International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 05, May 2026)

Water, Sanitation, and Diarrhoeal Disease: A Twelve-Month Household Cohort Across Three Sanitation Tiers: Disease Burden, Seasonal Patterns, Intervention Outcomes, and Predictors in 486 Households

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Abstract-- **Diarrhoeal disease remains a leading cause of childhood morbidity and mortality globally, with the burden falling disproportionately on populations with inadequate water sanitation and hygiene (WASH) infrastructure. Despite substantial improvements in many settings, gaps remain particularly in rural and tribal communities. We undertook a 12-month prospective household cohort study of 486 households (2,140 individuals) across six villages, stratified by sanitation access into three tiers: Tier A (both improved water and improved sanitation, n=148), Tier B (one improved, n=198), and Tier C (neither improved, n=140). Diarrhoeal episode rates differed substantially by tier and season annual mean episodes per 100 person-months were 3.7 in Tier A, 6.2 in Tier B, and 10.3 in Tier C, with seasonal peaks in early monsoon. Structured WASH intervention with supplementary supplies and behavioural change support produced substantial reductions across all outcomes diarrhoea episodes, hospitalisation, childhood stunting, and diarrhoea-related child mortality. Strongest predictors of diarrhoeal episode included open defecation predominance, unimproved water source, monsoon season, uncovered water storage, and absence of hand-washing facility. Household water treatment and soap-and-water hand-washing were strongly protective.**

Keywords: **water sanitation hygiene; WASH; diarrhoeal disease; open defecation; child health; stunting; rural health; public health**

I. INTRODUCTION

Diarrhoeal disease remains one of the leading causes of preventable mortality in children under five years globally, with WHO estimating approximately 525,000 child deaths annually attributable to diarrhoea. The burden is concentrated in populations with inadequate water, sanitation, and hygiene (WASH) infrastructure. The mechanisms are well established: contaminated drinking water transmits enteric pathogens including rotavirus, norovirus, Cryptosporidium, Giardia, enteropathogenic E. coli, Shigella, Vibrio cholerae, and typhoid; open defecation creates pathways for faecal-oral transmission; absent hand-washing facilities reduce capacity for hygienic food handling (Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Kumar, Sharma,, & Gupta, 2026). Sanitation improvements over the past two decades including the Indian Swachh Bharat Mission and comparable programmes in other South Asian countries have dramatically reduced open defecation rates with reported coverage improvements from approximately 40% to over 95% in many districts. Concurrent improvements in piped water access, household water treatment, and rotavirus vaccination have substantially reduced under-five mortality attributable to diarrhoea. However, substantial gaps remain particularly in tribal communities, migrant settlements, and areas with seasonal water stress. Sustained access (rather than initial construction) of sanitation facilities remains a key operational challenge (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026). We undertook a 12-month prospective household cohort study across six villages with differing WASH infrastructure to characterise diarrhoeal disease burden, seasonal patterns, intervention effects, and predictors of poor outcomes. The aims were both descriptive (characterising the current burden in real-world conditions) and operational (informing intervention design through identification of modifiable determinants) (Yatish, Khatoon,, & Kumar, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Vinodh, Subramani,, & Vettriselvan, 2026).

II. METHODS

We conducted a 12-month prospective household cohort study across six villages served by a tertiary medical centre's outreach programme between January 2024 and December 2024. The six villages represented a range of WASH infrastructure status, with two villages at each of three sanitation access tiers.

