

Short-term Wet Climatic Exposure and Childhood Diarrhoeal Morbidity in India: A Nationally Representative Study

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Abstract

Increasing hydroclimatic variability is likely to alter the transmission of enteric pathogens by degrading water quality and disrupting sanitation systems, yet its influence on childhood diarrhoeal morbidity has rarely been examined using nationally representative data from India. We investigated whether recent wet climatic exposure was associated with childhood diarrhoeal morbidity and whether household water, sanitation, and hygiene (WASH) conditions modified this relationship. The analysis included 171,285 children aged 0–59 months from the National Family Health Survey (NFHS-5, 2019–2021). Wet climatic exposure was defined using the one-month Standardized Precipitation Evapotranspiration Index (SPEI-01), spatially linked to buffered survey clusters according to each child's interview month. Associations were estimated using survey-weighted multivariable logistic regression, and interaction analyses were performed to examine effect modification by household WASH conditions. Overall, 6.9% of children experienced diarrhoea during the two weeks preceding the survey, and 28.1% lived in clusters exposed to wet climatic conditions. Wet climatic exposure was associated with a 36% increase in the odds of childhood diarrhoeal morbidity (AOR: 1.36; 95% CI: 1.26–1.46). Children with low birth weight, higher birth order, and triple anthropometric failure were at greater risk. Safe child stool disposal significantly reduced the excess risk associated with wet climatic exposure ($p = 0.012$). These findings suggest that short-term wet climatic conditions contribute to childhood diarrhoeal morbidity in India and that strengthening household hygiene practices, particularly the safe disposal of child faeces, alongside climate-informed WASH programmes could help reduce the health impacts of increasing hydroclimatic variability.

Contributions to the Literature

- Provides nationally representative evidence on the relationship between short-term wet climatic exposure and childhood diarrhoeal morbidity in India, an area where evidence has been limited.
- Extends previous research by using the Standardized Precipitation Evapotranspiration Index (SPEI) to characterise hydroclimatic variability rather than relying solely on rainfall or flood events.
- Demonstrates how climatic exposure interacts with household and nutritional vulnerabilities, supporting a broader understanding of climate-sensitive child health inequalities.
- Integrates geospatial hydroclimatic data with nationally representative household survey data, offering a scalable approach for studying climate-sensitive health outcomes in low- and middle-income countries.
- Provides evidence to support climate-informed WASH and child health programmes aimed at reducing diarrhoeal morbidity among vulnerable children.

1. Introduction

Despite substantial reductions in under-five mortality over the past two decades, diarrhoeal diseases remain one of the leading causes of illness and death among young children worldwide [1]. In 2021, an

estimated 444,000 children under five died from diarrhoeal diseases, which continue to contribute to growth faltering, undernutrition, impaired cognitive development, and poor long-term health outcomes [2, 3]. The burden is greatest in low- and middle-income countries, particularly in South Asia and sub-Saharan Africa, where limited access to safe water, sanitation, hygiene (WASH), adequate nutrition, and healthcare increases children's exposure and susceptibility to enteric infections [4, 5]. Diarrhoea and undernutrition also reinforce one another through a well-recognised cycle: repeated infections impair nutrient absorption and growth, while poor nutritional status increases susceptibility to subsequent infections [6, 7].

Household WASH conditions and socioeconomic disadvantage are well-established determinants of childhood diarrhoeal morbidity [8, 9]. More recently, attention has shifted towards the role of climatic variability in shaping the transmission of enteric diseases [10–12]. Variations in rainfall and moisture influence pathogen survival, transport, and human exposure by altering environmental moisture, water quality, and contamination pathways [13, 14]. Periods of unusually wet conditions can overwhelm sanitation systems, mobilise faecal contaminants, contaminate drinking water sources, and prolong the survival of enteric pathogens in the environment [15–17]. Consistent associations between heavy rainfall, flooding, and childhood diarrhoeal morbidity have been reported across diverse climatic and geographical settings [18–20]. As hydroclimatic extremes become more frequent and variable under climate change, understanding their implications for child health has become increasingly important.

India offers an important setting for examining these relationships because it combines a substantial burden of childhood diarrhoeal disease with pronounced climatic variability and marked socioeconomic inequalities. National programmes such as the Swachh Bharat Mission and Jal Jeevan Mission have expanded access to sanitation and drinking water services [21], yet marked differences remain in service quality, hygiene practices, and environmental conditions across states and population groups. Recent evidence indicates that children living in flood-prone areas face a higher risk of diarrhoeal morbidity [22]. However, most studies from India have examined household socioeconomic factors or evaluated the effects of rainfall, temperature, or discrete flood events within specific regions [19, 22, 23]. National evidence linking short-term hydroclimatic variability with childhood diarrhoeal morbidity remains scarce.

Most previous studies have relied on individual climatic indicators, such as rainfall totals, temperature anomalies, or flood occurrence [19, 22]. These measures capture specific aspects of climate but do not reflect the combined influence of precipitation and atmospheric evaporative demand on environmental water availability. The Standardized Precipitation Evapotranspiration Index (SPEI) incorporates both precipitation and potential evapotranspiration to quantify anomalies in climatic water balance [24–26]. By accounting for both water inputs and atmospheric water demand, SPEI provides a more complete representation of hydroclimatic conditions than precipitation alone and may better capture the environmental processes that facilitate enteric disease transmission [27–29]. Although the effectiveness of WASH interventions in reducing childhood diarrhoeal morbidity is well established, much less is known about whether they mitigate the health risks associated with wet climatic conditions.

