Sedimentation Crisis. With 5,700+ reservoirs losing 13-19% storage globally (India projected 26% by 2050), early 2025 levels at 64% (114.914 BCM/180.852 BCM) expose risks like Punjab's 17% lows and Salal's 95% siltation. Discussion centres on dredging (10-20 MCM/site/year), afforestation, and surveys to reclaim 5-10 BCM annually, stabilizing rabi/kharif supplies amid monsoon shortfalls.
4. Conveyance Efficiency's Quantifiable Gains. Unlined systems deliver just 35-52% efficiency due to 40-65% seepage; lining elevates to 75-90%, saving 0.376 Mm^3/command (0.263 Mm^3 mains, 0.113 Mm^3 fields) and cutting losses 22.5%. Barriers like Rs 1-2 crore/km costs slow minors/fields, but PMKSY's CAD&WM and warabandi enforce progress, highlighting micro-systems as bypass solutions.
5. Agricultural Productivity's Regional Stakes. Shortages in 86% deficient districts amplify north-eastern deficits (vs. Tamil Nadu's 84%), risking crop failures, price spikes, and livestock distress. PMKSY's 20% efficiency push has raised irrigated area to 55%, irrigation intensity to 154.5%, and food grains to 347 MT (2024-25), underscoring stabilized yields as a buffer against food insecurity.
6. Technology and PMKSY's Implementation Engine. IoT/GIS/SCADA reduce pilferage 15-20% via dashboards; HKKP's 55,290 km pipelines, CAD&WM's 30% seepage cuts via laser levelling, and PDMC's 0.7M solar pumps (~50 BCM saved) are funded by Rs 16B (2025) and Rs 47B funds. Gujarat's 120,000 ha exemplifies scalable tech-infra synergy for field efficiency.
7. Regional and Climate Resilience Imperative. North-south divides demand watershed check dams, recharge in 42% rainfed zones, and predictive analytics against erratic monsoons. Metrics like universal 75% lining, desilting scale, and Jal Shakti convergence counter 2050 threats, emphasizing private investment for equitable adaptation.
8. Interlinkages Driving Systemic Impact. Modernization sustains reservoirs, feeding efficiency and productivity; technology bridges disparities, creating a virtuous cycle where 50 BCM conserved translates to resilient cropland, vital as agriculture consumes 80% freshwater.
9. Persistent Challenges Temper Optimism. Uneven adoption, land hurdles, groundwater overexploitation (25% global draw), and policy fragmentation persist, with only 6-10% micro-irrigation coverage vs. 69 Mha potential; fragmented maintenance yields 38% efficiency vs. global 55%.

10. PMKSY's Blueprint for Scale. All KRAs converge under PMKSY, from AIBP repairs to PDMC subsidies, proving 354k ha gains and 20% targets achievable; yet, state-level bottlenecks demand decentralized governance and awareness to match successes like Gujarat.
11. Path Forward: Metrics for 2030. Prioritize 75% lining, 10 BCM desilting/year, 50% micro-coverage, and real-time equity to secure 55% irrigated land against scarcities; sustained Rs 47B+ funding and convergence will define irrigation's role in India's food sovereignty.

VIII-KEY INFERENCE FROM THE DISCUSION POINTS

India's irrigation challenges reveal a foundational inference: infrastructure modernization is non-negotiable for sustainability. The 150,000+ km canal network's unlined sections, leaking 200-500 mm/day, underscore how repairs via PMKSY's AIBP—completing 62 projects for 354,000 ha—directly expand cultivable land while SCADA cuts downtime 20-30%, proving targeted upgrades yield immediate scalability.

India's dam safety protocols and audits, as analysed and discussed, infer a robust yet imperfect system poised for enhancement to avert disasters. The tiered institutional framework under the Dam Safety Act, 2021, effectively standardizes surveillance and emergency planning, mitigating risks from structural failures in over 5,000 aging dams, but reveals critical gaps in uniform state-level implementation and resource allocation. From the discussion, key inferences point to the need for digitized real-time monitoring, increased third-party audits, and climate-adaptive strategies to bolster resilience. While protocols and audits foster accountability and risk foresight, their success hinges on bridging funding shortfalls and capacity disparities, ultimately ensuring dams sustain water security amid escalating environmental pressures.

