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Review

Prevalence of diarrhoeal cases and deaths associated with food-borne illnesses in India: a systematic review and meta-analysis

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Abstract

Introduction: Foodborne illnesses are infections or intoxications caused by consuming contaminated food or beverages. This study aims to find the prevalence of diarrheal cases and deaths associated with food-borne illnesses in India.

Methodology: A Search was performed on PubMed and other platforms from 2011 to 2022. Sensitivity and quality analyses were also performed. The pooled prevalence was reported with effect sizes, considering the random-effects and quality-effects models. A subgroup analysis was also performed based on the regions and age groups

Results: The prevalence of diarrheal cases due to foodborne illnesses in India was 18%. The prevalence was 22% in the North Eastern region, 20% in the Eastern region, 18% in the Southern region, 16% in the Western region, and 13% in the Northern region. Among the age groups, prevalence was 34% for 5-10 years, 22% for under 5, 13% for 20-60 years, 14% for 10-19 years, and 10% for more than 60 years.

Conclusions: The prevalence of diarrhea is still on the higher side in India. Although programs like Intensified Diarrhea Control Fortnight are running, interventions and awareness, ensuring intake of safe food and water are necessary.

Key words: diarrhea; foodborne illnesses; meta-analysis; prevalence; systematic review.

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Introduction

Diarrhea is defined as passing three or more loose stools in a day, or more frequently than the individual is accustomed to. The most common cause of diarrhea is a digestive tract infection, which is caused by several bacterial, viral, and parasite pathogens that are transferred from one individual to another or through contaminated food or water due to poor hygiene. After acute respiratory infections, diarrhea is the second most prevalent cause of morbidity and death worldwide [1].

Diarrhea is one of the top 10 diseases worldwide in terms of disability-adjusted life year (DALY), even in recent times [2]. Diarrhea was the ninth most common cause of death in 2016, accounting for more than 1.6 million fatalities. The majority of diarrheal deaths (26.93%) involved children under the age of five, with South Asia and sub-Saharan Africa accounting for about 90% (89.37%) of these deaths [3]. Enteric infections account for 5.3% of India's disease burden, while diarrheal illnesses comprise about 4%, according to estimates from the Global Burden of Diseases (GBD) 2019 report [4]. In 2016, around 500,000 kids died from diarrheal illnesses, making it the seventh most common cause of death for children under the age of five. If current trends hold, it is predicted that in 2030, 4.4 million children will pass away before turning five. About 9% of those fatalities would be related to diarrhea [5]. The National Family Health Survey (NFHS) reports that between 2016 and 2020, the prevalence of childhood diarrhea in India increased from 9% to 9.2% [6]. The majority of cases of childhood diarrhea occur in developing nations like India [3]. Approximately 90% of childhood diarrhea cases in Asia, Africa, and Latin America in 2016 were found in underdeveloped nations [7].

The goal of SDG 3.2 is to reduce the death rate of children under five to 25 per 1000 live births. In contrast, by 2030, SDG 3.3 seeks to eradicate infectious diseases and waterborne illnesses [8]. The monsoons in India lead to waterborne diseases, especially in the densely populated regions of the Indo-Gangetic Plain.

Diarrheal infections disproportionately impact low-income communities with limited access to clean water, sanitation, and healthcare, leading to higher morbidity and mortality rates compared to wealthier areas. To tackle this issue, the WHO and UNICEF launched a Global Action Plan in 2013 to reduce severe diarrhea and related deaths in children by 2025 [9].

Nearly all diarrhea interventions and the majority of studies on the burden of diarrhea are restricted to children under the age of five due to the high illness burden in young children [10]. Nonetheless, the burden is significant for those over 70, with deaths from diarrheal disease accounting for over one-sixth of all deaths among children under the age of five. Due to immunosenescence and co-morbidities, the elderly may be more susceptible to diarrhea [11].

Foodborne Diarrhea

An estimated 600 million people, or around 10% of the global population, are predicted to become unwell each year from eating contaminated food, with diarrheal illnesses being the most prevalent, according to a WHO factsheet. Children under the age of five bear 40% of the burden of FBD, resulting in 125,000 fatalities annually. Foodborne illnesses are mostly caused by bacterial pathogens, including *Salmonella, Campylobacter, Enterohaemorrhagic Escherichia coli (EHEC), and Listeria monocytogenes*; however, typhoid and norovirus also cause sizable disease burdens [12]. Child and adult mortality rates were utilised to pinpoint 14 global sub-regions, with those in Africa showing the highest burden of food-borne and water-borne diseases (FBDs), followed by South-East Asia and the Eastern Mediterranean. Disease burden disparities stem from deficiencies in public health infrastructure, preventative measures, and variations in regulatory standards, enforcement, education, surveillance, and research efforts across regions [13].

In 2019, *Campylobacter* was the leading bacterium causing diarrheal deaths, while adenovirus emerged as the primary cause of pediatric diarrhea-related fatalities. Surprisingly, adenovirus-related deaths in children under five were found to be significantly higher than those attributed to rotavirus, at 8864.36 per 100,000 children [14].

WHO highlights foodborne illnesses as a significant global threat, with an estimated 600 million cases annually, leading to 420,000 deaths and 33 million lost disability-adjusted life years worldwide. In India, around 100 million cases and 120,000 deaths occur each year, contributing to 8 million years lost due to disability. Despite 40% of reported outbreaks in India from 2011 to 2017 lacking laboratory diagnosis, the cause remains unidentified. Biological food contamination is implicated in approximately 70% of the world's 1.5 billion annual cases of diarrhea [14].

In light of the worldwide effort to improve public health, national organizations such as the Centre for Disease Control and Prevention (CDC) in the United States and many other nations have established a variety of disease surveillance systems. Every year, foodborne infections in the US result in around 48 million illnesses, 128,000 hospital admissions, and 3000 fatalities [15]. Studies on the national burden of foodborne diseases are essential to establish food safety as a public health priority. This study thus aims to estimate the prevalence of diarrheal cases and deaths caused due to food-borne pathogens in India and study the current knowledge base on the burden of food-borne diarrheal diseases due to various pathogens.