This study links cluster-level SPEI data with nationally representative NFHS-5 data to examine the association between recent wet climatic exposure and childhood diarrhoeal morbidity among children under five years of age in India. We assessed whether exposure to short-term wet climatic conditions was associated with childhood diarrhoeal morbidity after adjustment for child, maternal, household, and state-level characteristics, and examined whether household WASH conditions modified this association. By combining a nationally representative household survey with a hydroclimatic indicator that captures climatic water balance, this study provides evidence on how recent wet conditions interact with household environments to influence childhood diarrhoeal morbidity in India.

2. Data and methods

2.1 Data sources

This study utilised data from the children recode (KR) file of the fifth round of the National Family Health Survey (NFHS-5), conducted between 2019 and 2021. NFHS-5 is a nationally representative household survey implemented by the International Institute for Population Sciences (IIPS), Mumbai, under the stewardship of the Ministry of Health and Family Welfare, Government of India. The survey provides comprehensive information on population health, nutrition, reproductive health, and household characteristics across all states and union territories of India [30].

NFHS-5 employed a two-stage stratified random sampling design to generate nationally representative estimates. In rural areas, villages were selected as primary sampling units (PSUs) using probability proportional to size (PPS) sampling, followed by the systematic selection of households within each village. In urban areas, Census Enumeration Blocks (CEBs) were selected as PSUs using PPS sampling, followed by the systematic selection of households. The survey covered 636,699 households and collected information from 724,115 women aged 15–49 years, 101,839 men aged 15–54 years, and 232,920 children under five years of age [30].

To characterise short-term wet climatic conditions, gridded Standardized Precipitation Evapotranspiration Index (SPEI) data at a one-month timescale (SPEI-01) were obtained from the SPEIbase version 2.8 dataset [31]. The value of SPEI can range from -2 to $+2$ (though it can extend to -5 or $+5$ in extreme cases), where positive SPEI values indicate wetter-than-normal conditions, whereas negative values indicate drier-than-normal conditions [32, 33]. The one-month timescale (SPEI-01) captures short-term hydroclimatic variability that may influence the environmental transmission of enteric pathogens and the risk of childhood diarrhoeal morbidity.

2.2 Study design and analytical sample

This study adopted a cross-sectional analytical design to examine the association between recent wet climatic exposure and childhood diarrhoeal morbidity among children aged 0–59 months in India.

The initial analytical sample comprised 232,920 children aged 0–59 months. Observations with missing information on the outcome variable, climatic exposure, or covariates included in the multivariable models were excluded using complete-case analysis. The final analytical sample consisted of 171,285 children, across 707 districts, and 36 states and union territories.

2.3 Variable description

Outcome variable

The outcome of interest was childhood diarrhoeal morbidity, assessed using maternal reports of whether the child had experienced diarrhoea during the two weeks preceding the survey interview (NFHS variable: h11). Responses were recoded into a binary variable indicating the presence (1) or absence (0) of diarrhoeal morbidity.

Exposure variable

The primary exposure variable was recent wet climatic exposure, measured using the one-month Standardized Precipitation Evapotranspiration Index (SPEI-01). The SPEI is a multiscalar climate index that quantifies anomalies in climatic water balance by integrating precipitation and potential evapotranspiration, thereby accounting for both moisture availability and atmospheric evaporative demand [34]. Positive SPEI values indicate wetter-than-normal conditions, whereas negative values indicate drier-than-normal conditions.

The one-month timescale (SPEI-01) was selected because childhood diarrhoeal morbidity reflects an acute health outcome with a two-week recall period in the NFHS-5 survey. Short-term hydroclimatic anomalies are more likely to influence immediate environmental transmission pathways of enteric pathogens through changes in water quality, sanitation conditions, and pathogen survival [35, 36]. Consequently, SPEI-01 provides a temporally appropriate measure for capturing recent wet conditions relevant to the occurrence of diarrhoeal episodes.

Cluster-level mean SPEI-01 values were derived by spatially linking gridded SPEI data to buffered NFHS cluster locations to account for the geographic displacement of survey coordinates implemented to protect respondent confidentiality. The SPEI-01 value corresponding to the month of each child's interview was assigned to the respective survey cluster, ensuring temporal alignment between climatic exposure and the two-week recall period for childhood diarrhoeal morbidity.

Following established climatological classifications, clusters with SPEI-01 values greater than + 1 were categorised as exposed to wet climatic conditions, representing moderately to extremely wet conditions, whereas clusters with SPEI-01 values less than or equal to + 1 were classified as non-exposed [26, 31]. A binary indicator of wet climatic exposure was subsequently created and assigned to each child based on the SPEI-01 value of their corresponding cluster and interview month.

Covariates

Potential confounding variables were selected based on existing evidence on the determinants of childhood diarrhoeal morbidity and the availability of relevant variables in NFHS-5 [22, 23, 37]. The analysis included child-, maternal-, household-, and contextual-level characteristics that may influence both climatic exposure and the risk of diarrhoeal disease.

Child-level covariates comprised age (0–11, 12–23, 24–35, 36–47, and 48–59 months), sex (male/female), birth weight, birth order, and nutritional status, measured using the multiple anthropometric failure index. Household-level characteristics included place of residence (urban/rural), social group (Scheduled Caste, Scheduled Tribe, Other Backward Class, and Others), religion (Hindu, Muslim, and Others), household wealth quintile (poorest, poorer, middle, richer, and richest), source of drinking water (improved/unimproved), sanitation facility (improved/unimproved), and child stool disposal practices (safe/unsafe). Maternal characteristics included educational attainment and age at the time of the survey.