A second key inference highlights sedimentation as an existential reservoir threat, with 26% projected loss by 2050 far outpacing global 13-19% averages in silt-laden basins. Early 2025's 64% storage (114.914 BCM) and extremes like Salal's 95% siltation infer that desilting (10-20 MCM/site/year) and catchment treatments must accelerate to reclaim 5-10 BCM annually, averting rabi/kharif crises.

Conveyance efficiency emerges as a high-ROI inference: lifting from 35-52% to 75-90% via lining saves 0.376 Mm^3/command, yet cost barriers (Rs 1-2 crore/km) in minors/fields signal PMKSY's CAD&WM and warabandi as essential enforcers. This quantifies how micro-systems bypass legacy gaps, prioritizing farmer-level adoption for systemic gains.

Agricultural productivity's inference is starkly regional: northern deficits (Punjab 17%) vs. southern stability (Tamil Nadu 84%) in 86% deficient districts amplify food risks, but PMKSY's 20% efficiency has boosted irrigated area to 55% and food grains to 347 MT. Stable yields thus hinge on equitable water to curb price volatility and livestock strain.

Technology integration infers PMKSY as an execution powerhouse, with IoT/GIS/SCADA slashing pilferage 15-20% and components like HKKP's 55,290 km pipelines enabling 68,000 ha minors without land issues. Rs 16B (2025) and Rs 47B funds, powering Gujarat's 120,000 ha, demonstrate dashboards' role in data-driven resilience.

Regional/climate resilience infers tailored interventions over uniformity: watershed check dams and recharge in 42% rainfed areas counter north-south divides, aligning with Jal Shakti for predictive releases. Universal 75% lining and private convergence emerge as metrics to defy erratic monsoons and 2050 scarcities.

Interlinkages yield a holistic inference: modernization sustains reservoirs, fuelling efficiency and productivity in a virtuous cycle where 50 BCM conserved secures 80% freshwater for agriculture. Isolated fixes fail; PMKSY's convergence model amplifies compounded impacts across KRAs.

Persistent challenges infer implementation gaps as the Achilles' heel—land acquisition, uneven states, and low micro-coverage (6-10%) despite 69 Mha potential. Only 38% overall efficiency vs. global 55% warns that without decentralized governance, gains like 354k ha risk stalling.

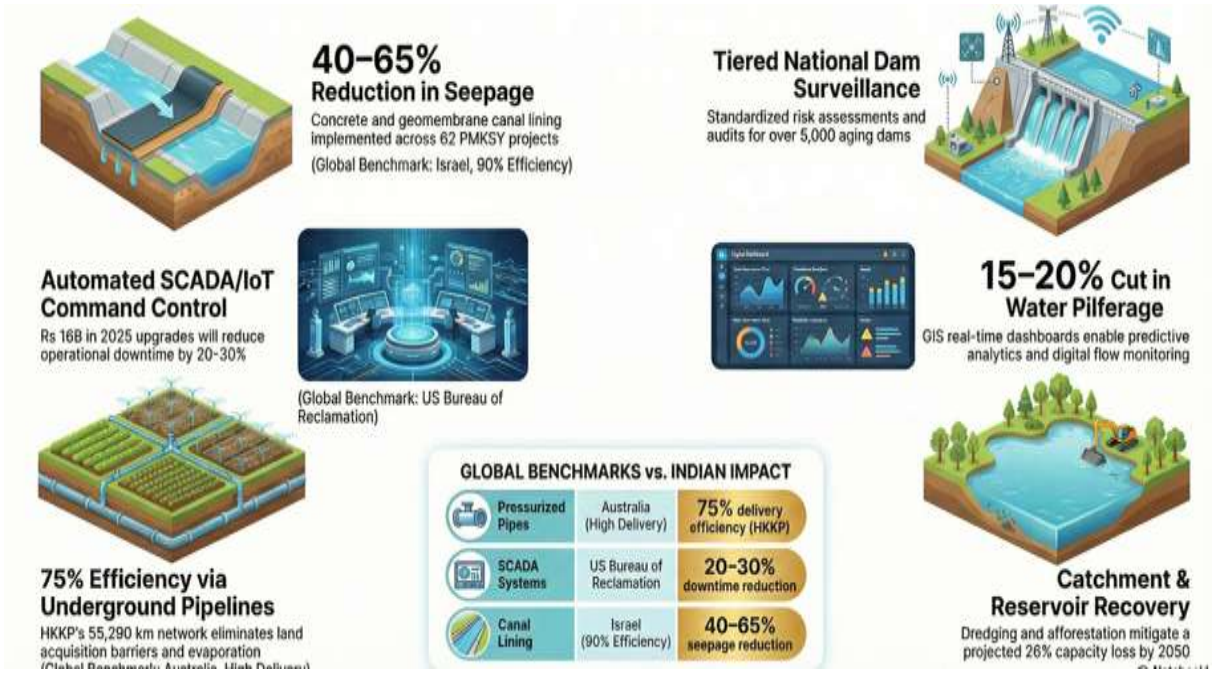
PMKSY's blueprint infers proven scalability: from AIBP repairs to PDMC's 0.7M solar pumps, it has conserved ~50 BCM and hit 20% targets in leaders like Gujarat. Inference: replicate via awareness and funding to bridge laggards, turning policy into nationwide transformation.