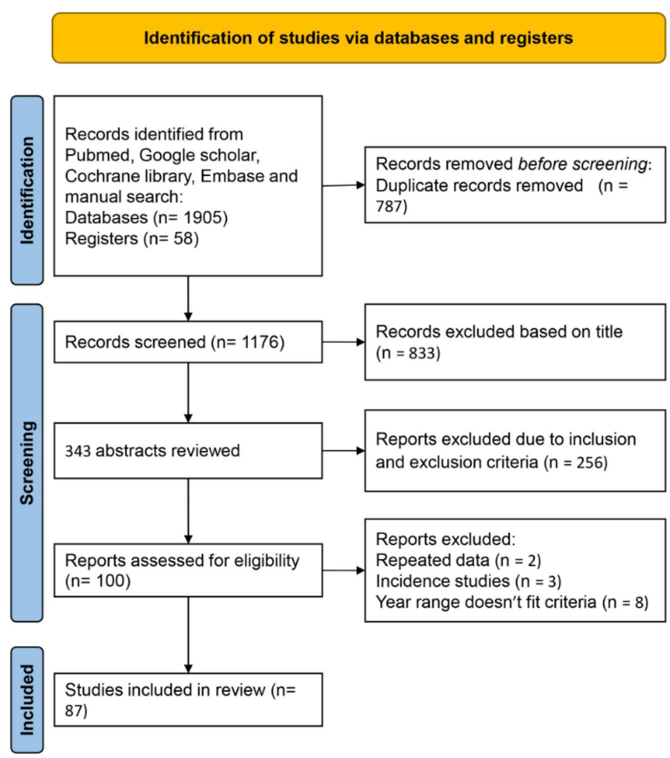
Methodology

This systematic review and meta-analysis were performed in accordance with the 2020 preferred reporting items for systematic review and meta-analysis (PRISMA guidelines) [16]. The review protocol was registered on PROSPERO International Prospective register of systematic reviews (CRD42023464781). PubMed platform, Google Scholar, Cochrane library, Web of Science, Scopus, and Embase were searched to find relevant papers published in the past ten years (2011–2022).

Study selection and Search strategy

The search strategy was created in accordance with PECOS guidelines. Studies published between January 1, 2011, and December 31, 2022, were chosen. Keywords and their combinations were entered in PubMed/MEDLINE using advanced filters. Using PECOS criteria, we expanded the search to include

Figure 1. PRISMA flowchart showing number of studies identified, screened and finally included in meta-analysis.



databases from the Cochrane Library, EBSCOhost, EMBASE, ProQuest, Scopus, and ISI Web of Knowledge (Supp. File – 1). For PubMed, a search method utilizing MeSH terms, Boolean operators, and truncations was created. The articles relevant by title and abstract were accessed in full text to check for eligibility criteria. Cross-referencing from all the selected articles was done to check for other similar articles.

Eligibility criteria

Inclusion criteria

The study was based on the Indian population, including 14 Pathogens: *Campylobacter, Cryptosporidium*, EPEC, ETEC, *Entamoeba histolytica, Giardia, Salmonella enterica, Shigella*, Norovirus, STEC and *Vibrio cholerae, Cyclospora*, Enteroaggregative *E. coli,* and Rotavirus. It included studies published during the years 2011–2022 (10 years), cross-sectional studies and prevalence-based studies, and studies across all types of settings (clinics, old age homes, or community).

Exclusion criteria

It excluded studies where diarrhea was caused by reasons other than food-borne, like severe malnutrition or any chronic disease, and data that was repeated in different studies.

Data collection process

After discussing and resolving any divergence, two writers (AS and SK) independently retrieved data from the relevant papers. Authors RJ and VS were involved in resolving the discrepancies in the study and data (if any). If the data were unclear, the article was excluded after a full-text review by PK and AS. Data was then compiled in an Excel file independently based on the title, abstract, study design, study setting, age group, and publication year, following the first search and separation of publications. Regarding the indices of interest, we extracted the prevalence data for each study (Table 1). The articles were managed using Zotero software. Further information about different age groups was extracted from each study (Figure 1).

Table 1. Characteristics summary of the 87 selected studies for a systematic review of the prevalence of the Diarrhoea due to foodborne illnesses in India (2011 - 2022).

S. No.	Author	Study design	Region of India	Age (years)	Sample size	Prevalence	Quality score	Quality Index
1	vijayan_et_al	cross sec	India	< 5	6,99,686	83962	10	1
2	purval_et_al	cross sec	W	< 5	300	197	6	0.6
3	purval_et_al	cross sec	W	< 5	300	16	6	0.6
4	purval_et_al	cross sec	W	< 5	300	12	6	0.6
5	purval_et_al	cross sec	W	< 5	300	1	6	0.6
6	purval_et_al	cross sec	W	NS	300	6	6	0.6
7	purval_et_al	cross sec	W	NS	300	11	6	0.6
8	purval_et_al	cross sec	W	NS	300	40	6	0.6
9	purval_et_al	cross sec	W	NS	300	30	6	0.6
10	purval_et_al	cross sec	W	NS	300	15	6	0.6
11	purval_et_al	cross sec	W	NS	300	1	6	0.6
12	purval_et_al	cross sec	W	NS	300	4	6	0.6
13	purval_et_al	cross sec	S	all	575	69	9	0.9
14	bawankule_et_al	cross sec	India	< 5	19490	1754	10	1
15	bawankule_et_al	cross sec	India	< 5	2330	322	10	1
16	reddy_et_al	cross sec	S	< 5	669	143	7	0.7
17	jeyakumar_et_al	cross sec	W	< 5	577	193	7	0.7
18	borkakoty_et_al	cross sec	NE	< 5	407	41	6	0.6
19	sangma_et_al	cross sec	N	< 5	553	225	7	0.7
20	lakshmi_et_al	cross sec	S	all	400	76	7	0.7
21	lakshmi_et_al	cross sec	S	all	400	168	7	0.7
22	lakshmi_et_al	cross sec	S	all	400	40	7	0.7
23	lakshmi_et_al	cross sec	S	all	400	20	7	0.7
24	lakshmi_et_al	cross sec	S	all	400	4	7	0.7
25	lakshmi_et_al	cross sec	S	all	400	8	7	0.7
26	srivastav_et_al	cross sec	E	all	310	54	7	0.7
27	srivastav_et_al	cross sec	E	all	310	48	7	0.7
28	srivastav_et_al	cross sec	E	all	310	43	7	0.7
29	srivastav_et_al	cross sec	E	all	310	30	7	0.7
30	srivastav_et_al	cross sec	E	all	310	14	7	0.7
31	srivastav_et_al	cross sec	E	all	310	12	7	0.7
32	srivastav_et_al	cross sec	E	all	310	2	7	0.7
33	avachat_et_al	cross sec	W	< 5	652	64	7	0.7
34	rajendran_et_al	cross sec	S	< 5	394	158	6	0.6
35	gupta_et_al	cross sec	W	< 5	1480	360	6	0.6
36	aggrawal_et_al	cross sec	N	< 5	385	70	6	0.6
37	gupta_et_al	cross sec	N	< 5	331	149	6	0.6

