E-WASH in Rural India: Closing the Coverage-to-Functionality Gap

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Abstract

Energy, water, sanitation, hygiene, and health constitute an interlocked developmental nexus—here termed E-WASH—whose combined performance dictates everyday living standards, personal dignity, and public health outcomes for nearly 900 million rural Indian citizens. This paper synthesises evidence across government ministries, national sample surveys, multilateral institutional reports, and scholarly literature to examine the present operational status of the E-WASH nexus in rural India, diagnose structural bottlenecks constraining last-mile effectiveness, and articulate actionable strategies for policy and field implementation. The empirical foundation draws on sequential rounds of the National Family Health Survey, the National Sample Survey Office 76th Round unit-level dataset, NITI Aayog's SDG India Index, and administrative records from the Ministry of Jal Shakti, Ministry of New and Renewable Energy, Ministry of Petroleum and Natural Gas, and the Department of Drinking Water and Sanitation. These datasets are critically evaluated alongside assessments from the World Bank, Asian Development Bank, World Health Organisation, and United Nations Development Programme. The core thesis posits that while flagship national initiatives—including the Jal Jeevan Mission, Swachh Bharat Mission (Grameen), Pradhan Mantri Ujjwala Yojana, Saubhagya, PM-KUSUM, and PM Surya Ghar—have generated unprecedented physical infrastructure coverage, a persistent "coverage-to-functionality gap" severs asset creation from reliable, safe, and health-improving service delivery. Resolving this structural failure requires an integrated convergence model spanning energy, water, and sanitation at the Gram Panchayat level, systematic deployment of decentralised renewable energy for water pumping and purification, robust community-led water-quality surveillance, sustained behaviour-change communication, and fiscal-governance reforms that equip local self-governments with the financial autonomy and technical capacity necessary to maintain long-term asset functionality.

Keywords: E-WASH Nexus, Rural Development, Coverage-to-Functionality Gap, Environmental Determinants of Health, Local Governance.

1.0 Introduction

Rural India encompasses roughly two-thirds of the nation's populace distributed across approximately 6.4 lakh villages and 2.5 lakh Gram Panchayats. Historically, public interventions targeting basic needs operated within compartmentalised administrative silos—energy, water, sanitation, hygiene, and healthcare each maintaining dedicated ministerial mandates, outlays, and monitoring dashboards. However, at the rural household level, these domains are experienced as a single, continuous, and integrated reality [1]. A woman navigating early-morning water collection, cooking over a biomass stove that emits hazardous particulates, and managing household care during episodes of waterborne illness lives the multi-dimensional impacts of the E-WASH nexus every day. The structural interdependencies within the E-WASH nexus operate through distinct operational channels. Reliable electrical power determines whether village water purification systems operate continuously, whether public sanitary complexes possess adequate lighting and water, and whether Primary Health Centres preserve vaccine cold chains. The adoption of clean thermal energy sources eliminates household air pollution and dangerous biomass smoke, protecting health at the domestic level [2, 3]. Adequate, pressurised water supply makes sanitation facilities functional and hygienic, preventing system failure [4]. Proper excreta containment and sludge management interrupt environmental contamination, suppressing pathogen transmission to water bodies and households [5]. Safe domestic water handling, storage, and handwashing with soap act as critical final barriers, preventing pathogen ingestion and facilitating effective menstrual hygiene management [6]. This framework intersects directly with the United Nations Sustainable Development Goals, primarily SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 3 (Good Health and Well-Being). It further influences SDG 5 (Gender Equality), given the time poverty and physical strain imposed on rural women by water fetching and solid-fuel gathering [7, 8], alongside SDG 11 (Sustainable Cities and Communities). NITI Aayog's SDG India Index (2023–24) tracks this alignment, showing a national composite score improvement from 57 at the 2018 baseline to 71 [9]. Crucially, the country's highest individual goal scores occur in SDG 7 at 96 and SDG 6 at 89 [10]. This empirical distribution highlights a fundamental dynamic: physical access and energy connectivity have expanded rapidly, yet translating these gains into equitable, long-term health and environmental outcomes requires bridging the structural gap between asset deployment and functional reliability [11]. E-WASH in rural India is defined as a composite developmental condition comprising: (a) household and community access to dependable, clean, and affordable energy for domestic lighting, thermal cooking, and productive agricultural use; (b) uninterrupted access to potable, safe, and adequate drinking water; (c) consistent access to and utilization of safe excreta disposal alongside environmentally sound faecal sludge management; (d) the sustained practice of essential hygiene behaviors, including handwashing with soap, safe domestic water handling, and dignified menstrual hygiene management; and (e) downstream health outcomes—evidenced by reduced communicable disease incidence, lowered under-five mortality, reduced stunting, and improved maternal well-being [12, 13].