2.4 Statistical analysis

Descriptive and inferential analyses were conducted to examine the association between wet climatic exposure and childhood diarrhoeal morbidity. Weighted percentages and corresponding 95% confidence intervals (CIs) were calculated to describe the socio-demographic, environmental, and nutritional characteristics of the study population. The weighted prevalence of diarrhoeal morbidity was estimated across categories of the explanatory variables, and design-adjusted Pearson's chi-square tests were used to compare differences between groups.

The association between wet climatic exposure and childhood diarrhoeal morbidity was estimated using survey-weighted multivariable logistic regression models that accounted for the complex sampling design of the National Family Health Survey (NFHS-5). Survey weights, primary sampling units (PSUs), and sampling strata were incorporated using the *svyset* procedure to obtain nationally representative estimates and valid standard errors. Results are presented as adjusted odds ratios (AORs) with 95% confidence intervals (CIs). The multivariable model adjusted for child characteristics (age, sex, birth weight, birth order, and multiple anthropometric failure), maternal characteristics (education and age), household characteristics (place of residence, social group, religion, wealth quintile, drinking water source, sanitation facility, and child stool disposal practices), and climatic exposure.

The survey-weighted multivariable logistic regression model can be expressed as

$$\text{logit} [P(Y_i = 1)] = \beta_0 + \beta_1 \text{Wet exposure} + \sum_{p=2}^P \beta_p X_{pi}$$

where Y_{ijkl} denotes the diarrhoeal status of the i th child (1 = diarrhoea, 0 = no diarrhoea), β_0 is the intercept, *Wet exposure* represents the binary indicator of current wet climatic exposure (SPEI-01 > +1), X_{pi} denotes the vector of covariates included in the model, and β_p represents the corresponding regression coefficients.

Potential effect modification was assessed by introducing interaction terms between wet climatic exposure and selected WASH indicators, including drinking water source, sanitation facility, and child stool disposal practices. For statistically significant interactions, adjusted predicted probabilities and corresponding 95% confidence intervals were estimated using post-estimation marginal effects.

Sensitivity analyses were conducted to evaluate the robustness of the findings. Separate survey-weighted multivariable logistic regression models were fitted after stratifying the sample by child sex and place of residence (urban/rural) to assess whether the association between wet climatic exposure and childhood diarrhoeal morbidity remained consistent across population subgroups.

All analyses accounted for the complex sampling design of NFHS-5 through the survey design specification (*svyset*). Statistical analyses were performed using *Stata version 17.0*, and statistical significance was assessed at a two-sided p value < 0.05 .

3. Result

3.1 Characteristics of the study population

The analytical sample comprised 171,285 children aged 0–59 months. Overall, 6.9% (95% CI: 6.75–6.96) of children experienced diarrhoea during the two weeks preceding the survey, while 28.1% (95% CI: 27.94–28.31) resided in clusters exposed to wet climatic conditions. The age distribution was relatively balanced across categories, with children aged 48–59 months accounting for the largest proportion (21.0%). Male children constituted 51.7% of the analytical sample, and nearly four-fifths (79.6%) resided in rural areas. Approximately 38.3% of children were first-born, whereas 28.6% had a birth order of three or higher. In terms of socioeconomic characteristics, 38.3% of children belonged to the Other Backward Class (OBC) social group, 73.3% resided in Hindu households, and more than half (50.2%) lived in households classified within the poorest or poorer wealth quintiles (Table 1).

Substantial variation was observed in nutritional status and household environmental conditions. Nearly half of the children (48.3%) had no anthropometric failure, whereas 27.3% experienced either double or triple anthropometric failure. Low birth weight was reported among 16.8% of children, while 3.1% were classified as overweight. Although access to improved drinking water sources (93.1%) and sanitation facilities (74.8%) was high, unsafe child stool disposal practices remained widespread, among three-fourth of households (75.5%). Maternal educational attainment was relatively low, with 34.5% of mothers having no education or incomplete primary education, whereas only 13.9% had attained higher education. Most mothers (68.3%) were aged between 20 and 29 years, reflecting the concentration of births among younger women.

Table 1

Weighted distribution of socio-demographic, environmental, and nutritional characteristics of children aged 0–59 months in India, NFHS-5 (2019–21).

Variable	Category	Percentage (%)	95% CI
Diarrhoea (last 2 weeks)	Yes	6.9	[6.75–6.96]
	No	93.2	[93.04–93.25]
Wet month exposure	Yes	28.1	[27.94–28.31]
	No	71.9	[71.69–72.06]
Child age (months)	0–11	20.0	[19.84–20.17]
	12–23	19.4	[19.21–19.54]
	24–35	19.7	[19.53–19.86]
	36–47	19.9	[19.74–20.07]
	48–59	21.0	[20.86–21.20]
Sex of child	Male	51.7	[51.46–51.88]
	Female	48.3	[48.12–48.54]
Place of residence	Urban	20.4	[20.20–20.53]
	Rural	79.6	[79.47–79.80]
Birth weight	Normal	80.1	[79.92–80.27]
	Underweight	16.8	[16.68–17.00]
	Overweight	3.1	[2.99–3.14]
Birth order	First	38.3	[38.07–38.48]
	Second	33.1	[32.89–33.28]
	Third or higher	28.6	[28.45–28.83]
Multiple anthropometric failure	None	48.3	[48.08–48.52]
	Single anthropometric failure	24.5	[24.27–24.65]
	Double anthropometric failure	22.4	[22.21–22.58]
	Triple anthropometric failure	4.9	[4.75–4.94]

Note: Values are weighted percentages with corresponding 95% confidence intervals (CIs). Estimates are based on children aged 0–59 months included in the National Family Health Survey (NFHS-5), 2019–21.