The forward path infers 2030 benchmarks—75% lining, 10 BCM desilting, 50% micro-coverage—as imperatives for 55% irrigated security. Sustained Rs 47B+ investments and metrics-driven execution will define irrigation's pivot to food sovereignty amid Bengaluru-like urban water pressures.

IX-BEST PRACTICES

Infographic outlines India’s strategic roadmap for modernizing irrigation infrastructure by integrating global engineering benchmarks with domestic legislative frameworks like the Dam Safety Act of 2021. To address the challenges of aging reservoirs and water scarcity, the documentation details various technological upgrades, including automated SCADA gates, underground

piping, and GIS-based monitoring to reduce wastage. These initiatives, supported by national programs like PMKSY, aim to significantly improve water use efficiency while mitigating risks through standardized safety audits and tiered surveillance. By adopting methods such as geomembrane canal lining and catchment afforestation, India seeks to reclaim reservoir capacity and protect agricultural stability against climate-driven threats. Ultimately, the sources emphasize a shift toward digitized real-time oversight and structural resilience to secure the nation's freshwater resources.



India's irrigation infrastructure enhancements, aligned with the Dam Safety Act, 2021, integrate best practices across canals, reservoirs, and technology to optimize water use efficiency while embedding dam safety protocols and audits. The table outlines global benchmarks, Indian implementations like PMKSY and HKKP, and specific dam safety measures—such as tiered surveillance and real-time monitoring—to mitigate risks from aging dams, reduce seepage, and ensure resilience against climate threats

Category	Best Practice	India Implementation	Global Example	Key Benefit	Dam Safety & Audit Best Practice
Dam Safety Protocol & Audits	Tiered surveillance & risk assessments	Dam Safety Act 2021: NCDS/NDSA/State SDSOs	US Army Corps of Engineers dam program	Mitigates failures; ensures accountability	Standardized protocols with periodic third-party audits
Canal Repairs	Concrete geomembrane lining	PMKSY AIBP: 62 projects, 354k ha	Israel drip-lined networks (90% efficiency)	Seepage cut 40-65%	Tiered audits under Dam Safety Act for lining integrity
Automated Control	SCADA/IoT gates	Rs 16B 2025 command upgrades	US Bureau Reclamation SCADA	20-30% downtime reduction	Real-time instrumentation per CWC guidelines
Minor/Field Upgrades	Underground pipelines	HKKP: 55,290 km	Australia pressurized systems	No land acquisition; 75% delivery	Hazard-based structural checks via NDSA