1.1 Status of Energy, Water, Sanitation, and Hygiene in Rural India

The physical expansion of E-WASH infrastructure across rural India reflects substantial capital outlays across multiple national flagship initiatives, as detailed in **Table 1.**

Table 1: E-WASH Programmatic Infrastructure Status

Sector	Key Flagship Schemes	Coverage / Output Metric (Mid-2026 Status)
Energy	Saubhagya, Pradhan Mantri Ujjwala Yojana (PMUY), PM-KUSUM, PM Surya Ghar	100.0 per cent Household Grid Connectivity; 10.55 Cr LPG Connections; >150 GW Installed Solar Capacity.
Water	Jal Jeevan Mission (JJM), Atal Bhujal Yojana	15.80 Cr Household Tap Connections (81.6 per cent coverage); 2.7+ Lakh Har Ghar Jal Certified Villages.
Sanitation	Swachh Bharat Mission (Grameen) Phase I and Phase II	>100 Million Toilets Constructed (Phase I); 5.68 Lakh Certified ODF Plus Villages.
Hygiene	SBM-G Behaviour Change Communication (BCC), School MHM Initiatives	79.2 per cent Hygienic Menstrual Product Usage (Ages 15–24); Persistent Handwashing Infrastructure Gaps.

Source: Compiled from Ministry of Jal Shakti [8, 14], Ministry of Petroleum and Natural Gas [15], Ministry of New and Renewable Energy [16, 17], and IIPS NFHS-6 Data [13].

The Rural Energy Transition: Electrification, Solarisation, and Clean Cooking: The rural energy landscape in India has undergone a major physical expansion over the past decade [9]. The Pradhan Mantri Sahaj Bijli Har Ghar Yojana (Saubhagya), initiated in 2017, achieved universal household grid connectivity, extending power lines to millions of previously off-grid rural habitations [9]. To support agricultural energy demands and decouple irrigation from fossil fuels, the PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan) initiative targeted 34,800 MW of solar capacity across three components: decentralised grid-connected plants, standalone solar agricultural pumps, and the solarisation of existing grid-connected pumps [16, 18, 19]. Complementing this, PM Surya Ghar: Muft Bijli Yojana has accelerated rooftop solar installations, pushing India's cumulative installed solar capacity past 150 GW in early 2026 [17, 20, 21]. In the clean cooking domain, the Pradhan Mantri Ujjwala Yojana (PMUY), launched in 2016, distributed over 10.55 crore deposit-free Liquefied Petroleum Gas (LPG) connections to women from low-income households by mid-2026 [15, 22]. This expansion expanded the domestic LPG customer base nationally and generated documented reductions in indoor particulate matter ($PM_{2.5}$) concentrations [3]. However, empirical studies reveal a persistent "connection-without-consumption" challenge: approximately 47.0 per cent of surveyed rural LPG users report refill costs as a primary barrier, resulting in periodic reliance on traditional biomass fuels ("fuel stacking") during times of financial tightness [3].

Water Access Dynamics: The Jal Jeevan Mission and Groundwater Realities: Before the launch of the Jal Jeevan Mission (JJM) in August 2019, only 3.23 crore (17.0 per cent) of India's 19.4 crore rural households had access to tap water connections [23]. By March 2026, tap connectivity expanded to 15.80 crore households (81.6 per cent), representing an absolute growth from 17 percent to 81.6 percent coverage nationwide, with several States achieving 100 percent saturation [11, 24]. Under JJM 2.0, the scheme timeline has been extended to December 2028 to ensure full coverage across remaining geographies [25]. Parallel investments in water-quality testing infrastructure have established 2,870 certified laboratories and equipped over 24.8 lakh rural women to conduct Field Test Kit (FTK) sample analyses [8, 11]. Despite this coverage, national functionality surveys indicate that physical tap installations do not automatically ensure continuous, safe, and potable supply [4]. Roughly 85.0 per cent of rural drinking water schemes depend on groundwater sources [26]. Annual national groundwater extraction stands at approximately 245–250 billion cubic metres—predominantly driven by agricultural irrigation [27, 28]. In over a thousand assessment blocks categorised as "over-exploited" or "critical," declining water tables force local authorities to continuously drill deeper borewells [29, 30, 31, 32, 33]. This extraction dynamic increases the risk of tapping deeper aquifers affected by geogenic contaminants such as fluoride, arsenic, nitrates, and high salinity [26, 34].