Variable	Category	Percentage (%)	95% CI
Social group	Scheduled Caste	20.4	[20.23–20.56]
	Scheduled Tribe	20.2	[20.04–20.37]
	OBC	38.3	[38.10–38.51]
	Others	21.1	[20.93–21.26]
Religion	Hindu	73.3	[73.13–73.50]
	Muslim	14.4	[14.29–14.58]
	Other	12.3	[12.12–12.39]
Wealth index	Poorest	26.9	[26.68–27.05]
	Poorer	23.3	[23.12–23.47]
	Middle	19.5	[19.30–19.63]
	Richer	16.9	[16.78–17.09]
	Richest	13.4	[13.30–13.58]
Drinking water source	Unsafe	6.9	[6.78–7.00]
	Safe	93.1	[93.00–93.22]
Sanitation facility	Unsafe	25.2	[25.04–25.41]
	Safe	74.8	[74.59–74.96]
Stool disposal	Unsafe	75.5	[75.37–75.72]
	Safe	24.5	[24.28–24.63]
Maternal education	No education	21.7	[21.49–21.84]
	Incomplete primary	12.8	[12.68–12.96]
	Incomplete secondary	49.9	[49.66–50.07]
	Complete secondary	1.8	[1.73–1.84]
	Higher	13.9	[13.72–14.01]
Maternal age (years)	15–19	2.3	[2.26–2.39]
	20–24	28.5	[28.29–28.66]
	25–29	39.8	[39.59–40.00]

Note: Values are weighted percentages with corresponding 95% confidence intervals (CIs). Estimates are based on children aged 0–59 months included in the National Family Health Survey (NFHS-5), 2019–21.

Variable	Category	Percentage (%)	95% CI
	30–34	19.6	[19.44–19.77]
	35–39	7.6	[7.45–7.67]
	40–44	2.3	[2.19–2.31]
Note: Values are weighted percentages with corresponding 95% confidence intervals (CIs). Estimates are based on children aged 0–59 months included in the National Family Health Survey (NFHS-5), 2019–21.			

3.2 Prevalence of childhood diarrhoeal morbidity across socio-demographic and environmental characteristics

The findings indicate a relatively higher prevalence of diarrhoea among children exposed to wet climatic conditions compared to those who were not exposed (Table 2). Approximately 7.2% of children living in wet-exposed clusters reported diarrhoea during the two weeks preceding the survey, which is 0.5 percentage points higher than children residing in wet unexposed clusters. Age-wise distribution shows that the prevalence of diarrhoea declines with increasing age of the child. The highest burden was observed among infants aged 0–11 months (10.2%), which gradually decreases among older age groups. In terms of sex differentials, male children reported a slightly higher prevalence of diarrhoea (7.4%) compared to female children. A similar pattern was observed across place of residence, where children residing in rural areas (7.3%) experienced a higher prevalence of diarrhoeal morbidity than those in urban areas.

Nutritional status also shows a clear association with diarrhoeal prevalence. Children experiencing multiple anthropometric failures reported the highest prevalence of diarrhoea, highlighting the vulnerability of nutritionally deprived children to infectious diseases. Differences were also observed across socio-cultural groups, with children belonging to Hindu households reporting a relatively higher prevalence of diarrhoea compared to other religious groups. Sanitation-related behavioural practices further demonstrate an important influence on diarrhoeal outcomes. The results indicate that children whose mothers practiced safe disposal of child stool had a comparatively lower prevalence of diarrhoea, suggesting that improved hygiene and sanitation practices play a crucial role in reducing the risk of diarrhoeal diseases among young children.

Table 2

Prevalence of Diarrhoea among different socio-economic covariates across wet exposed and unexposed group, NFHS-5, 2019-21

Variable (category)	Wet Unexposed	χ^2	Wet exposed	χ^2
Overall (Diarrhoea)	6.7	12.75***	7.2	12.75***
Child age (months)				
0–11	9.0		10.2	
12–23	9.2		10.1	
24–35	6.2	1000.00***	6.4	606.66***
36–47	5.0		5.3	
48–59	4.4		4.0	
Child sex				
Male	7.0	14.91***	7.4	3.85*
Female	6.5		7.0	
Place of residence				
Urban	5.9	42.80***	6.8	4.67*
Rural	6.9		7.3	
Birth weight				
Normal	6.5		6.9	
Underweight	7.8	71.95***	8.3	25.26***
Overweight	8.4		8.1	
Birth order				
First	6.5		7.1	
Second	6.6	19.06***	7.2	0.08
Third or higher	7.2		7.2	
Multiple anthropometric failure				
None	6.4		7.1	

Note: Values represent the weighted prevalence (%) of diarrhoeal morbidity among children aged 0–59 months during the two weeks preceding the survey. Pearson's chi-square tests were used to assess differences in diarrhoeal prevalence across covariate categories separately for wet-exposed and non-exposed groups. Significance levels are denoted as follows: * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