Category	Best Practice	India Implementation	Global Example	Key Benefit	Dam Safety & Audit Best Practice
Reservoir Desilting	Dredging & surveys	Salal/Punjab pilots (10-20 MCM/year)	Netherlands Rhine dredging	Reclaims 5-10 BCM/year	Annual capacity audits for high-hazard dams
Catchment Treatment	Afforestation/ check dams	Watershed under PMKSY	China Three Gorges basin	26% loss mitigation by 2050	Emergency action plans by State SDSOs
Tech Integration	GIS real-time dashboards	Rajasthan Sriganganagar digital flow	California CVP GIS monitoring	15-20% pilferage cut	Digitized risk monitoring via state organizations
Micro-Irrigation Backend	Pressurized farm-gate pipes	PDMC: Gujarat 120k ha	Spain pressurized drips	20% WUE gain	Protocol audits reviewing instrumentation data

X-KEY TAKEAWAY FROM THE BEST PRACTICES

1. India's irrigation modernization relies on proven practices like canal lining with geomembranes or concrete, as demonstrated by PMKSY's AIBP achieving 354,000 ha potential through 62 projects.
2. Robust Tiered Framework with Gaps: The Act creates a strong national-to-state institutional structure for standardized surveillance, risk assessments, emergency plans, and audits on over 5,000 aging dams, but faces uneven state adoption, resource shortages, and reliance on manual inspections.
3. Strengths in Accountability, Limits in Execution: Audits excel at identifying vulnerabilities, projecting costs, and ensuring protocol compliance, yet are hampered by inconsistent frequencies, limited third-party involvement, and vulnerability to climate stresses like intensified monsoons.
4. Path Forward for Resilience: Prioritize digitized real-time monitoring, capacity-building training, annual third-party audits with climate integration, and dedicated funding to bridge gaps and enhance water security.
5. Reservoir siltation control through hydrographic surveys and afforestation directly counters 26% projected capacity loss by 2050, prioritizing upstream catchment interventions.
6. Global benchmarks like Israel's 90%+ efficiency via buried PVC pipes highlight precision lining's superiority, mirrored in India's CAD&WM warabandi for equitable flow.
7. Automated SCADA/IoT gates, funded by Rs 16B in 2025 upgrades, reduce operational downtime 20-30%, akin to US Bureau of Reclamation systems for real-time command control.
8. Underground pipelines under HKKP (55,290 km) eliminate land acquisition barriers, delivering 75% efficiency like Australia's pressurized networks for minors and fields.
9. Dredging pilots in Salal/Punjab (10-20 MCM/year) draw from Netherlands' Rhine tech, enabling 5-10 BCM national reclamation to sustain rabi/kharif impounding.
10. Watershed afforestation and check dams under PMKSY mitigate silt from Ganges/Brahmaputra basins, paralleling China Three Gorges' basin-scale sediment trapping.
11. GIS dashboards in Rajasthan's Sriganganagar cut pilferage 15-20%, emulating California CVP monitoring for predictive analytics across distributaries.
12. PDMC's pressurized farm-gate pipes in Gujarat (120k ha) boost WUE 20%, adopting Spain's drip backend to bypass seepage in unlined field channels.
13. Overall, blending Indian schemes with global tech infers scalable resilience: 40-65% seepage cuts and universal adoption could secure agriculture's 80% freshwater share.