Sanitation Trajectories: SBM-G Phase II, ODF Plus, and Waste Management: The Swachh Bharat Mission (Grameen), launched in October 2014, restructured India's rural sanitation paradigm [35, 36, 37]. Phase I delivered over 100 million individual household latrines, culminating in the national Open Defecation Free (ODF) declaration in October 2019 [38]. Phase II (2020–21 to 2026–27) transitioned the policy focus toward "ODF Plus" status—maintaining ODF behaviours while expanding solid and liquid waste management infrastructure [39]. By May 2026, over 5.68 lakh villages were certified ODF Plus, with the vast majority reaching ODF Plus Model status supported by dedicated Fifteenth Finance Commission grants [38, 40]. The institutional progression under SBM-G Phase II follows a sequential developmental tier:

Sustained Open Defecation Free (ODF) Base: Ensuring 100.0 per cent toilet usage and maintenance across all households in the village [36].

ODF Plus Aspiring Tier: Achieving sustained ODF behaviour alongside the installation of functional arrangements for *either* Solid Waste Management *or* Liquid Waste Management [39].

ODF Plus Rising Tier: Expanding infrastructure to establish functional arrangements for *both* Solid Waste Management *and* Liquid Waste Management simultaneously [38].

ODF Plus Model Tier: The highest status, where the village sustains ODF status, maintains functional solid and liquid waste management systems, ensures visual cleanliness with no stagnant waste or litter, and displays clear community IEC messaging [39, 40]. The critical technical challenge in the sanitation sector remains Faecal Sludge Management (FSM). While twin-pit and septic-tank latrines solved immediate containment needs, safe emptying, transport, and off-site treatment mechanisms lag behind toilet construction [5]. In regions characterised by high seasonal water tables, permeable sandy soils, or rocky strata, unmanaged faecal sludge can leach into shallow aquifers, recontaminating the drinking water sources that public investments seek to protect [5].

Hygiene Practices, Behaviour Change, and Menstrual Health: Hygiene forms the behavioural bridge that converts water and sanitation infrastructure into positive health outcomes. WHO/UNICEF Joint Monitoring Programme (JMP) estimates indicate that approximately 330 million individuals in India still lack household handwashing facilities equipped with soap and water [41]. Econometric analyses of NSSO 76th Round data confirm that handwashing with soap exhibits a steep socioeconomic gradient, lagging behind physical toilet construction [6, 42]. In contrast, menstrual hygiene management has shown steady progress. NFHS-6 (2023–24) data indicate that the use of hygienic menstrual protection methods among women aged 15–24 rose to 79.2 per cent [43, 44]. This progress has been supported by expanded access to affordable sanitary products, gender-segregated school sanitation facilities, and community outreach led by Accredited Social Health Activists (ASHAs), Anganwadi workers, and women's Self-Help Groups (SHGs) [36, 37].

1.2 Health Outcomes Linked to the E-WASH Nexus

Empirical Evidence from NFHS-6 and National Datasets: The release of NFHS-6 (2023–24) offers a comprehensive baseline to evaluate downstream health impacts linked to E-WASH investments, as shown in **Table 2.**

Table 2: NFHS-5 vs. NFHS-6 Key Health and Demographic Indicators

Health and Demographic Indicator	NFHS-5 Baseline (2019–21)	NFHS-6 Progress (2023–24)	Relative Change / Impact Direction
Under-Five Children Stunting (per cent)	35.5 per cent	29.3 per cent	17.0 per cent Relative Reduction (Environmental Enteropathy Suppression)
Under-Five Children Severe Wasting (per cent)	7.7per cent	5.2 per cent	Significant Decline in Acute Malnutrition
Institutional Deliveries (per cent)	88.6 per cent	90.6 per cent	Improved Running Water and Power at Health Facilities
Hygienic Menstrual Protection (Ages 15–24, per cent)	77.6 per cent	79.2 per cent	Steady Expansion in Product Access and School Sanitation