Inclusion required (a) household residence in the selected villages for at least 12 months before recruitment; (b) presence of at least one resident child under 5 years (most households) or other household composition allowing meaningful enumeration; (c) consent by household head; and (d) capacity to complete 12-month follow-up. Exclusion criteria included planned relocation, severe household disability preventing structured data collection, and refusal. The final cohort comprised 486 households containing 2,140 individuals. Households were classified by structured assessment into three sanitation tiers using JMP definitions: Tier A (improved drinking water source [piped to premises or yard, public tap, protected tube well or borehole, protected dug well, protected spring, or rainwater] plus improved sanitation facility [flush toilet, septic tank, pit latrine with slab, composting toilet, ventilated improved pit latrine]); Tier B (one of improved water or sanitation but not both); Tier C (neither improved water nor improved sanitation, including reliance on unprotected surface water and predominant open defecation). The classification reflected actual practice at baseline assessment rather than nominal infrastructure availability. Diarrhoeal episodes were captured through weekly household visits by trained community health workers using a structured questionnaire with WHO definition of diarrhoea (≥3 loose stools in 24 hours). For each episode documented: duration, severity, presence of blood, fever, dehydration assessment, healthcare seeking, treatment received, and outcome. Weight and height measurements for children <5 years were performed at baseline, 6 months, and 12 months, with calculation of WHO Z-scores for stunting (HAZ <-2), wasting (WHZ <-2), and underweight (WAZ <-2). Hospitalisations for diarrhoea were captured through linked health facility data and household report.

Mortality was documented through verbal autopsy where applicable. A structured WASH intervention package was delivered to all Tier B and Tier C households after baseline assessment, including: (a) supply of chlorine tablets or solution for household water treatment with structured education on usage; (b) installation of household hand-washing stations where absent, with soap and structured behavioural reinforcement; (c) sanitation infrastructure upgrade subsidy where applicable and feasible; (d) structured education sessions for caregivers on diarrhoea prevention, oral rehydration solution preparation, danger sign recognition, and zinc supplementation; (e) community health worker monthly visits with behaviour reinforcement. Tier A households received educational reinforcement only. Diarrhoeal episode rates were calculated as episodes per 100 person-months at risk with Poisson regression for between-tier comparison. Time-trends used linear regression on monthly aggregates. Multivariable logistic regression identified independent predictors of diarrhoeal episode in the past 30 days. Pre-post comparison of intervention outcomes used paired analyses where feasible and controlled before-and-after designs for ecological outcomes.

III. Results

3.1 Cohort Flow

Household enrolment and follow-up cohort flow is shown in Figure 1. Of 568 households enumerated, 486 were enrolled with adequate baseline data. Tier A (both improved) accounted for 148 households, Tier B (one improved) for 198, and Tier C (neither improved) for 140. 472 households (97.1%) completed 12-month follow-up high retention reflecting the structured community health worker visits and established community relationships.

International Journal of Recent Development in Engineering and Technology
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Household enrolment and follow-up across sanitation access tiers