Variable (category)	Wet Unexposed	χ^2	Wet exposed	χ^2
Single anthropometric failure	6.9	64.90***	7.1	22.94***
Double anthropometric failure	7.5		7.5	
Triple anthropometric failure	8.2		9.6	
Social group				
Scheduled caste	7.1		7.6	
Scheduled tribe	6.5	14.74**	7.6	11.97**
OBC	6.8		6.9	
Others	6.5		6.9	
Religion				
Hindu	6.7		7.4	
Muslim	6.9	2.89	6.8	32.76***
Other	6.5		5.4	
Wealth index				
Poorest	7.6		8.5	
Poorer	7.1		7.8	
Middle	6.7	177.80***	7.2	93.49***
Richer	6.0		6.9	
Richest	5.0		5.4	
Drinking water source				
Unsafe	6.5	0.82	7.6	0.95
Safe	6.7		7.1	
Sanitation facility				
Unsafe	7.8	96.72***	8.5	46.48***
Note: Values represent the weighted prevalence (%) of diarrhoeal morbidity among children aged 0–59 months during the two weeks preceding the survey. Pearson's chi-square tests were used to assess differences in diarrhoeal prevalence across covariate categories separately for wet-exposed and non-exposed groups. Significance levels are denoted as follows: *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.				

Variable (category)	Wet Unexposed	χ^2	Wet exposed	χ^2
Safe	6.3		6.7	
Stool disposal				
Unsafe	6.6	24.29***	7.2	0.02
Safe	7.3		7.1	
Mother's education				
No education	6.8		7.0	
Incomplete primary	7.8		7.1	
Incomplete secondary	6.8	124.40***	7.5	17.97**
Complete secondary	6.8		7.8	
Higher	5.1		6.3	
Mother's age (years)				
15–19	10.8		13.9	
20–24	8.0		8.6	
25–29	6.4	334.71***	6.9	192.07***
30–34	5.5		5.6	
35–39	5.7		5.7	
40–44	5.9		7.1	
Note: Values represent the weighted prevalence (%) of diarrhoeal morbidity among children aged 0–59 months during the two weeks preceding the survey. Pearson's chi-square tests were used to assess differences in diarrhoeal prevalence across covariate categories separately for wet-exposed and non-exposed groups. Significance levels are denoted as follows: * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.				

3.3 Association between wet climatic exposure and childhood diarrhoeal morbidity

After adjustment for child, maternal, household, environmental, and state-level characteristics, recent wet climatic exposure remained independently associated with childhood diarrhoeal morbidity (Table 3). Children residing in clusters exposed to wet conditions had 36% higher odds of experiencing diarrhoea during the two weeks preceding the survey than those living in non-exposed clusters (AOR: 1.36; 95% CI: 1.26–1.46).

Child characteristics showed clear gradients in diarrhoeal risk. Compared with infants aged 0–11 months, the odds of diarrhoea declined steadily with age, reaching 62% lower odds among children aged

48–59 months (AOR: 0.38; 95% CI: 0.35–0.42). Female children had lower odds of diarrhoea than males (AOR: 0.92; 95% CI: 0.87–0.96). Children with low birth weight and high birth weight were more likely to experience diarrhoea than those with normal birth weight (AOR: 1.12; 95% CI: 1.05–1.19 and AOR: 1.26; 95% CI: 1.10–1.44, respectively). A similar gradient was observed for birth order, with the odds of diarrhoea increasing among second-born children (AOR: 1.09; 95% CI: 1.02–1.15) and those of third or higher birth order (AOR: 1.13; 95% CI: 1.05–1.22). Nutritional vulnerability was also associated with diarrhoeal morbidity, as children experiencing triple anthropometric failure had 18% higher odds of diarrhoea than children without anthropometric failure (AOR: 1.18; 95% CI: 1.05–1.31).

Household socioeconomic characteristics also influenced diarrhoeal risk. Compared with children from the poorest households, those belonging to richer and richest households had lower odds of diarrhoea (AOR: 0.85; 95% CI: 0.76–0.94 and AOR: 0.69; 95% CI: 0.61–0.79, respectively), indicating a socioeconomic gradient in disease risk. Household drinking water source and sanitation facility were not independently associated with diarrhoeal morbidity after adjustment. In contrast, safe child stool disposal remained significantly protective, reducing the odds of diarrhoea by 13% (AOR: 0.87; 95% CI: 0.81–0.93). Children from Other Backward Class households also had slightly lower odds of diarrhoea than those from Scheduled Caste households (AOR: 0.93; 95% CI: 0.86–0.99), whereas no significant differences were observed according to religion or place of residence.

Among maternal characteristics, children born to mothers aged 25–29 years (AOR: 0.84; 95% CI: 0.72–0.98), 30–34 years (AOR: 0.70; 95% CI: 0.60–0.83), and 35–39 years (AOR: 0.77; 95% CI: 0.64–0.93) had lower odds of diarrhoeal morbidity than those born to mothers aged 15–19 years. Maternal education showed no consistent association with childhood diarrhoea after adjustment for the other covariates included in the model.