Household Health Insurance Coverage (per cent)	41.0 per cent	60.0 per cent	Substantial Reduction in Out-of-Pocket Expenditure Risk

Source: Compiled from Ministry of Health and Family Welfare Press Releases [13], IIPS NFHS-6 Report [12], Insights on India [45], Lukmaan IAS [46], and CDPP Analysis [43].

Epidemiological Pathways: Diarrhoeal Disease, Air Pollution, and Contamination: The public-health returns of E-WASH interventions operate through three distinct biological and epidemiological pathways: Pathogen Interruption via the F-Diagram: Acute diarrhoeal disease accounts for the overwhelming majority of waterborne infections in rural India [5]. Pathogens originate at the faecal source and migrate toward host ingestion via fingers, flies, fields, fluids, and food. Establishing a combined E-WASH barrier—comprising safe latrine containment, clean water delivery at the tap, and systematic handwashing with soap—breaks these transmission links before food contamination or oral ingestion [6]. World Health Organization modeling indicates that universal, safe tap-water access under JJM could avert nearly 400,000 diarrhoeal deaths and save 14 million Disability-Adjusted Life Years (DALYs) [8]. Prior WHO assessments of Swachh Bharat Mission estimated that roughly 300,000 diarrhoeal deaths were averted in 2019 compared to 2014 [36]. Respiratory Health and Indoor Particulates: Household air pollution caused by solid biomass combustion exposes women and young children to elevated indoor $PM_{2.5}$ concentrations [2]. Sustained access to LPG reduces acute respiratory infections in children, chronic obstructive pulmonary disease (COPD), and cardiovascular strain among women [3, 22]. Geogenic Toxicity and Chronic Disease: Excessive extraction of groundwater lowers piezometric heads, mobilising geogenic contaminants [26]. Continuous intake of arsenic and fluoride leads to fluorosis, skin lesions, peripheral vascular diseases, and chronic renal complications, imposing heavy long-term healthcare burdens on vulnerable households [28, 33].

Gendered Dimensions, Time Poverty, and Socioeconomic Impacts: E-WASH deficits carry a distinct gendered burden. The baseline situation is characterised by severe "time poverty," where rural women and school-aged girls dedicate hours every day to fetching drinking water from distant sources and collecting solid biomass fuel [7, 8]. This excessive physical burden leads to chronic fatigue, spinal and musculoskeletal damage, missed schooling opportunities for adolescent girls, and restricted economic participation [1]. The systematic provision of E-WASH infrastructure—primarily individual household tap connections under JJM and deposit-free LPG stoves under PMUY—interrupts this cycle [8, 15]. By providing reliable home water delivery and clean cooking fuel, the interventions reclaim an estimated 5.5 crore daily hours nationally [8]. Reallocating this saved time toward income-generating activities, micro-enterprise participation, enhanced maternal childcare, and education creates substantial multi-generational social and economic returns [7, 47].

1.3 Literature Review and Structural Analysis

Governmental, Dataset, and Survey Literature: The literature base for E-WASH in rural India spans multiple administrative and academic tiers**. (Table 3)** Official progress metrics are tracked via national administrative portals, including the eJalShakti portal [14], the SBM-G dashboard [36], and MNRE portals for PM-KUSUM and PM Surya Ghar [18]. Parliamentary Standing Committee reports reviewed by PRS Legislative Research provide periodic assessments, pointing to supply-chain delays, vendor empanelment bottlenecks, and regional variations in scheme execution [16]. In contrast, the National Sample Survey Office (NSSO) 76th Round (2018) report, *Drinking Water, Sanitation, Hygiene and Housing Condition in India*, provides a peer-reviewed micro-data baseline [42]. Econometric analyses using unit-level records from over 63,000 rural households demonstrate that adopting WASH practices as an integrated "bundle" (safe water + functional toilet + handwashing with soap) yields significantly higher health benefits than isolated single-practice interventions [6]. Complementing these datasets, the longitudinal National Family Health Survey series (NFHS-1 through NFHS-6) provides a multi-decade record of health outcomes [12]. Conducted under the administrative coordination of the International Institute for Population Sciences (IIPS), NFHS-6 demonstrates how rural infrastructure expansion correlates with declining infant mortality and improved nutritional indicators [13, 44].