S. No.	Author	Study design	Region of India	Age (years)	Sample size	Prevalence	Quality score	Quality Index
38	moharans_et_al	cross sec	E	< 5	320	40	6	0.6
39	moharans_et_al	cross sec	E	< 5	320	33	6	0.6
40	goru_et_al	cross sec	S	< 5	404	30	6	0.6
41	giri_et_al	cross sec	N	< 5	1954	663	6	0.6
42	giri_et_al	cross sec	S	< 5	4622	1406	6	0.6
43	pol_et_al	cross sec	W	< 5	100	35	6	0.6
44	bera_et_al	cross sec	N	< 5	175	48	6	0.6
45	gupta_et_al	cross sec	N	< 5	85	69	6	0.6
46	gupta_et_al	cross sec	N	< 5	85	37	6	0.6
47	selvarajan_et_al	cross sec	S	< 5	247	121	6	0.6
48	selvarajan_et_al	cross sec	S	20-60	310	43	6	0.6
49	kumar_et_al	cross sec	N	< 5	240	35	6	0.6
50	raghvan_et_al	cross sec	S	< 5	1394	68	6	0.6
51	raghvan_et_al	cross sec	S	< 5	1394	19	6	0.6
52	raghvan_et_al	cross sec	S	< 5	1394	10	6	0.6
53	kumar_et_al	cross sec	N	all	21	8	6	0.6
54	maher_et_al	cross sec	W	< 5	168	20	6	0.6
55	sinha_et_al	cross sec	E	all	122	29	6	0.6
56	sinha_et_al	cross sec	E	all	122	8	6	0.6
57	sinha_et_al	cross sec	E	all	122	14	6	0.6
58	sinha_et_al	cross sec	E	all	122	7	6	0.6
59	sinha_et_al	cross sec	E	all	122	1	6	0.6
60	sinha_et_al	cross sec	E	all	122	9	6	0.6
61	kumar_et_al	cross sec	India	< 5	10207	4042	6	0.6
62	nayak_et_al	cross sec	E	< 5	830	443	6	0.6
63	nayak_et_al	cross sec	E	5-10	30	10	6	0.6
64	nayak_et_al	cross sec	E	20-60	300	80	6	0.6
65	gupta_et_al	cross sec	N	< 5	239	45	6	0.6
66	nath_et_al	cross sec	NE	all	356	29	7	0.7
67	nath_et_al	cross sec	NE	all	356	121	7	0.7
68	nath_et_al	cross sec	NE	all	356	52	7	0.7
69	nath_et_al	cross sec	NE	all	356	26	7	0.7
70	hussain-et_al	cross sec	NE	< 5	1119	34	6	0.6
71	chowdhury_et_al	cross sec	E	all	44	6	6	0.6
72	yenkhom_et_al	cross sec	NE	< 5	204	144	6	0.6
73	yadav_et_al	cross sec	India	all	800	19	6	0.6
74	vijayan_et_al	cross sec	India	< 5	22500	2700	10	1
75	hussain-et_al	cross sec	NE	< 5	215	34	6	0.6
76	hussain-et_al	cross sec	NE	20-60	300	80	6	0.6
77	bashar_et_al	cross sec	N	< 5	624	5	10	1
78	dass_et_al	cross sec	S	< 5	60	11	6	0.6
79	verma_et_al	cross sec	N	20-60	550	17	6	0.6
80	venkatachalam_et_al	cross sec	S	< 5	613	129	7	0.7
81	uppal_et_al	cross sec	N	< 5	3823	194	6	0.6
82	uppal_et_al	cross sec	N	< 5	3823	49	6	0.6
83	uppal_et_al	cross sec	N	< 5	3823	28	6	0.6
84	uppal_et_al	cross sec	N	all	6527	159	6	0.6
85	uppal_et_al	cross sec	N	all	6527	126	6	0.6
86	uppal_et_al	cross sec	N	all	6527	148	6	0.6
87	uppal_et_al	cross sec	N	all	6527	42	6	0.6
88	uppal_et_al	cross sec	N	all	6527	10	6	0.6
89	tiku_et_al	cross sec	N	< 5	350	6	6	0.6
90	thakur_et_al	cross sec	N	all	572	79	6	0.6
91	thakur_et_al	cross sec	N	all	572	33	6	0.6
92	thakur_et_al	cross sec	N	all	572	8	6	0.6
93	bashar_et_al	cross sec	N	> 60	624	23	7	0.7
94	bashar_et_al	cross sec	N	< 5	624	4	7	0.7
95	bashar_et_al	cross sec	N	20-60	624	19	7	0.7
96	sabramani_et_al	cross sec	S	all	400	20	6	0.6
97	srivastava_et_al	cross sec	India	> 60	31464	4719	10	1
98	srivastava_et_al	cross sec	N	< 5	256	67	6	0.6
99	srivastava_et_al	cross sec	N	< 5	256	14	7	0.7
100	snehaa_et_al	cross sec	N	< 5	200	19	6	0.6
101	sisodia_et_al	cross sec	N	all	200	36	9	0.9
102	sinha_et_al	cross sec	E	all	122	29	6	0.6
103	sinha_et_al	cross sec	E	all	122	14	6	0.6
104	sinha_et_al	cross sec	E	all	122	8	6	0.6
105	sinha_et_al	cross sec	E	all	122	7	6	0.6
106	sinha_et_al	cross sec	E	all	122	9	6	0.6
107	sinha_et_al	cross sec	E	all	122	1	6	0.6