Table 3

Adjusted association between wet climatic exposure and childhood diarrhoeal morbidity among children aged 0–59 months in India: findings from survey-weighted multivariable logistic regression, NFHS-5 (2019–21)

Variable	Category	AOR	95% CI
Wet climatic exposure	Non-wet	Ref.	—
	Wet	1.36***	[1.26–1.46]
Child age	0–11 months	Ref.	—
	12–23 months	0.94	[0.88–1.01]
	24–35 months	0.59***	[0.54–0.63]
	36–47 months	0.47***	[0.43–0.51]
	48–59 months	0.38***	[0.35–0.42]
Child sex	Male	Ref.	—
	Female	0.92**	[0.87–0.96]
Place of residence	Urban	Ref.	—
	Rural	1.01	[0.92–1.10]
Birth weight	Normal	Ref.	—
	Underweight	1.12**	[1.05–1.19]
	Overweight	1.26**	[1.10–1.44]
Birth order	First child	Ref.	—
	Second child	1.09**	[1.02–1.15]
	Third or higher	1.13***	[1.05–1.22]
Multiple anthropometric failure	No anthropometric failure	Ref.	—
	Single anthropometric failure	0.95	[0.89–1.02]
	Double anthropometric failure	1.05	[0.98–1.12]
	Triple anthropometric failure	1.18**	[1.05–1.31]
Social group	Scheduled caste	Ref.	—
	Scheduled tribe	0.99	[0.89–1.09]

Note: AOR = adjusted odds ratio; CI = confidence interval; Ref. = reference category. Estimates were obtained from a survey-weighted multivariable logistic regression model accounting for the complex sampling design of NFHS-5 using the svyset procedure. The model adjusted for child, maternal, household, and environmental characteristics. Significance levels are denoted as * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

Variable	Category	AOR	95% CI
	Other backward class	0.93*	[0.86–0.99]
	Other caste	1.00	[0.91–1.09]
Religion	Hindu	Ref.	—
	Muslim	1.08	[0.98–1.18]
	Other religions	0.92	[0.79–1.07]
Household wealth quintile	Poorest	Ref.	—
	Poorer	0.95	[0.88–1.03]
	Middle	0.91*	[0.83–1.00]
	Richer	0.85**	[0.76–0.94]
	Richest	0.69***	[0.61–0.79]
Drinking water source	Unsafe	Ref.	—
	Safe	0.97	[0.87–1.09]
Sanitation facility	Unsafe	Ref.	—
	Safe	0.99	[0.92–1.05]
Child stool disposal	Unsafe	Ref.	—
	Safe	0.87***	[0.81–0.93]
Maternal education	No education	Ref.	—
	Incomplete primary	1.10*	[1.01–1.21]
	Incomplete secondary	1.13**	[1.05–1.22]
	Complete secondary	1.02	[0.82–1.26]
	Higher education	1.02	[0.91–1.14]
Maternal age	15–19 years	Ref.	—
	20–24 years	0.94	[0.81–1.08]
	25–29 years	0.84*	[0.72–0.98]
	30–34 years	0.70***	[0.60–0.83]

Note: AOR = adjusted odds ratio; CI = confidence interval; Ref. = reference category. Estimates were obtained from a survey-weighted multivariable logistic regression model accounting for the complex sampling design of NFHS-5 using the svyset procedure. The model adjusted for child, maternal, household, and environmental characteristics. Significance levels are denoted as * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

Variable	Category	AOR	95% CI
	35–39 years	0.77**	[0.64–0.93]
	40–44 years	0.88	[0.68–1.15]

Note: AOR = adjusted odds ratio; CI = confidence interval; Ref. = reference category. Estimates were obtained from a survey-weighted multivariable logistic regression model accounting for the complex sampling design of NFHS-5 using the svyset procedure. The model adjusted for child, maternal, household, and environmental characteristics. Significance levels are denoted as * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

3.4 Modification of the association between wet climatic exposure and childhood diarrhoeal morbidity by WASH conditions

To assess whether household WASH conditions modified the association between wet climatic exposure and childhood diarrhoeal morbidity, interaction terms between wet climatic exposure and key WASH indicators were evaluated using survey-weighted logistic regression models. Among the interaction terms examined, only child stool disposal practices significantly modified the association between wet climatic exposure and diarrhoeal morbidity (Wald $F = 6.35$, $p = 0.012$). Interactions involving drinking water source ($p = 0.403$) and sanitation facilities ($p = 0.087$) were not statistically significant (Table S1).

Adjusted predicted probabilities indicated that wet climatic exposure was associated with a higher probability of diarrhoeal morbidity irrespective of stool disposal practices; however, the magnitude of this association varied according to household hygiene behaviours (Fig. 1). Among households practising unsafe child stool disposal, the predicted probability of diarrhoeal morbidity increased from 7.0% among children unexposed to wet climatic conditions to 9.5% among those exposed to wet conditions. In contrast, among households practising safe child stool disposal, the corresponding increase was more modest, rising from 6.4% to 7.6%. These findings suggest that safe child stool disposal practices may mitigate the adverse effects of wet climatic exposure on childhood diarrhoeal morbidity (Table S2).

Note

Predicted probabilities and 95% confidence intervals were estimated from a survey-weighted logistic regression model including an interaction term between wet climatic exposure and child stool disposal practices (wet $\times$ stool disposal). The model was adjusted for several socio-demographic covariates.

3.5 Sensitivity analyses

Sensitivity analyses were conducted to evaluate whether the association between wet climatic exposure and childhood diarrhoeal morbidity remained consistent across key population subgroups (Table S3).

Stratified survey-weighted multivariable logistic regression models showed a positive association between wet climatic exposure and diarrhoeal morbidity regardless of child sex or place of residence. Although the magnitude of the association was greater among female children (AOR: 1.49; 95% CI: 1.35–1.64) than among male children (AOR: 1.25; 95% CI: 1.14–1.38), and was stronger among rural children (AOR: 1.39; 95% CI: 1.28–1.51) than urban children (AOR: 1.24; 95% CI: 1.06–1.44), the direction and statistical significance of the association remained unchanged across all subgroups. These findings indicate that the observed relationship between recent wet climatic exposure and childhood diarrhoeal morbidity was consistent across population groups.