Table 3: Categorised Literature Review Matrix

Category	Key Institutional Sources	Core Analytical Focus
Government Dashboards and Administrative Data	Ministry of Jal Shakti, MNRE, MoPNG, MoHFW (IIPS)	Physical infrastructure coverage, asset distribution, capital outlays, and target dates.
National Datasets and Sample Surveys	NSSO 76th Round, NFHS-1 through NFHS-6	Micro-data econometrics, household adoption rates, social gradients, health correlations.

Multilateral and Policy Institutions	World Bank, ADB, WHO, UNDP, NITI Aayog SDG Index	Institutional governance, water utility reform, economic cost-benefit ratios, global SDG alignment.
Academic and Periodical Literature	EPW, Down To Earth, Frontline, PLOS Water, Frontiers in Public Health	Coverage-to-functionality gap, political economy, groundwater stress, fuel stacking dynamics.

Source: Compiled from NSSO [42], IIPS [12], NITI Aayog [48], World Bank [1, 47], Asian Development Bank [49], Nguyen et al. [6], and Down To Earth [29, 31].

Multilateral, Academic, and Periodical Synthesis: Multilateral institutional assessments—including those from the World Bank, Asian Development Bank, WHO, and UNDP—place India's E-WASH evolution within a global comparative context [1, 2, 47, 49, 50]. World Bank analytical frameworks highlight that infrastructure expansion must be accompanied by sustainable operation-and-maintenance (OandM) financing, independent regulatory oversight, and performance-based incentive structures [47]. WHO/UNICEF Joint Monitoring Programme datasets highlight that while India's rural coverage expansion is historically rapid, absolute deficit numbers remain high due to overall population size [41]. Academic journals (*PLOS Water*, *Frontiers in Public Health*, *AQUA*) and analytical policy periodicals (*Economic and Political Weekly*, *Down To Earth*, *Policy Circle*) provide critical evaluation of these programs [5, 6, 11, 29, 30, 31, 34]. A recurring theme across independent field studies is the emergence of the "coverage-to-functionality gap." These analyses argue that political incentives prioritise upfront capital expenditure and asset delivery over long-term water source preservation, repair infrastructure, and sustained behaviour change [4, 11].

1.4 Issues, Problems, and Challenges in the E-WASH Nexus

The Coverage-to-Functionality Deficit: The primary operational challenge across the E-WASH nexus is the rift separating asset creation from sustained service functionality [11]. (**Table 4**) High tap coverage does not guarantee potability or regular water pressure [4]; latrine installation does not ensure safe sludge handling [5]; and LPG distribution does not guarantee continuous clean cooking if fuel refills remain unaffordable [3]. This problem stems from an institutional design that centralises capital expenditure (CapEx) through Centrally Sponsored Schemes while shifting operation and maintenance expenditure (OpEx) onto local bodies [11]. Gram Panchayats often lack the financial resources, technical personnel, and revenue-collection mandates needed to keep complex infrastructure functioning over time.

Table 4: The Coverage-to-Functionality Deficit Matrix

E-WASH Sector	Surface Coverage Metric	Underlying Deep Functionality Bottleneck
Energy	Near-Universal Grid Connectivity and High LPG Connection Rates	Refill Affordability Constraints ("Fuel Stacking") and Rural Voltage Fluctuations.
Water	High Tap Connection Density (81.6 per cent Households Nationally)	Aquifer Depletion, Intermittent Supply, Unaddressed Arsenic and Fluoride Contamination.
Sanitation	Universal ODF Status Declared Across Rural Districts	Unsafe Faecal Sludge Disposal and Pit Leaching into Shallow Water Tables.
Governance	Dispersed Centrally Funded Sectoral Missions	Unfunded Gram Panchayat OandM Mandates and Broken Local Maintenance Chains.

Source: Compiled from Sanskriti [4], ScienceDirect [3], IWA Publishing [5], Policy Circle [11], and PLOS Water [34].