XI-CONCLUSION

1. India's irrigation infrastructure crisis demands comprehensive revitalization through prioritized Key Result Areas (KRAs), where modernization emerges as the bedrock for addressing seepage losses up to 500 mm/day in unlined canals spanning 150,000+ km.
2. Robust Framework with Implementation Gaps: India's Dam Safety Act, 2021, establishes a strong tiered institutional structure for protocols and audits that standardizes surveillance, risk assessments, and emergency planning across 5,000+ aging dams, yet uneven state adoption, resource constraints, and manual inspection reliance hinder timely remediation and climate resilience. Path Forward for Enhanced Resilience:
3. Key inferences highlight the urgent need for digitized real-time monitoring, increased third-party audits, capacity-building, and funding to bridge gaps, ensuring protocols and audits effectively mitigate structural risks and sustain water security amid rising environmental threats.
4. Reservoir sedimentation—projected at 26% capacity loss by 2050—necessitates urgent desilting and catchment treatments to reclaim 5-10 BCM annually, stabilizing 64% storage levels seen in early 2025 amid regional disparities like Punjab's 17% lows.
5. Conveyance efficiency gains from 35-52% to 75-90% via lining offer high-ROI water savings (0.376 Mm^3/command), though cost barriers in minors/fields underscore PMKSY's CAD&WM enforcement as critical for scaling.
6. Agricultural productivity hinges on bridging north-south gaps (Tamil Nadu 84% vs. northern deficits), with PMKSY's 20% efficiency target already lifting irrigated area to 55% and food grains to 347 MT by 2024-25.
7. Technology integration via IoT, GIS, and SCADA slashes pilferage 15-20%, powering PMKSY components like HKKP's 55,290 km pipelines and PDMC's 0.7M solar pumps to conserve ~50 BCM effectively.
8. Regional resilience requires tailored watershed interventions in 42% rainfed areas, aligning check dams and real-time dashboards with Jal Shakti Abhiyan to counter erratic monsoons and 2050 threats.
9. Interlinked KRAs form a virtuous cycle: modernization sustains reservoirs, boosts efficiency, and secures productivity, proving PMKSY's convergence model amplifies impacts across agriculture's 80% freshwater use.
10. Persistent challenges—land hurdles, uneven adoption, and 38% national efficiency vs. global 55%—reveal implementation gaps, demanding decentralized governance to prevent stalling 354k ha gains.
11. Best practices blending Indian lining (PMKSY AIBP's 62 projects) with global benchmarks like Israel's 90% PVC pipes and Netherlands dredging highlight scalable paths to 40-65% seepage cuts.
12. PMKSY's blueprint, from Gujarat's 120k ha PDMC success to Rs 47B funding, infers nationwide replicability through awareness, state convergence, and youth-engaging tech like M-CADWM's Rs 1,600 crore push.
13. Forward metrics for 2030—75% lining, 10 BCM desilting, 50% micro-coverage—position irrigation as food sovereignty's pivot, countering Bengaluru-like urban pressures on shared resources.
14. In conclusion, holistic KRA execution under PMKSY offers transformative potential, reclaiming water value to secure 55% irrigated cropland against scarcities.
15. Sustained Rs 47 Billion + investments and data-driven scaling will define success, turning vulnerabilities into resilient agricultural backbone by 2050.
16. Prioritizing equity across regions ensures stable rabi/kharif yields, curbing food insecurity and price volatility nationwide.
17. Global tech adoption accelerates India's path, mirroring Israel's efficiency to safeguard 80% freshwater for farms.

XII-RECOMMENDATION

Infographic outlines a comprehensive strategy to modernize India’s irrigation infrastructure and water management systems by 2030. The proposal emphasizes universal canal lining and aggressive reservoir desilting to combat significant seepage losses and storage depletion. By integrating advanced digital technologies like SCADA, IoT, and GIS, the plan seeks to improve distribution efficiency and transparency across the national grid. Financial recommendations include substantial central subsidies and dedicated funding streams to bridge regional productivity gaps and support aging dam infrastructure. Additionally, the text advocates for decentralized governance through Water User Societies and the promotion of micro-irrigation to ensure sustainable groundwater use. Ultimately, these interlinked initiatives aim to bolster national food security by reclaiming billions of cubic meters of water for agricultural resilience.