4. Discussion

The present study found that recent exposure to wet climatic conditions was associated with a higher likelihood of childhood diarrhoeal morbidity in India, even after adjustment for child, maternal, household, and state-level characteristics. Children living in wet-exposed areas had 36% higher odds of experiencing diarrhoea than those residing in non-exposed areas. The association persisted after accounting for nutritional status, socioeconomic conditions, and household WASH characteristics, indicating that short-term hydroclimatic variability acts as an independent environmental determinant of childhood diarrhoeal morbidity. Rather than creating entirely new pathways of disease transmission, wet climatic conditions are likely to intensify existing faecal–oral transmission routes by increasing environmental contamination and children's exposure to enteric pathogens.

The association observed in this study is consistent with evidence from a wide range of climatic and geographical settings showing that periods of excessive rainfall and hydrological extremes are followed by increases in diarrhoeal disease [16, 18, 19, 35, 38, 39]. Heavy rainfall can overwhelm drainage systems, flood sanitation infrastructure, and transport faecal contaminants into drinking water sources and household environments, thereby increasing opportunities for pathogen transmission [40, 41]. Moist environmental conditions may also prolong the survival and dissemination of bacterial, viral, and protozoan pathogens [42, 43]. Unlike many previous studies that relied on rainfall totals, temperature anomalies, or flood occurrence, the present analysis used the Standardized Precipitation Evapotranspiration Index (SPEI), which integrates precipitation with atmospheric evaporative demand to characterise anomalies in climatic water balance [44, 45]. Because SPEI captures both water inputs and atmospheric drying, it provides a more comprehensive representation of short-term hydroclimatic conditions that may influence the environmental transmission of enteric pathogens.

The findings further suggest that the health impacts of wet climatic conditions are socially patterned rather than evenly distributed across the population. Younger children, those experiencing triple anthropometric failure, and children from economically disadvantaged households consistently faced a greater risk of diarrhoeal morbidity. These characteristics reflect underlying vulnerabilities that extend beyond climatic exposure itself. The socioeconomic gradient observed in this study may reflect differences in access to resources, living environments, healthcare utilisation, and household capacity to prevent exposure to enteric pathogens. Likewise, children with multiple anthropometric failures are

biologically more susceptible because undernutrition impairs immune function, while repeated diarrhoeal episodes further compromise nutritional status, reinforcing a well-established cycle of infection and malnutrition [46–48]. The elevated risk among younger children is also biologically plausible. Immature immune systems, the transition to complementary feeding, and greater contact with contaminated household environments through crawling and exploratory behaviour increase their exposure to enteric pathogens [49, 50]. These findings indicate that wet climatic exposure amplifies existing biological and socioeconomic vulnerabilities rather than affecting all children equally.

An important finding of this study is that safe child stool disposal reduced the excess risk of diarrhoeal morbidity associated with wet climatic exposure. In contrast, improved drinking water sources and sanitation facilities were not independently associated with diarrhoeal morbidity after adjustment for other household characteristics. This pattern suggests that access to infrastructure alone may not be sufficient to reduce climate-related health risks if hygienic practices remain inadequate. During periods of excessive rainfall, improperly disposed child faeces can be dispersed more easily into household surroundings through runoff and surface water, increasing opportunities for faecal contamination and pathogen transmission. Safe disposal interrupts this pathway and may therefore provide an additional layer of protection under increasingly variable hydroclimatic conditions. This finding is consistent with growing evidence that child faeces management remains an under-recognised component of WASH interventions despite its importance in reducing environmental contamination and enteric infections [36, 50, 51]. It also supports previous observations that the effectiveness of WASH interventions depends not only on infrastructure but also on the safe management and consistent use of sanitation and hygiene practices [52].

The findings have important implications for climate adaptation and child health policy in India. National programmes such as the Swachh Bharat Mission and Jal Jeevan Mission have substantially expanded access to sanitation and drinking water services, yet reducing climate-sensitive diarrhoeal diseases will also require greater attention to household hygiene practices and environmental management during periods of excessive rainfall. Integrating hydroclimatic information into disease surveillance systems and community-based WASH programmes could help identify periods of elevated diarrhoeal risk and support timely public health responses. Targeting interventions towards younger children, nutritionally vulnerable households, and communities exposed to recurrent wet conditions may further improve the effectiveness of climate adaptation strategies aimed at reducing childhood enteric diseases.

Several limitations should be considered when interpreting these findings. First, the cross-sectional design of NFHS-5 does not permit causal inference or establish temporal relationships between wet climatic exposure and childhood diarrhoeal morbidity. Second, diarrhoeal episodes were reported by mothers and may therefore be affected by recall bias. Third, the spatial displacement of NFHS cluster coordinates to protect respondent confidentiality may have introduced some exposure misclassification, although buffered cluster locations were used to minimise this limitation. Finally, although the analyses adjusted for a broad range of child, maternal, household, and environmental characteristics, residual

confounding from unmeasured factors, including healthcare access, local environmental conditions, and seasonal variation in pathogen circulation, cannot be excluded.