Institutional Fragmentation and Governance Friction: Horizontal coordination remains weak across Union ministries, State line departments, and rural local bodies [11, 35]. Water supply (Jal Shakti), agricultural power (MNRE), clean cooking (Petroleum), and primary healthcare (MoHFW) function under separate budgets, administrative protocols, and reporting hierarchies. At the local level, Village Water and Sanitation Committees (VWSCs) often operate in isolation from Gram Panchayat Development Plan (GPDP) workflows. This institutional fragmentation prevents integrated resource planning, leading to missed opportunities for shared infrastructure—such as using solar mini-grids to simultaneously power water treatment units, health clinic cold chains, and street lighting.

1.5 Comprehensive Strategies and Solutions

Resource Depletion, Energy Incentives, and Climate Stress: The close connection between groundwater extraction and rural power supply creates an ongoing resource policy dilemma [26]: The formula states that the Groundwater Extraction Volume is directly proportional to the Pumping Capacity multiplied by the reciprocal (or inverse) of the Marginal Energy Cost. In plain terms, it means: As pumping capacity increases, the volume of groundwater extracted increases. As the marginal cost of energy decreases (for instance, when electricity or solar power for pumping becomes free or heavily subsidised), the volume of groundwater extracted increases. Agricultural irrigation accounts for nearly 89.0 per cent of total groundwater extraction in India [26, 51]. Subsidised or unmetered agricultural electricity, combined with the expansion of solar pumping under PM-KUSUM, reduces the marginal cost of water extraction toward zero [34]. Without concurrent demand-side regulation, free solar power risks accelerating aquifer depletion [26, 52]. This resource extraction spiral progresses through a direct chain of ecological and health consequences: **(Table 5)**

Unregulated Solar Pumping: The rapid expansion of unmetered agricultural solar pumps under PM-KUSUM lowers operational costs [16].
Zero Marginal Pumping Cost: Removing the energy-cost constraint encourages continuous, unmetered groundwater pumping for agriculture [34].
Accelerated Aquifer Depletion: Extraction significantly exceeds natural annual monsoon recharge rates, causing water tables to fall [27, 29].
Drying Out of Shallow Sources: Local drinking-water borewells and handpumps dry out, creating localised seasonal water deficits [34].
Deeper Borewell Drilling: Panchayats drill progressively deeper borewells (150–200+ feet) to reach remaining deep aquifers [28].

Geogenic Toxic Contamination: Tapping deeper, ancient hydro-geological strata mobilises naturally occurring arsenic, fluoride, and heavy metals, delivering contaminated water directly to domestic taps [26, 33]. Climate change acts as a threat multiplier across these systems [29]. Shifting monsoon patterns and intense dry spells reduce natural aquifer recharge, while extreme rainfall events can flood shallow wells and flush biological waste into drinking water sources [11, 33].

Table 5: Integrated E-WASH Operational Strategy Map

Strategic Pillar	Actionable Operational Mechanism
Functionality Focus	Shift funding allocation metrics from physical asset creation to tested water potability, regular pressure, and verified LPG refill frequency.
Energy-Water Convergence	Pair PM-KUSUM solar deployment with mandatory Atal Bhujal community groundwater budgeting and agricultural feeder metering.
Decentralised DRE Infrastructure	Earmark dedicated solar mini-grid funds to power village water filtration plants, health clinic cold chains, and street lighting.
Granular Surveillance	Implement public, real-time IoT water quality monitoring dashboards integrated with community Field Test Kits (FTKs).
Scaled FSM Services	Cluster Gram Panchayats into block-level mechanised faecal sludge collection, transport, and treatment hubs.
Clean Cooking Affordability	Deploy targeted refill vouchers via SHGs and expand Direct Benefit Transfer subsidies during lean economic seasons.
Unified Local Governance	Merge VWSC planning directly into the annual statutorily mandated Gram Panchayat Development Plan (GPDP) process.

Source: Synthesised from Policy Circle [11], PLOS Water [34], ScienceDirect [3], World Bank [47], and Sanskriti IAS [4].

Programmatic Shift toward Functionality Metrics: National funding and evaluation frameworks should transition from tracking output metrics (number of taps installed or toilets built) to verifying outcome and functionality metrics [11]:

Water Sector: Fund disbursement under JJM 2.0 should be tied to verified household supply regularity (minimum 55 LPCD), adequate pressure, and verified water potability [4].