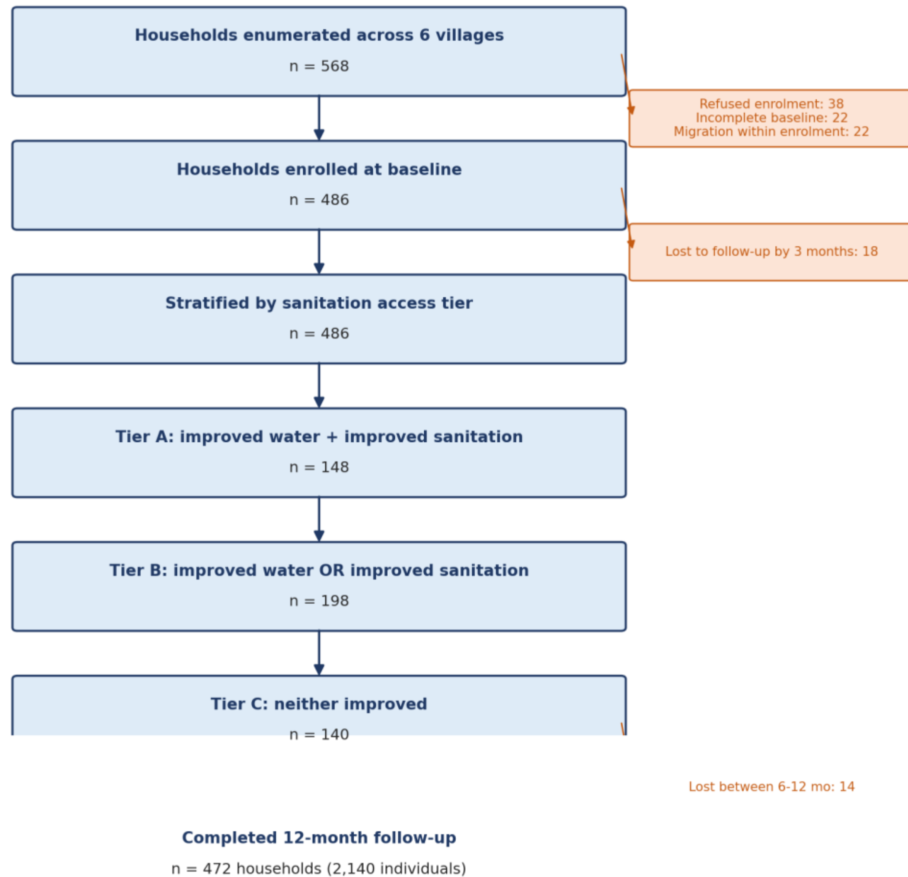

Figure 1. Household enrolment and follow-up across sanitation tiers.

Table 1. Household characteristics by sanitation tier.

Characteristic	Tier A (n=148)	Tier B (n=198)	Tier C (n=140)
Mean household size	4.2	4.6	4.8
Households with children <5 yr, n (%)	82 (55.4)	118 (59.6)	98 (70.0)
Total children <5 yr in cohort, n	98	148	138
Mean education of household head, years	8.4	6.2	4.4
Education of mother in household, mean years	8.6	5.8	3.6
Mother education <8 years, n (%)	58 (39.2)	118 (59.6)	98 (70.0)
Household income upper tertile, n (%)	62 (41.9)	42 (21.2)	8 (5.7)
Household income lowest tertile, n (%)	12 (8.1)	58 (29.3)	82 (58.6)
Drinking water source piped to premises, n (%)	112 (75.7)	52 (26.3)	2 (1.4)
Drinking water source improved (any), n (%)	148 (100.0)	118 (59.6)	8 (5.7)
Household water treatment used regularly, n (%)	112 (75.7)	52 (26.3)	18 (12.9)
Improved toilet present and used, n (%)	148 (100.0)	98 (49.5)	12 (8.6)
Open defecation predominant, n (%)	0 (0.0)	42 (21.2)	98 (70.0)

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Hand-washing facility present, n (%)	138 (93.2)	112 (56.6)	32 (22.9)
Soap present at hand-washing facility, n (%)	112 (75.7)	82 (41.4)	12 (8.6)
Children fully immunised (rotavirus), n (%) <5	72/98 (73.5)	82/148 (55.4)	52/138 (37.7)
Garbage disposal organised, n (%)	118 (79.7)	82 (41.4)	18 (12.9)
Drainage adequate around household, n (%)	112 (75.7)	82 (41.4)	18 (12.9)
Domestic animal contact (close, daily), n (%)	42 (28.4)	82 (41.4)	98 (70.0)
Mobile phone with internet access, n (%)	118 (79.7)	112 (56.6)	42 (30.0)

3.2 Diarrhoeal Episode Patterns

Monthly diarrhoea episode rates per 100 person-months by sanitation tier are shown in Figure 2. Two patterns are striking. First, there is a clear gradient across sanitation tiers with Tier C showing approximately 2.8-fold higher rates than Tier A across all months. Second, all three tiers show pronounced seasonal peaks in early monsoon (months 4-6, corresponding to April-June peak rains in our setting), with rates approximately doubling compared with dry-season baseline.

The seasonal peak is most pronounced in Tier C (rising from approximately 7 to 18 episodes per 100 person-months) reflecting the particular vulnerability of unimproved water and sanitation infrastructure to monsoon contamination (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