1. Accelerate Canal Lining Nationwide. To combat seepage losses of 200-500 mm/day in unlined sections of India's 150,000+ km canal network, prioritize universal lining using cost-effective geomembranes and concrete across main canals, distributaries (>2.5 cumecs), minors (<2.5 cumecs), and field channels. Drawing from PMKSY's AIBP success (62 projects unlocking 354,000 ha by 2024), allocate Rs 50,000 crore over 2026-2030 for phased rollout, integrating automated SCADA gates to cut downtime 20-30% and ensure equitable warabandi distribution, directly scaling cultivable land while curbing erosion.
2. Prioritize Digital Upgrades and Capacity Building: Implement real-time instrumentation and digitized monitoring systems across all high-hazard dams, coupled with targeted training programs for state-level Dam Safety Organizations to address resource gaps and ensure uniform protocol adherence under the Dam Safety Act, 2021.
3. Enhance Audits and Funding Mechanisms: Mandate annual third-party audits with climate risk integration for aging infrastructure, alongside dedicated federal funding streams to accelerate remediation, bridging implementation disparities and bolstering long-term resilience for India's 5,000+ dams.
4. Mandate Annual Reservoir Desilting Programs. Address the 26% projected storage loss by 2050 through mandatory dredging of 10-20 MCM per major site annually in 5,700+ reservoirs, starting with critical cases like Salal (95% silted) and Punjab-Haryana basins (17% levels). Combine with hydrographic surveys every two years and upstream catchment afforestation (target 1 million ha/year), reclaiming 5-10 BCM to stabilize 64% early-2025 levels, ensuring reliable rabi wheat and kharif rice impounding amid deficient monsoons.
5. Subsidize Lining for Minors and Fields. Overcome Rs 1-2 crore/km cost barriers in distributaries/minors (35-52% efficiency) and field channels (~35%) by offering 80% central subsidies under CAD&WM, aiming for 75-90% conveyance gains and 0.376 Mm^3 savings per command. Enforce pari-passu implementation with PDMC micro-systems, prioritizing fragmented holdings to achieve 22.5% loss reductions, bypassing legacy inefficiencies for farmer-level resilience.
6. Launch Regional Productivity Equity Fund. Bridge north-south disparities (Punjab 17% vs. Tamil Nadu 84% storage) in 86% rainfall-deficient districts by creating a Rs 20,000 crore fund for tailored rabi/kharif interventions, targeting 20% WUE gains to stabilize yields, curb crop failures, and reduce price volatility. Replicate PMKSY's irrigated area expansion (49% to 55%) nationwide, boosting food grain output beyond 347 MT while supporting livestock in water-stressed zones.
7. Expand Tech Integration Mandatorily. Roll out IoT/GIS/SCADA across all commands by 2028, reducing pilferage 15-20% via real-time PMKSY dashboards, as proven in Rajasthan's Sriganganagar. Fund HKKP extensions (beyond 55,290 km pipelines) and CAD&WM laser leveling (30% seepage cuts) with Rs 16,000 crore annually, linking to PDMC's 0.7M solar pumps for ~50 BCM conservation, empowering Gujarat-like 120,000 ha successes at scale.
8. Decentralize Governance to Water User Societies. Counter uneven adoption and land hurdles by transferring Irrigation Management (IMT) to empowered Water User Societies (WUS), providing 5-year handholding via FPOs/PACS linkages under M-CADWM (Rs 1,600 crore 2025-26). This addresses policy fragmentation, boosts micro-irrigation from 6-10% to 50% of 69 Mha potential, and lifts national efficiency from 38% toward global 55%.
9. Prioritize 42% Rainfed Area Recharge. Implement watershed check dams and rooftop aquifer recharge in rainfed zones, converging with Jal Shakti Abhiyan for predictive SCADA releases against erratic monsoons. Target north-south equity with private investment incentives (Rs 47B Micro Fund model), scaling desilting and 75% lining to counter 2050 threats, fostering adaptive cropland resilience.
10. Enforce 2030 KRA Metrics with Incentives. Set binding targets—75% universal lining, 10 BCM desilting/year, 50% micro-coverage—tied to state funding releases and performance bonuses, securing 55% irrigated land. Monitor via national dashboard, rewarding leaders like Gujarat to replicate 354k ha gains, defining irrigation's food sovereignty role.