Sanitation Sector: ODF Plus verification must evaluate operational solid and liquid waste processing volumes rather than the physical existence of processing structures [39].
Clean Energy Sector: PMUY monitoring should prioritise annualised refill frequencies per household over new connection numbers [3].

Energy-Water Convergence and Groundwater Governance: To prevent solar pump expansion under PM-KUSUM from depleting groundwater reserves, component deployment must be coupled with local groundwater management tools [26, 34, 52]: Mandatory feeder-level smart metering must be combined with community groundwater budgeting models developed under the Atal Bhujal Yojana [28]. In over-exploited blocks, solar pump subsidies should be made conditional on farmers adopting micro-irrigation systems (drip/sprinkler) and less water-intensive crop rotations [31]. Solar-diesel hybrid and battery-buffered systems should be deployed for rural piped water supply schemes, ensuring water pumping schedules match community consumption patterns regardless of grid stability [50].

Local Institutional Integration and Financed Operation and Maintenance: The Gram Panchayat should serve as the central administrative hub for unified E-WASH implementation [36]. Unified E-WASH Action Plans: Village-level water, sanitation, health, and energy targets should be integrated into the annual Gram Panchayat Development Plan (GPDP) process. Ring-Fenced OandM Funding: A fixed portion of Fifteenth Finance Commission rural grants must be earmarked for operations and maintenance [40]. This should be combined with low-barrier, digital micro-tariff collections (e.g., ₹30–₹100/month per household for piped water) managed by VWSCs to build sustainable local revenue [47]. Salaried Hygiene Cadres: Swachhagrahis should be developed into a salaried, professionally trained community cadre [36]. Integrated with ASHA workers, Anganwadi staff, and women's SHGs, they can drive continuous, long-term hygiene behaviour change [1, 6].

1.6 Economic, Technological, Policy, and Regional Dimensions

Economic Valuations, Fiscal Federalism, and Financial Architecture: Health economics literature demonstrates that investments in basic water, sanitation, and clean energy yield high benefit-cost ratios—typically ranging between 3:1 and 7:1 in lower-middle-income contexts [47, 53]. These returns are driven by saved out-of-pocket medical expenses, averted productivity losses from illness, and time reclaimed from water and fuel collection [8, 38]. From a macroeconomic standpoint, the construction phase of the Jal Jeevan Mission generated an estimated 59.9 lakh person-years of direct labour alongside over 2 crore person-years of indirect employment, demonstrating how infrastructure investments double as local economic stimuli [8]. Addressing the E-WASH deficit requires structural adjustments within India's fiscal federalism architecture [25, 40]. While capital outlays rely on Centrally Sponsored Scheme financing formulas (ranging from 50:50 to 90:10 State co-funding), long-term operational costs fall on State and local budgets. Inter-governmental fiscal transfers must explicitly incorporate performance-linked incentive grants, rewarding States and local bodies that maintain functional, high-quality service delivery [47].

Technological Innovations and Digital Governance Systems: Modern technology platforms offer tools to improve service transparency and system longevity. Real-Time Quality Dashboards: Merging Field Test Kit mobile entries with IoT-enabled sensor data on the JJM Water Quality Management Information System allows automated detection of contamination spikes across remote distribution lines [11, 14]. Remote Sensing and Aquifer Mapping: Combining satellite imagery (Landsat, Sentinel) with spatial analysis in Google Earth Engine allows hydrological models to map crop patterns against aquifer drawdown in real time, guiding groundwater recharge interventions under the Jal Shakti Abhiyan [34]. Low-Cost Sensor Networks: Deploying low-cost air and water quality sensors enables community-level monitoring of indoor $PM_{2.5}$ reductions and local water potability, building local trust through readable, transparent data [3]. Digital Architecture Pipeline: Streamlining data flows by connecting IoT pipe sensors and mobile FTK entries directly to the JJM WQMIS digital portal generates automated alerts on public dashboards [14]. In parallel, satellite remote sensing (GEE) feeds regional aquifer data directly to the Central Ground Water Board, creating a unified digital monitoring infrastructure [34, 51].