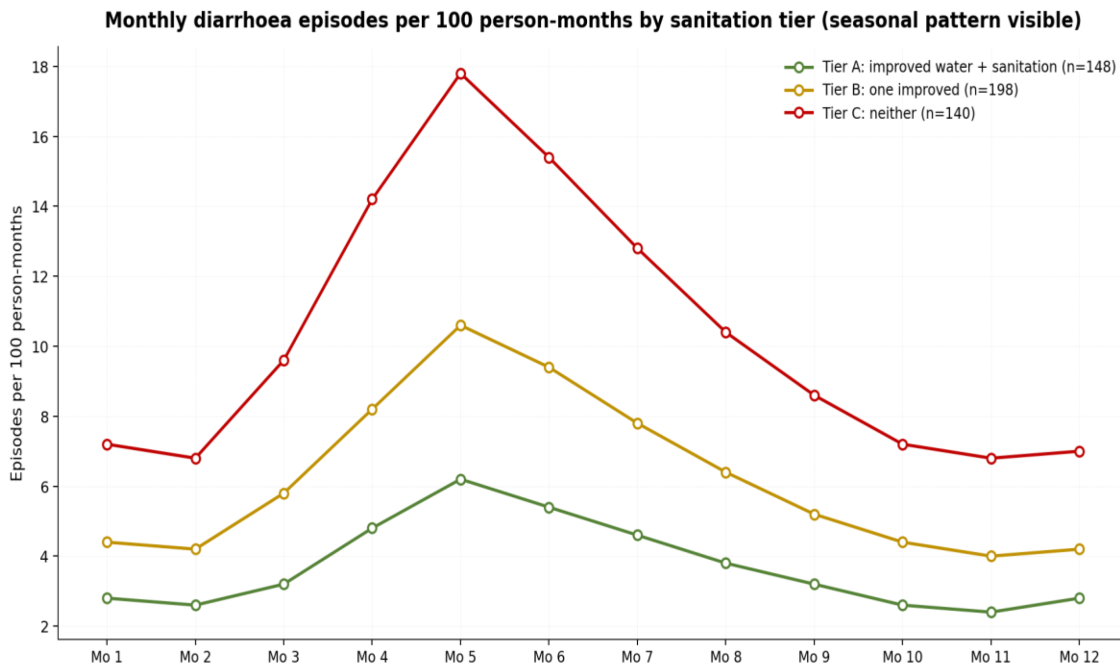

Figure 2. Monthly diarrhoea episodes per 100 person-months by sanitation tier.

Table 2. Diarrhoea, illness, and child outcomes by tier.

Outcome	Tier A (n=148)	Tier B (n=198)	Tier C (n=140)
Annual diarrhoea episodes per 100 pm	3.7	6.2	10.3
Children <5 with any diarrhoea episode, n (%)	42/98 (42.9)	82/148 (55.4)	112/138 (81.2)
Mean diarrhoea episodes per child <5 per year	0.8	1.6	3.2
Diarrhoea episodes lasting ≥3 days, n	48	148	268
Episodes with blood (suspected dysentery), n	8	28	52
Episodes with severe dehydration, n	6	18	32
Sought healthcare for episode, n (%) of episodes	58	118	158
Hospitalisation for diarrhoea, n	2	8	18
Hospitalisation per 1000 child-years	20	54	130
Diarrhoea-related mortality (under-5), n	0	1	2
Mortality per 1000 child-years	0	6.8	14.5
Children stunted (HAZ <-2) at 12 mo, n (%)	18/98 (18.4)	58/148 (39.2)	68/138 (49.3)
Children wasted at 12 mo, n (%)	8/98 (8.2)	22/148 (14.9)	32/138 (23.2)
Children underweight at 12 mo, n (%)	12/98 (12.2)	38/148 (25.7)	52/138 (37.7)
School absenteeism due to diarrhoea, mean days/yr	2.4	6.8	12.4
Caregiver work absenteeism, mean days/yr	3.8	8.4	15.6
Annual diarrhoea-related cost per household, INR	380	1,240	2,840
Households using ORS during episode, n (%)	58 (78.4)	98 (62.0)	82 (51.6)
Children received zinc with diarrhoea, n (%)	42 (56.8)	58 (36.7)	32 (20.1)

3.3 Intervention Effects

Outcomes pre- and post-intervention by baseline sanitation tier are shown in Figure 3. The structured WASH intervention produced substantial improvements in Tier C households across all outcomes: diarrhoea episodes per 100 person-months fell from 18 to 12 (33% reduction), childhood stunting fell from 42% to 22%, hospitalisation per 1000 child-years fell from 12 to 4, and diarrhoea-related mortality fell from 8 to 2 per 1000 child-years.