S. No.	Author	Study design	Region of India	Age (years)	Sample size	Prevalence	Quality score	Quality Index
108	singh_et_al	cross sec	India	< 5	120	87	6	0.6
109	singh_et_al	cross sec	India	< 5	120	76	6	0.6
110	singh_et_al	cross sec	India	< 5	120	55	6	0.6
111	singh_et_al	cross sec	N	< 5	100	18	6	0.6
112	singh_et_al	cross sec	N	< 5	100	8	6	0.6
113	singh_et_al	cross sec	N	< 5	100	4	6	0.6
114	singh_et_al	cross sec	N	< 5	100	10	6	0.6
115	singh_et_al	cross sec	N	< 5	100	6	6	0.6
116	shrivastav_et_al	cross sec	E	< 5	320	98	6	0.6
117	sharma_et_al	cross sec	W	< 5	892	169	6	0.6
118	sharma_et_al	cross sec	N	< 5	851	196	6	0.6
119	sarangi_et_al	cross sec	E	< 5	265	123	6	0.6
120	sangma_et_al	cross sec	N	< 5	553	225	9	0.9
121	saluja_et_al	cross sec	India	< 5	2051	541	6	0.6
122	sabharittha_et_al	cross sec	S	< 5	150	26	6	0.6
123	roy_et_al	cross sec	NE	all	1168	267	7	0.7
124	reesu_et_al	cross sec	S	< 5	1078	356	6	0.6
125	rathaur_et-al	cross sec	India	< 5	211	124	9	0.9
126	rathaur_et-al	cross sec	India	< 5	211	29	9	0.9
127	rathaur_et-al	cross sec	India	< 5	211	51	9	0.9
128	rathaur_et-al	cross sec	India	< 5	211	17	9	0.9
129	rathaur_et-al	cross sec	India	5-10	46	20	9	0.9
130	rathaur_et-al	cross sec	India	5-10	46	5	9	0.9
131	rathaur_et-al	cross sec	India	5-10	46	22	9	0.9
132	raorane_et_al	cross sec	W	all	58	22	6	0.6
133	raorane_et_al	cross sec	NE	all	100	36	6	0.6
134	rajendirakumar_et_al	cross sec	S	< 5	1138	300	7	0.7
135	rajagunlan_et_al	cross sec	N	all	260	4	7	0.7
136	prusty_et_al	cross sec	E	< 5	675	256	6	0.6
137	pradhan_et_al	cross sec	E	< 5	1963	715	6	0.6
138	patil_et_al	cross sec	S	< 5	168	52	6	0.6
139	nirmal_et_al	cross sec	N	all	9577	100	6	0.6
140	nirmal_et_al	cross sec	N	< 5	9577	44	6	0.6
141	Nayak_et_al	cross sec	E	< 5	1356	818	6	0.6
142	Nayak_et_al	cross sec	E	< 5	3652	1817	6	0.6
143	Nir_et_al	cross sec	India	< 5	6935	2291	6	0.6
144	Naraayanet_al	cross sec	S	< 5	670	215	6	0.6
145	sethuvel_et_al	cross sec	S	all	3647	176	4	0.4
146	mullick_et_al	cross sec	E	< 5	1830	50	6	0.6
147	kumar_et_al	cross sec	N	< 5	240	35	6	0.6
148	kumar_et_al	cross sec	N	< 5	240	5	6	0.6
149	kumar_et_al	cross sec	N	< 5	240	10	6	0.6
150	kumar_et_al	cross sec	N	< 5	240	19	6	0.6
151	kumar_et_al	cross sec	N	< 5	240	3	6	0.6
152	kumar_et_al	cross sec	N	< 5	240	2	6	0.6
153	kumar_et_al	cross sec	N	< 5	240	7	6	0.6
154	kumar_et_al	cross sec	N	< 5	240	8	6	0.6
155	kumar_et_al	cross sec	N	< 5	75	5	6	0.6
156	kar_et_al	cross sec	E	< 5	250	58	6	0.6
157	joseph_et_al	cross sec	S	all	167	69	9	0.9
158	jain_et_al	cross sec	N	< 5	247	121	6	0.6
159	jain_et_al	cross sec	N	10-19	310	43	6	0.6
160	jain_et_al	cross sec	N	< 5	111	55	6	0.6
161	jain_et_al	cross sec	N	< 5	111	4	6	0.6
162	jain_et_al	cross sec	N	< 5	140	21	6	0.6
163	jain_et_al	cross sec	N	< 5	140	7	6	0.6
164	gupt_et_al	cross sec	N	< 5	418	47	6	0.6
165	gupt_et_al	cross sec	N	< 5	345	69	6	0.6
166	gupt_et_al	cross sec	E	< 5	152	34	7	0.7
167	gopalkrishna_et_al	cross sec	W	< 5	308	94	6	0.6
168	gopalkrishna_et_al	cross sec	W	< 5	308	44	6	0.6
169	goel_et_al	cross sec	N	< 5	1343	148	6	0.6
170	kumar_et_al	cross sec	India	< 5	10207	4042	10	1
171	gaurav_et_al	cross sec	N	all	311	8	7	0.7
172	daniels_et_al	cross sec	E	all	85	10	7	0.7
173	bhowmik_et-al	cross sec	E	< 5	505	185	6	0.6
174	bhowmik_et-al	cross sec	E	< 5	320	93	6	0.6
175	ballal_et_al	cross sec	S	all	3187	98	6	0.6
176	ballal_et_al	cross sec	S	all	3187	1481	6	0.6
177	ballal_et_al	cross sec	S	all	3187	338	6	0.6

S. No.	Author	Study design	Region of India	Age (years)	Sample size	Prevalence	Quality score	Quality Index
178	ballal_et_al	cross sec	S	all	3187	198	6	0.6
179	ballal_et_al	cross sec	S	< 5	3187	1	6	0.6
180	arun_et_al	cross sec	S	< 5	401	167	6	0.6
181	ari_et_al	cross sec	N	< 5	349	104	6	0.6
182	anandan_et_al	cross sec	S	20-60	626	52	6	0.6
183	akdag_et_al	cross sec	N	< 5	312	57	6	0.6

Study risk of bias assessment

The quality of the studies that were part of this review was assessed using the DOI scale, which is extensively used in the prevalence-based meta-analysis article. When it came to quality control, the authors' collective decision on the final score for each study was made.