5. Conclusion

The study findings suggest that recent wet climatic exposure was associated with a higher likelihood of childhood diarrhoeal morbidity among children under five years of age in India, independent of child, maternal, household, and state-level characteristics. The increased risk was not evenly distributed across the population but was concentrated among children already experiencing biological and socioeconomic disadvantages, including those children born with low or high birth weight, higher birth order, multiple anthropometric failures, and poorer household conditions. Safe child stool disposal reduced the excess risk associated with wet climatic exposure, suggesting that household hygiene behaviours remain an important component of disease prevention even where access to water and sanitation infrastructure has improved. These findings indicate that strengthening resilience to climate-sensitive diarrhoeal disease will require greater integration of climate information into child health and WASH programmes. During periods of unusually wet climatic conditions, health departments could combine seasonal hydroclimatic monitoring with intensified diarrhoeal surveillance, promotion of safe child stool disposal, and targeted outreach to nutritionally vulnerable households. Adopting such approach can help in reducing the growing health burden associated with increasing hydroclimatic variability while improving child health outcomes in India.

Declarations

Ethical approval statement

The study used anonymized secondary data from the fifth National Family Health Survey (NFHS-5, 2019–2021), which is publicly available through the Demographic and Health Surveys (DHS) Program. Ethical approval for NFHS-5 was obtained by the International Institute for Population Sciences (IIPS), Mumbai, in collaboration with the Institutional Review Board of ICF International, USA. The present study involved secondary analysis of de-identified data and therefore did not require additional ethical approval or informed consent.

Consent to publish

Not applicable

Consent to participate

As the study utilizes secondary data collected by survey agency, and no human interaction was involved. The study doesn't require any consent of participation.

Data availability

The datasets analysed during the current study are publicly available from the Demographic and Health Surveys (DHS) Program upon reasonable request and registration through the DHS website: <https://dhsprogram.com/data/>.

Author contributions

AY: Conceptualization, methodology, literature review, data preparation, formal analysis, interpretation of results, manuscript drafting, and manuscript revision.

MJR: Study supervision, methodology, manuscript review and editing.

ARS: Study supervision, manuscript review and editing.

AG: Data analysis, manuscript drafting, and manuscript review.

SR: Literature review, data analysis, manuscript drafting, and manuscript review.

All authors read and approved the final manuscript.

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Conflict of interest

The authors declare no personal and financial conflict.

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Figures

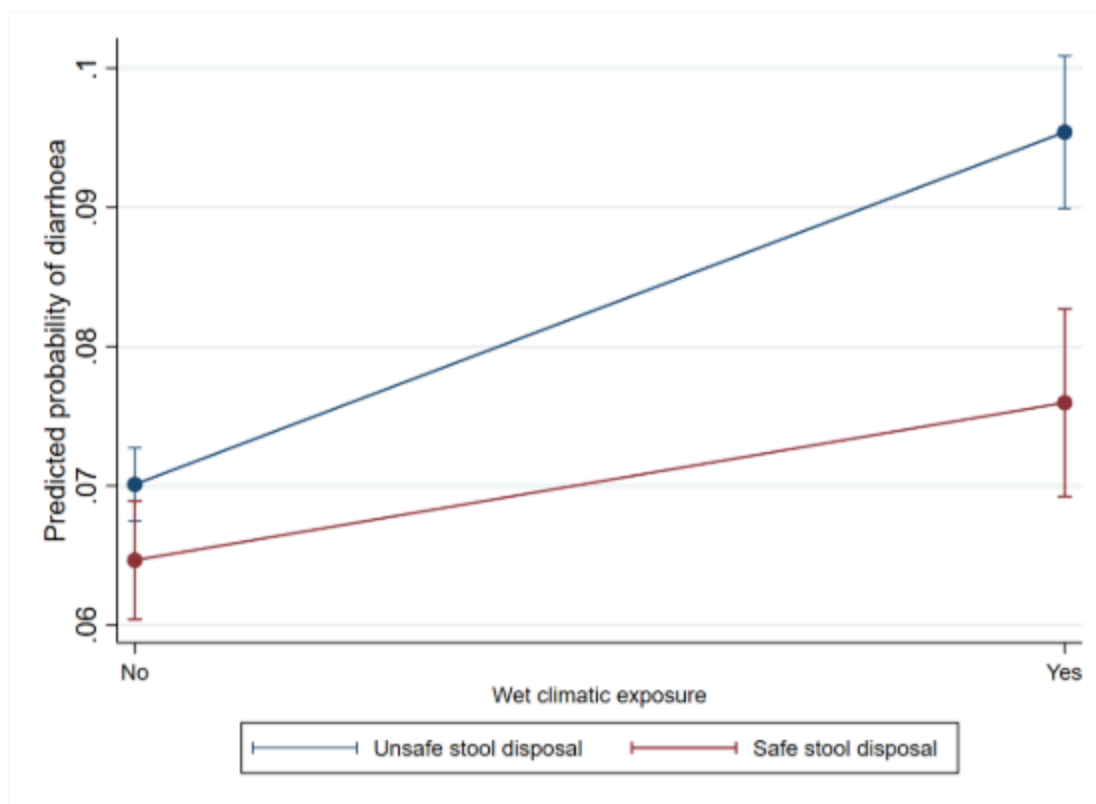


Figure 1

Predicted probability of childhood diarrhoeal morbidity according to wet climatic exposure and child stool disposal practices among children aged 0–59 months in India, NFHS-5 (2019–21).

Note: Predicted probabilities and 95% confidence intervals were estimated from a survey-weighted logistic regression model including an interaction term between wet climatic exposure and child stool disposal practices (wet × stool disposal). The model was adjusted for several socio-demographic covariates.

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