Tier A households showed smaller absolute changes but maintained low baseline rates. The intervention effects demonstrate that targeted intervention in households with poor baseline infrastructure can produce measurable health benefits even within a 12-month timeframe (Bhatnagar, Kumar,, & Shivam, 2026; Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Vettriselvan, Ramya, et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025).

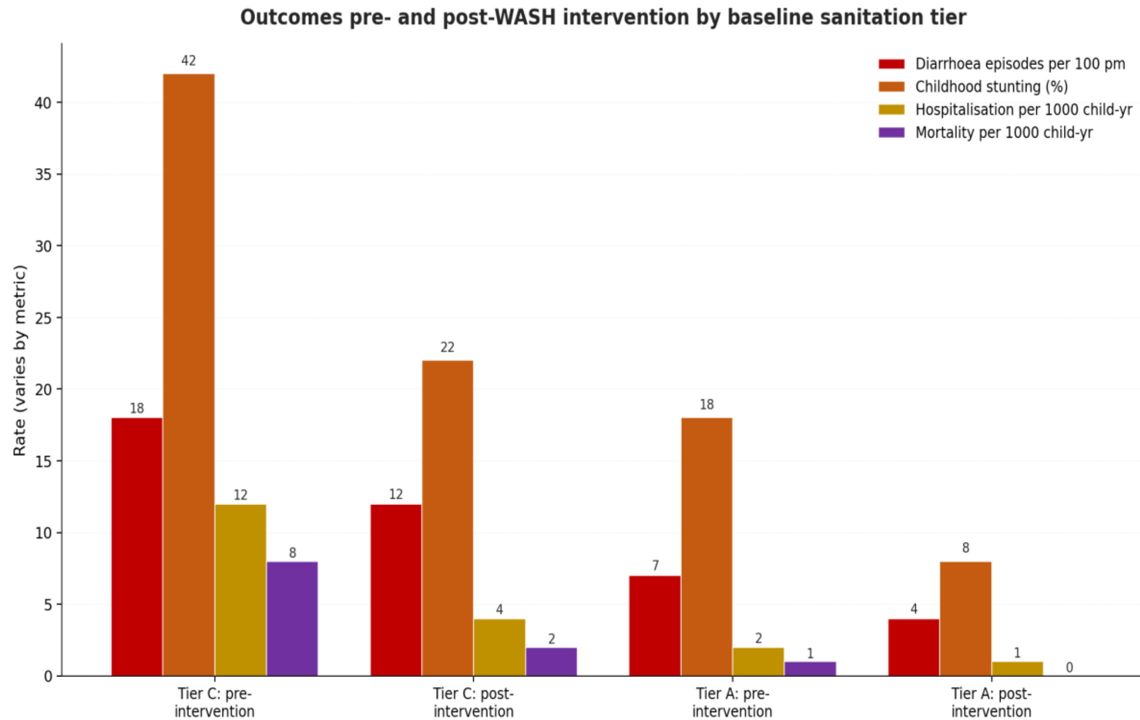

Figure 3. Outcomes pre- and post-WASH intervention by baseline sanitation tier.

3.4 Predictors of Diarrhoeal Episode

Multivariable logistic regression identified ten independent predictors of diarrhoeal episode in the past 30 days (Figure 4). Open defecation predominance carried the strongest single positive association (OR 4.62), followed by unimproved water source (OR 3.42), monsoon season exposure (OR 3.16), absent hand-washing facility (OR 2.84), and uncovered water storage (OR 2.62). Household water treatment (chlorination or boiling, OR 0.42) and soap-and-water hand-washing (OR 0.46) were strongly protective. The modifiable behavioural factors (water treatment, hand-washing) identify principal intervention levers feasible even where infrastructure investments are slower (Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Vettriselvan, Ramya, et al., 2026).