Synthesis methods

The data collected was prepared before they were included in the analysis. The results of the main analyses were represented graphically by the forest plot (Figure 2). Both the random-effects (RE) model and quality-effects (QE) model were used to determine the pooled estimate and subgroup analyses at a 95% confidence level. The I-squared statistic (I2) was used to assess variability attributable to heterogeneity. The I2 > 50% was considered a significant determinant for heterogeneity. A funnel plot was used to assess the symmetry among the studies, and the Egger test was performed to assess the significance of asymmetry in determining the prevalence. Sensitivity analyses were carried out using the leave-one-out method, omitting one study from each analysis and observing how each study affects the total effect-size estimate [17]. The pooled prevalence was reported in "effect size". We performed subgroup analyses by region of India (North, South, East, West, North East) (Figure 3) and by age group (< 5, 5-10, 11-19, 19-60, > 60) (Figure 4). After conducting a sensitivity analysis to assess substantial heterogeneity (I2 > 50%), meta-regression was performed in Stata 17.0. This assessed the effect of different covariates (regions and age) on predicting the prevalence of food-borne diarrhea in India (significant at $p < 0.05$).

Results

Study characteristic

One thousand nine hundred five studies from databases and 58 from registers were identified when a search was performed in PubMed, Embase, Google Scholar, and the Cochrane Library. 787 studies were identified as duplicates and removed. 1176 records were then screened, of which 833 were excluded based on title. 343 abstracts were reviewed, and due to discrepancies in fulfilling the inclusion and exclusion criteria, 256 studies were further excluded. 100 reports were assessed for eligibility; among which 2 were again found to be repeated studies, 3 were incidence studies, and 6 studies did not fulfil the year criteria. Thereafter, 87 studies were identified and included in the review (Figure 1).

Results of syntheses

After studies were retrieved and identified from databases, and final inclusion of studies was done, the studies were then distributed into 5 age groups. Maximum studies pertain to the < 5 years old age group, followed by studies in which all age groups were covered, followed by studies in which age group was not specified, followed by 20-60 years of age group then 5-10 age group, > 60 years age group and finally 10-19 years of age group. Similarly, for region-wise studies, maximum studies are found related to the North region (Himachal, Uttarakhand, Punjab, Haryana, Utter Pradesh) followed by Eastern region (Bihar, Jharkhand, Orissa, West Bengal), then South (Andhra, Kerela, Karnataka, Tamil Nadu), then Western region (Rajasthan, Gujrat, Goa, Maharashtra) and India followed by North east region (Assam, Meghalaya, Nagaland, Manipur, Tripura) [18]. The prevalence of diarrhea due to food-borne illnesses was found to be 18% (95% C.I. = 0.15–0.20). Significantly high heterogeneity among studies in the case of diarrhea (I2 = 98.39%) was observed.

Subgroup Analyses

Subgroup Analyses by regions of India – We assessed heterogeneity across the different regions of India. There were 62 studies pertaining to the Northern region, 37 to the Eastern region, 33 to the Southern region, 20 to the Western region, and 11 to the Northeast region. The prevalence among the Eastern region was 20% (95% C.I. = 0.14–0.26) in contrast to Northern region where prevalence was 13% (95% C.I. = 0.09–0.17), North Eastern region as 22% (95% C.I. = 0.11–0.33), Southern region as 18% (95% C.I. = 0.13–0.23), Western region as 16% (95% C.I. = 0.09–0.23).

Figure 2. Forest plot of pooled prevalence of food-borne diarrhea in India.