Regional Case Study: Sub-National Insights from Tamil Nadu: Tamil Nadu provides an instructive sub-national model for E-WASH execution. The State ranks high nationally in Swachh Survekshan Grameen assessments and ODF Plus village certifications, benefiting from a well-established history of Panchayati Raj institutional governance [38]. In the clean energy sector, high solar irradiance combined with net-metering policies has supported rooftop solar adoption under PM Surya Ghar [17, 21]. However, Tamil Nadu faces severe hydro-geological constraints [28]. Expansive hard-rock aquifer zones across western and southern districts suffer from acute groundwater depletion caused by agricultural pumping [34]. This pattern illustrates that even States with strong local administrative capacity require macro-level water pricing, agricultural electricity reform, and enforced crop diversification to secure long-term drinking-water security [31].

1.7 Concrete Policy Recommendations

Union Government Level: Reallocate Scheme Outlays Based on Functionality: Re-anchor fund releases under JJM 2.0, SBM-G Phase II, and PMUY to verified functionality indicators—such as tested potability, continuous water pressure, operational waste processing volumes, and annual household LPG refill counts [3, 11]. Institute Groundwater Conditionalities for Solar Subsidies: Mandate community groundwater budgeting (Atal Bhujal model) and feeder metering as prerequisites for PM-KUSUM solar pump disbursements in over-exploited and critical blocks [26, 34, 52]. Establish Dedicated DRE Public Infrastructure Financing: Create a targeted funding window within PM Surya Ghar to install solar mini-grids for powering village water purification plants, health clinic cold chains, and public sanitation complexes [21, 50]. Mandate Open-Access Water Quality Portals: Expand the national JJM Water Quality Management Information System into a fully open-access, habitation-level portal that publishes real-time contamination alerts [11, 14].

State Government Level: Create Inter-Departmental E-WASH Convergence Cells: Establish dedicated convergence units within State Rural Development departments to coordinate line-agency operations across water, energy, sanitation, and health sectors at district and block levels [35]. Establish Cluster-Based Faecal Sludge Management Hubs: Organise Gram Panchayats into regional blocks or clusters to operate shared, mechanised faecal sludge collection, transport, and treatment systems [5, 39]. Deploy Seasonally Targeted Clean Fuel Refill Subsidies: Design targeted LPG refill vouchers timed to seasonal agricultural cash-flow troughs to mitigate fuel stacking among low-income PMUY households [3].

District Administration and Gram Panchayat Level: Integrate E-WASH Plans into Annual GPDPs: Consolidate village water, sanitation, energy, and health facility mapping into a unified E-WASH plan embedded directly within the annual Gram Panchayat Development Plan [36]. Professionalise Local Maintenance and Hygiene Cadres: Formalise community Swachhagrahis and local pump operators into salaried positions, supporting their work with training on IoT monitoring and Field Test Kit operations [8, 36]. Build Community Financed OandM Reserves: Implement transparent, digital micro-tariff collection systems for piped water supply, managed directly by Village Water and Sanitation Committees to fund routine repairs and upkeep [47].

1.8 Conclusion

Rural India's decade-long experience across the E-WASH nexus represents one of the largest simultaneous rural infrastructure expansions undertaken in the developing world [47]. The coordinated execution of the Jal Jeevan Mission, Swachh Bharat Mission (Grameen), Pradhan Mantri Ujjwala Yojana, Saubhagya, PM-KUSUM, and PM Surya Ghar has built extensive physical connectivity across energy, water, and sanitation domains [8, 15, 16, 18, 38]. Longitudinal data from NFHS-6 confirm that these investments have contributed to measurable improvements in child nutrition, reduced stunting, lowered infant mortality, and improved maternal health outcomes [12, 13, 43]. However, empirical evidence demonstrates that physical asset deployment alone does not guarantee long-term health and environmental benefits [4, 11]. A persistent coverage-to-functionality gap remains the primary obstacle to sustainable progress. Overcoming this challenge requires moving beyond headline construction targets toward long-term service functionality, source sustainability, and local governance capacity [34, 47]. By linking clean energy expansion with groundwater management, establishing cluster-based faecal sludge treatment, providing targeted clean-fuel refill support, and equipping Gram Panchayats with dedicated operation-and-maintenance resources, policymakers can ensure that rural infrastructure reliably improves the health, dignity, and economic well-being of India's rural population [3, 5, 31].

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