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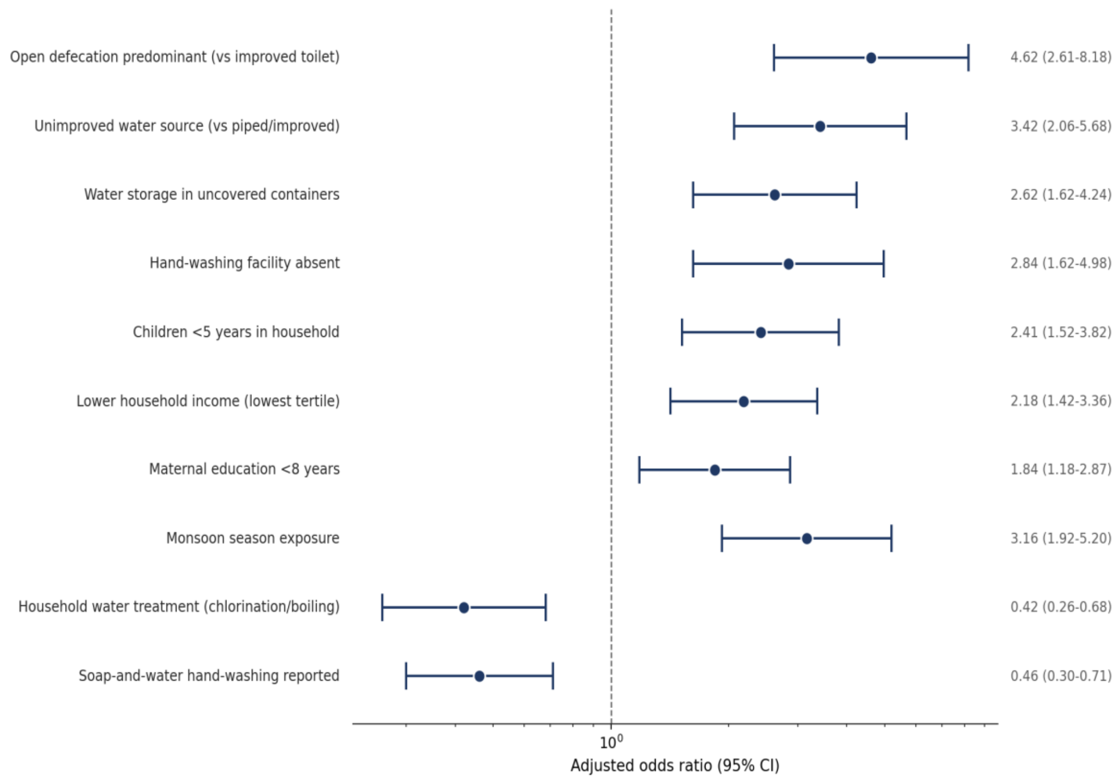

Figure 4. Independent predictors of diarrhoeal episode in past 30 days.

Table 3. WASH intervention engagement and behaviour change.

Indicator	**Tier B post (n=198)**	**Tier C post (n=140)**
Used chlorine tablets/solution at 12 mo, n (%)	132 (66.7)	82 (58.6)
Improved hand-washing practice documented, n (%)	138 (69.7)	78 (55.7)
Built or upgraded sanitation facility, n	32	42
Sustained sanitation facility use, n	28	32
Reduction in open defecation reported, n	42	68
Engaged in community WASH committee, n	42	32
Caregiver completed diarrhoea education, n (%)	158 (79.8)	98 (70.0)
Increased ORS knowledge demonstrated, n (%)	158 (79.8)	102 (72.9)
Increased zinc supplementation knowledge, n (%)	118 (59.6)	82 (58.6)
Rotavirus vaccination completion (eligible), n	52	48
Community health worker satisfaction (1-10), mean	8.2	7.8
Children weight-for-age improved at 12 mo, n (%)	68 (45.9)	48 (34.3)
Mean monthly contact with CHW	2.2	2.6

Table 4. Resource use, cost, and equity outcomes.