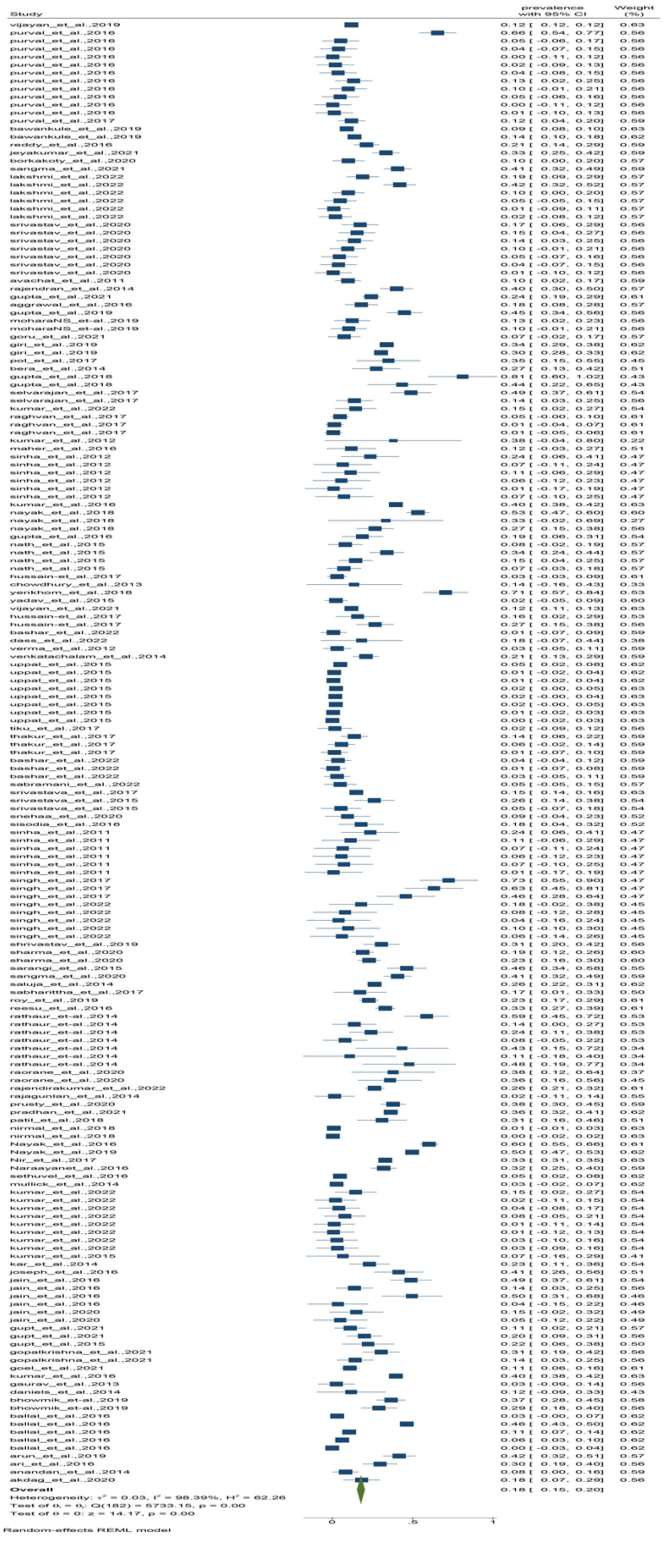
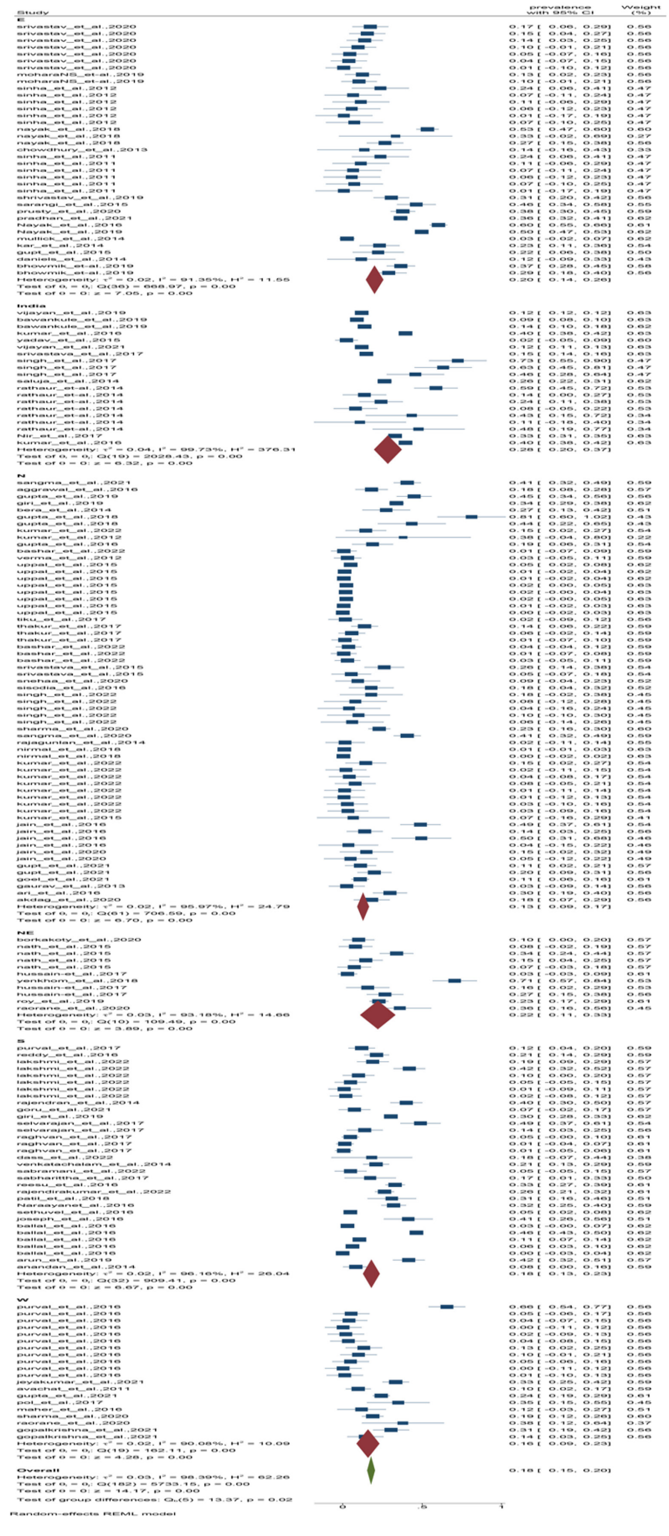


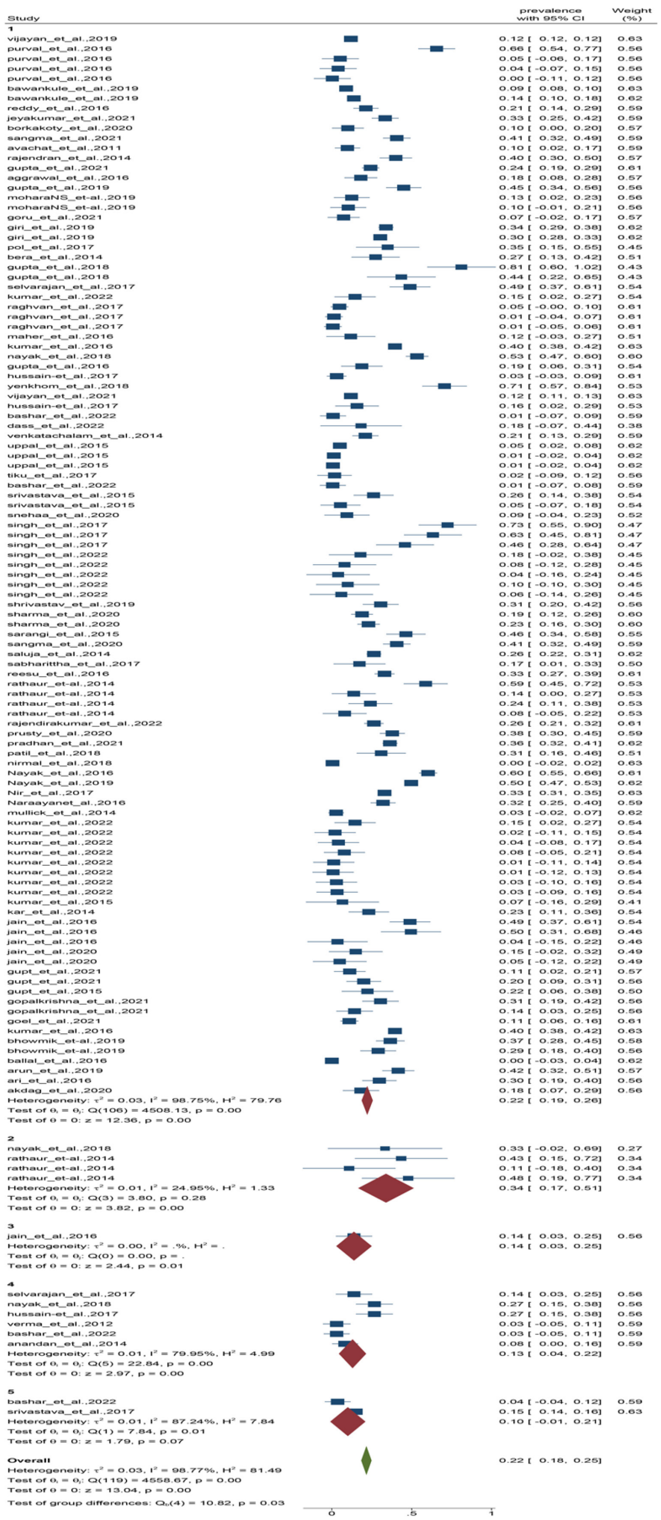
Figure 3. Forest plot of subgroup-analysis region-wise for prevalence of food-borne diarrhea in India.