11. Regulate Groundwater and Promote Crop Shifts. Curb 25% global overexploitation by mandating metered extraction and incentives for solar pumps linked to low-water crops (e.g., away from water-intensive rice/sugarcane in scarcity zones). Align with sustainable patterns via PMKSY district plans, reducing evaporation and overtopping for holistic WUE.
12. Blend Global Best Practices Locally. Adopt Israel's 90% PVC lining, Netherlands dredging, and California GIS via pilot clusters, customizing for Ganges/Brahmaputra silt (e.g., China Three Gorges afforestation). Fund tech transfers (Rs 10,000 crore) under PMKSY, achieving 40-65% seepage cuts and 20% WUE like Spain/Australia pressurized systems.
13. Boost Farmer Awareness and Youth Engagement. Launch nationwide campaigns via KVKs and digital apps for micro-irrigation adoption, attracting youth to farming through M-CADWM's farm-gate pipelines (up to 1 ha). Provide training for WUS on SCADA/IoT, ensuring 80% freshwater allocation to agriculture amid urban pressures like Bengaluru.
14. Sustain Rs 47,000 Crore+ Annual Funding. Secure multi-year budgets scaling Rs 47B Micro Fund and Rs 16B command upgrades, with 50% for tech-infra synergy. Tie to GDP-linked allocations (1% agri spend), enabling virtuous KRA cycles: modernization → reservoirs → efficiency → productivity.
15. Foster Public-Private Convergence. Incentivize PPPs for O&M of lined canals/pipelines, mirroring PDMC subsidies, to overcome capital barriers and ensure maintenance beyond fragmented systems. Target 20% private share in desilting/micro projects for scalable equity.
16. Monitor with AI-Driven National Dashboard. Integrate all KRAs into a unified PMKSY 2.0 platform for real-time equity metrics, predictive analytics, and adaptive releases, preventing 354k ha gains from stalling while curbing food insecurity nationwide.
17. Aim for Transformative Resilience by 2030. Holistic execution—interlinked KRAs under PMKSY—reclaims billions in water value, stabilizes rabi/kharif amid scarcities, and pivots irrigation to secure India's agricultural backbone, mirroring global leaders while addressing local challenges.

XIII-ACKNOLWDGMENT

A heartfelt acknowledgement is extended to all members of my professional network whose valuable insights, constructive feedback, and collaborative spirit greatly enriched this research. I am deeply thankful to my friends for their unwavering encouragement and intellectual companionship throughout this journey. Special gratitude goes to my family for their constant support, patience, and motivation that sustained me during challenging phases. Their collective contributions have been instrumental in bringing this work to fruition, and I sincerely appreciate their encouragement and belief in my efforts.

XIV-ETHICAL CONSIDERATION

This study utilizes publicly accessible secondary data, adhering to ethical standards by ensuring accurate citation and safeguarding confidentiality.

XV-LIST OF ACRONYMS

1. AIBP – Accelerated Irrigation Benefits Programme
2. BCM – Billion Cubic Meters
3. CAD&WM – Command Area Development & Water Management
4. cumecs – Cubic Meters per Second
5. DSAFR – Dam Safety Act Framework Resilience – Refers to the tiered institutional structure (NCDS, NDSA, State Committees, Organizations) standardizing surveillance, audits, and emergency plans for 5,000+ aging dams.
6. DRIFT – Digital Resilience Instrumentation Funding Training – Captures recommendations for digitized monitoring, real-time instrumentation, capacity-building, third-party audits, and funding to boost climate resilience and water security.
7. FPOs – Farmer Producer Organizations
8. GIS – Geographic Information System
9. ha – Hectare
10. HKKP – Har Khet Ko Pani (Water to Every Field)
11. IoT – Internet of Things
12. IMT – Irrigation Management Transfer
13. J&K – Jammu & Kashmir
14. Jal Shakti Abhiyan – Water Conservation Campaign
15. kharif – Monsoon crop season (June-September)
16. km – Kilometre
17. KVKs – Krishi Vigyan Kendras (Agricultural Science Centres)
18. M-CADWM – Modernization of Command Area Development & Water Management
19. MCM – Million Cubic Meters
20. Mm^3 – Million Cubic Meters
21. PACS – Primary Agricultural Credit Societies
22. PDMC – Per Drop More Crop

23. PIRAG – Protocols Inspections Risk Audits Gaps – Highlights strengths in risk assessments and accountability alongside implementation gaps like resource shortages, manual checks, and uneven state adoption.
24. PMKSY – Pradhan Mantri Krishi Sinchayee Yojana (Prime Minister's Agricultural Irrigation Scheme)
25. rabi – Winter crop season (October-March)
26. RCC – Reinforced Cement Concrete
27. SCADA – Supervisory Control and Data Acquisition
28. WUE – Water Use Efficiency
29. WUS – Water User Societies

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