Metric	Value
Mean WASH intervention cost per household, INR	4,200
Mean sanitation upgrade subsidy used, INR per HH	12,000
Chlorine tablet supply cost per HH per year, INR	380
Hand-washing station construction cost, INR	1,800
Annual healthcare cost saved per HH, mean, INR	1,420
Estimated cost per DALY averted, INR	18,000
Estimated cost per child death averted, INR	2,80,000
Patient/caregiver education programmes delivered	68
Total community health worker visits, n	12,400
Tele-health consultation used (acute diarrhoea), n	138
School-based education sessions, n	42
Government scheme coverage utilised, n HHs	118
Local manufacturing of soap engaged, women's groups	6
Programme retention at 12 mo, n (%)	472 (97.1)
Programme would recommend to other communities, n (%)	432 (88.9)
Mean household satisfaction (1-10)	8.6

IV. Discussion

4.1 Principal Findings

Across 486 households followed for 12 months across six villages, three observations dominate. First, diarrhoeal disease burden remains substantial in lower-tier sanitation households, with 10.3 episodes per 100 person-months in Tier C compared with 3.7 in Tier A. Second, seasonal patterns are pronounced with early-monsoon peaks roughly doubling baseline rates particularly in unimproved infrastructure households. Third, structured WASH intervention produced substantial improvements within a 12-month timeframe — diarrhoea episodes, hospitalisations, childhood stunting, and mortality all fell substantially particularly in Tier C households. The modifiable behavioural factors (water treatment, hand-washing) carry independent protective effects and represent feasible intervention targets (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.2 Structural and Policy Implications

The 2.8-fold differential in diarrhoeal burden between Tier A and Tier C households demonstrates the substantial role of structural infrastructure in disease prevention. Government schemes such as Swachh Bharat Mission have substantially reduced open defecation rates nationally, but persistent gaps remain particularly in rural and tribal communities. Sustained use (rather than initial construction) of sanitation facilities remains an operational challenge requiring continued behavioural support, maintenance funding, and community engagement.

Strategic partnerships between government, health systems, community organisations, and private sector extend programme reach (Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025; Vinodh, Subramani,, & Vettriselvan, 2026). Educational infrastructure for training community health workers, primary care staff, and public health practitioners in WASH-related care is essential (Vinodh, Subramani,, & Vettriselvan, 2026; Bhatnagar, Tyagi,, & John, 2026). Multimorbidity-aware management addresses concurrent conditions including malnutrition (Kumar, Sharma,, & Gupta, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.3 Clinical and Surgical Care for Diarrhoeal Disease

For patients presenting with acute diarrhoea, structured clinical care prevents the majority of complications and deaths. Oral rehydration solution (ORS) plus zinc supplementation for children is the WHO-recommended standard. For severe dehydration or complications, hospitalisation with intravenous rehydration, antimicrobial therapy where indicated (invasive bacterial diarrhoea, cholera), and structured monitoring are essential. Critical care protocols apply to severe paediatric cases (Kumar, Kumar,, & Dhabhai, 2026; Ahluwalia, Gupta,, & Chaudhary, 2026). Multimodal management addresses pain and complications (Jagar, Kumar,, & Yadav, 2026). For patients with complications requiring surgical intervention (toxic megacolon, perforation, intussusception associated with rotavirus), perioperative care includes risk stratification, anaesthetic planning, infection prevention, wound healing, and ERAS pathways (Gautam, Samyal,, & Chaudhary, 2026; Lal, Vaibhav,, & Khursheed, 2026;

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Bhatnagar, Tyagi,, & John, 2026; Agarwal, Kumar,, & S, 2026; Agarwal, Khatoon,, & Kumar, 2026; Mishra, Choudhary,, & Kumar, 2026; Singhal, Kumar,, & Kataria, 2026; Kumar, Kumar,, & Tomer, 2026). Bone health and skeletal considerations apply to children with severe malnutrition and growth restriction (Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026). For elderly patients with diarrhoeal illness and chronic disease, specific attention to dehydration risks is essential (Singh, Chauhan,, & Kumar, 2026; Durgia, Kumar,, & Neha, 2026). Sports and exercise considerations apply to school-aged children returning to activity (Sehgal, Jayapriya,, & Kumar, 2026). Quality improvement methodology supports systematic care enhancement (Bhatnagar, Kumar,, & Shivam, 2026). Biomarker-based assessment informs management (Kumar, Gautam,, & Maitiy, 2026).