Subgroup Analyses by different age groups

We also checked for any heterogeneity associated with the different age groups. There were 107 studies pertaining to the < 5 age group, 4 studies for 5-10 years, 1 for 10-19 years, 6 studies pertaining to 20-60 years, and 2 studies for > 60 years. The age group 20-60 years shows the prevalence as 13% (95% C.I. = 0.04–0.22) according to the random effect model. This was less as compared to the age group 10-19 years which was 14% (95% C.I. = 0.03–0.25) and the age group 5-10 years which was 34% (95% C.I. = 0.17–0.51), < 5 which was 22% (95% C.I. = 0.19–0.26) and age group > 60 years as 10% (95% C.I. = -0.01–0.21).

Figure 4. Forest plot of subgroup-analysis age-wise for prevalence of food-borne diarrhea in India.



The highest pooled prevalence was found in 5-10 years 34% (95% C.I. = 0.17–0.51) and North Eastern region as 22% (95% C.I. = 0.11–0.33) and lowest was found in age group > 60 years as 10% (95% C.I. = -0.01–0.21) and Northern region where prevalence was 13% (95% C.I. = 0.09–0.17).

Quality assessment, sensitivity analysis, and symmetry among studies

All 87 studies were assessed for quality; 6 studies have a maximum score of 10, 5 studies have a score of 9, 16 studies have a score of 7, and the rest have a score of 6 except 1 with a score of 4 (Table 1). Quality assessment was done using quality effect model, and pooled prevalence was estimated. Sensitivity analysis was done using the leave-one-out method, but the prevalence was unaffected.

Meta-regression

Meta-regression was performed for region of India and different age-groups to explore potential sources of variation among studies and to investigate whether certain study characteristics are associated with differences in effect sizes. The Northern study region seemed to be significantly predicting the prevalence of diarrhea in India ($p = 0.036$) (Table 2).

Discussion

Foodborne illnesses are a significant global health concern, causing a substantial burden of diarrheal diseases worldwide. Contaminated food and water can harbor pathogens that lead to diarrheal infections, resulting in significant morbidity and mortality, particularly in low-income regions with inadequate sanitation and hygiene practices.

This study showed the overall prevalence of diarrhea as 18% (95% C.I. = 0.15–0.20). According to Srivastava *et al* (2022), the highest percentage of older individuals with diarrhea was recorded in Mizoram (33.5%), followed by Chhattisgarh (30.7%) and Bihar (30.2%). Under-5 prevalence was 22%. This is much higher as compared to a study by Ghosh *et al*, which reported prevalence to be 9.2% for children under 5 at

Table 2. Meta-regression analysis table showing the strength of covariates in predicting the prevalence of Diarrhoea due to foodborne illnesses in India (2011 - 2022).

	Coefficient	Std. error	z	p > z	95% C.I.		Ref. cat
Region-wise							
North	-0.071	0.034	-2.10	0.036	-0.138	-0.004	East
South	-0.020	0.038	-0.53	0.595	-0.096	0.055	East
East	-0.017	0.055	-0.32	0.750	-0.126	0.091	NE
West	-0.042	0.045	-0.93	0.351	-0.131	0.046	East
Northeast	0.017	0.055	0.32	0.750	-0.091	0.126	East
Age-wise							
< 5	-0.126	-0.124	1.02	0.308	-0.116	-0.370	> 60
6-10	0.117	0.116	1.00	0.315	-0.111	0.346	< 5
10-19	-0.829	0.181	-0.46	0.648	-0.439	0.273	< 5
20-60	-0.087	0.075	-1.17	0.242	-0.234	0.059	< 5
> 60	0.126	0.124	-1.02	0.308	-0.370	0.116	< 5

the national level (6)

The prevalence of diarrhea in the Northeast region was 22% (C.I. 0.11 – 0.33). According to a different study, 10.1% of children under the age of five hospitalized for diarrhea had *Campylobacter* infection. Laboratories should utilize routine stool cultures to proactively identify Campylobacter spp., as endemic *Campylobacter* infection has been found in parts of Northeast India [19]. Another study in Southern Assam highlighted that the prevalence of cryptosporidium was around 6%, highest prevalence in the monsoon season [20]. Another study on *Giardia* in the Assam Barak Valley suggested a seasonal epidemic probably caused by the pre-monsoon water scarcity, which encourages unsanitary practices. Flooding during the rainy season encourages agricultural field or drinking water contamination. Additionally, improper cleaning of raw produce before ingestion may contribute to the spread of intestinal protozoan parasites [21]. A study in Meghalaya and Goa about *rotavirus* prevalence suggested that though the vaccination drive is successful but regular screening of these 2 tourist places is a must as there is continuous human inflow [22]

The prevalence of diarrhea in the East region was 20% (C.I. 0.14 – 0.26). Direct dispersal of animal excreta into the environment, open defecation, transmission of fecal pathogens through food and water are some of the reasons for the prevalence of major Enteropathogens in humans in Odisha [23]. Poor hygiene is a result of low income in developing nations, and the presence of numerous pathogens in stool samples from diarrheal illnesses suggests severe food and water pollution [24]. According to another study, children under five are primarily infected with *E. coli*, and the majority of isolates are resistant to treatment [25]. Absence of immunity, lack of surveillance, and behavioral practices and beliefs were linked to the prevalence of GARV (*Group A Rotavirus*) in Kolkata [26]. Proper planning is necessary to identify the source of contamination to avoid outbreaks [27]. Because of Kolkata's tropical environment, the seasonality of *rotavirus* infection is comparable to that of several Asian places, where a low level of RV is seen all year long but peaks in winters [28].