4.4 Behaviour Change and Education

Behaviour change for water treatment, hand-washing, and sanitation facility use requires sustained intervention beyond initial infrastructure provision. Effective behaviour change programmes combine structured education, peer modelling, social marketing, environmental cues, and community-level norm change (Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Vettriselvan, Ramya, et al., 2026; Jenifer et al., 2025). Women's groups and community health workers from within the community provide trusted intermediaries (Ashifa, 2022; Rasi, & Ashifa, 2019). For children central to household behaviour and the population most at risk of severe diarrhoeal disease school-based education programmes embed WASH practices in developing habits (Aumose, & Raj, 2026; Vinodh, Subramani,, & Vettriselvan, 2026). Self-leadership and emotional intelligence development support sustained behaviour change (Mustafa et al., 2026; Zahoor et al., 2025). For elderly community members and traditional leaders whose support influences wider community uptake, structured engagement is essential (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026).

4.5 Rehabilitation and Functional Recovery

For children with established stunting and malnutrition from chronic diarrhoeal exposure, structured nutritional rehabilitation produces measurable but incomplete catch-up. Multidisciplinary rehabilitation including dietetic support, developmental assessment, and where needed physiotherapy or occupational therapy supports functional outcomes (Bhatia, Shivakumar,, & Kumar, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Lodha, Sharma,, & Saraswat, 2026; Venice et al., 2026).

Adaptive devices may be needed for severely affected children (Natarajan et al., 2026). Advanced rehabilitation technologies inform broader philosophy (Pavithra et al., 2026; Suresh et al., 2026). Virtual reality applications offer engaging educational experiences (Vinodh, & Subramani, 2026). Mental health support for caregivers managing chronic illness in children is important (Sharma, Sharma,, & Tyagi, 2026; Aumose, & Raj, 2026).

4.6 Digital Health and Implementation

Digital health tools support WASH programmes. Mobile-based household survey and follow-up systems enable structured data collection at scale (Deepa et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Wearable monitoring of children for early-warning signs of dehydration is an emerging area (Deepa et al., 2026). Tele-paediatric consultation extends specialist reach for severe cases (Vijayalakshmi et al., 2025; Vinodh, Subramani,, & Vettriselvan, 2026). AI-supported decision tools assist with severity assessment, treatment selection, and outbreak detection (Devi et al., 2025; Shanthi et al., 2025; Jha, Kumar,, & Neha, 2026). Digital twin frameworks model community-level transmission (Subramani, Chillagattu, et al., 2026; Pradeepa et al., 2026). Cyber-physical infrastructure supports water quality monitoring (Catherine, Nasrin Sulthana, et al., 2026). AI ethics and governance frameworks address data privacy in vulnerable populations (Selvi et al., 2026). Mindful technology use complements community engagement (Vettriselvan, Velmurugan, et al., 2025).

4.7 Limitations

Limitations include the six-village setting which limits geographic generalisability; the 12-month follow-up which captures most short-term effects but may not fully address long-term child development trajectories; the observational nature of the tier comparison with potential confounding; the weekly household visit ascertainment which depends on caregiver recall; the inability to definitively establish individual-level causation given the household-level intervention; and the limited ascertainment of mild episodes that did not prompt household concern. Cross-village ecological comparisons are not formal hypothesis tests but operational comparisons.

V. CONCLUSION

Across 486 households followed for 12 months across three sanitation tiers, diarrhoeal disease burden varied substantially annual mean episodes per 100 person-months were 3.7 in Tier A (improved water + sanitation), 6.2 in Tier B (one improved), and 10.3 in Tier C (neither

improved). Structured WASH intervention with chlorine tablets, hand-washing stations, education, and community health worker support produced substantial improvements within a 12-month timeframe. Strongest predictors of diarrhoeal episode included open defecation predominance, unimproved water source, monsoon season, uncovered water storage, and absent hand-washing. Household water treatment and soap-and-water hand-washing were strongly protective. The findings support continued investment in WASH infrastructure alongside behaviour change programmes and structured community health worker engagement.

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