The prevalence of diarrhea in the South region was 18% (C.I. 0.13 – 0.23). In Mangalore, it was determined that education on appropriate feeding and management techniques is necessary to contain diarrhea [29]. Improved access to health care is needed to tackle the high prevalence of diarrhea in tribal Andhra [30]. Pre-vaccine surveillance data are required to evaluate changes in *rotavirus* prevalence [31]. Another study calls for increased vigilance of various agents causing diarrhea and further research on epidemiology and virulence potential [32]. A study conducted in Kolar concludes that improved sanitation and clean drinking water, and proper treatment guidelines, especially in developing countries, are needed to prevent shigellosis [33]. In unimmunized children, the risk of rotavirus is more prolonged [34]. Breastfeeding is important to develop immunity in < 5 to fight against rotavirus [35,36]. Due to diagnostic limitations, *non-typhoidal Salmonella* infections often go undetected in developing countries [37]

The prevalence of diarrhea in the West region was 16% (C.I. 0.09 – 0.23). WASH practices play an important role in the spread of infection [38]. The frequency of recurrent diarrhea is greatly influenced by low socioeconomic position, poor hygiene, and nutritional status [39]. Continued surveillance is essential for preventing foodborne illnesses and estimating the effectiveness of vaccination, especially for rotavirus [40,41]. A combination of coinfection and incomplete immunization may be the cause of the severe illness response in the vaccinated patients [42]

The prevalence of diarrhea in the North region was 13% (C.I. 0.09 – 0.17). Water samples were found to be unsatisfactory for consumption, especially during monsoons [43]. An antimicrobial therapy and a timely diagnosis are necessary to prevent shigellosis [44]. A study found that although several diarrhea-affected children also had *Cryptosporidium* infection, there was no significant correlation found between the infection and factors such as gender, history of contact with domestic animals, breastfeeding, or nutritional status [45]. The environment, such as soil, animal stool, etc., acts as a reservoir for infections [46]. The risk factors include local practices such as defecation in public areas, use of pumps to obtain water, poor water-supply system engineering with numerous leaks, and insufficient chlorination of tube-well water [47]. diarrhea was significantly influenced by mothers' literacy, socioeconomic position, and hygiene practices [48]. Higher vaccination rates can control *rotavirus* [49]. In 63.3% patients, etiological agents of diarrhea were identified. The burden of infectious diseases among children under five can be reduced by educating mothers about safe drinking water, healthy eating habits, and good sanitation [50]

Similar to the findings, the prevalence of diarrhea among children under five in Ethiopia was 22%. Childhood diarrhea was highly correlated with urban living, lack of maternal education, and lack of hand washing by mothers [51]. There was heterogeneity in the pooled prevalence of *Shigella* in South Asia, which was 7%. *Shigella* was more common in children under five years [52]. Despite the paucity of information on *Campylobacter* species, a systematic examination of the bacteria revealed that *Campylobacter spp*. was found more frequently in instances of diarrhea (3.2–17.4%) than in cases of non-diarrhea (0–13%) [53]. Overall, the prevalence estimates of FBP (*E. coli, Shigella, Campylobacter, Salmonella*, and pathogenic *Escherichia coli)* was 8%. Estimates from environmental samples (11%) were statistically higher than those from human stool (6%). According to the subgroup analysis, pathogenic *E. coli* and *Salmonella* were responsible for 11.6% and 5.7% of cases, respectively [54]. The average prevalence of *Salmonella spp*. in foods was found to be 20.5%. In RTE (raw foods and ready-to-eat) foods, the average prevalence of *Salmonella* was 21.7%, whereas in raw foods, it was 19.9% [55].

In nutshell, reasons for high prevalence of diarrhea in India due to food-borne vectors are found to be unhygienic practices like open defecation, water used directly from hand pumps, less knowledge to mothers about hygiene practices, staying in close contact with domesticated animals, inadequate chlorination, inaccurate molecular diagnosis and diagnostic constrains, seasonal factors like increase of diarrheal cases in monsoons, low socioeconomic status, absence of a study of vaccination coverage, absence of a study about its effectiveness and incomplete monitoring and vaccination.

Strengths of the Study

This is the first study to estimate prevalence of diarrheal deaths and cases in India caused due to common food-borne pathogens transmitted by food. The subgroup analysis shows differential prevalence based on age and study region. The quality effect model reduces the estimator variance while determining the pooled prevalence.

Limitations of the Study

The study is found to have certain limitations. Potential sources of bias include the criteria for inclusion/exclusion, the databases used, the date, the language, the number of articles included, and the type of article selected for this investigation. Furthermore, only 14 pathogens total were included in the research to obtain the pooled prevalence of FBP overall in India; additional pathogens were excluded from the analysis. The statistical estimations of the pooled prevalence of FBP may be impacted by this. The different number of studies involved in each subgroup variable, in our opinion, may also have an effect on the subgroup, since fewer than ten studies were included in a limited number of subgroups.

Conclusions

Although there is an increasing burden of non-communicable diseases, the continuing prevalence of communicable diseases cannot be neglected until it comes down to a minimum. In the era of modernization, where there is increasing use of pesticides and the quality of food products is already deteriorating and compromised, it is high time to practice good hygiene practices in everyday routine activities. We recommend that, in areas with a high prevalence of food-borne diseases, public health programs be initiated to target the causes, and necessary awareness practices should be practised to control outbreaks and the intensity of diarrheal cases across different age groups. The hotspot regions should be identified. Also, efforts for vaccination coverage and appropriate and effective surveillance are needed. In an integrated One Health strategy, it is imperative to promote the use of contemporary diagnostic technologies and procedures to examine the sources of infections in humans or animals.

Authors contributions

Designing the review: AS and PK, Data search and extraction: SK and AS, Data analysis: SK and RK, Data interpretation: PK, AS and VS. Wrote the paper: AS, VS and PK, Critical evaluation of manuscript: RK and VS.

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Conflict of interest

No conflict of interest is declared.

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