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RESEARCH ARTICLE

Temperature and risk of infectious diarrhea: a systematic review and meta-analysis

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Abstract
Infectious diarrhea (ID) is an intestinal infectious disease including cholera, typhoid and paratyphoid fever, bacterial and amebic dysentery, and other infectious diarrhea. There are many studies that have explored the relationship between ambient temperature and the spread of infectious diarrhea, but the results are inconsistent. It is necessary to systematically evaluate the impact of temperature on the incidence of ID. This study was based on the PRISMA statement to report this systematic review. We conducted literature searches from CNKI, VIP databases, CBM, PubMed, Web of Science, Cochrane Library, and other databases. The number registered in PROSPERO is CRD42021225472. After searching a total of 4915 articles in the database and references, 27 studies were included. The number of people involved exceeded 7.07 million. The overall result demonstrated when the temperature rises, the risk of infectious diarrhea increases significantly ($RR_{cumulative}$=1.42, 95%CI: 1.07–1.88, $RR_{single-day}$=1.08, 95%CI: 1.03–1.14). Subgroup analysis found the effect of temperature on the bacillary dysentery group ($RR_{cumulative}$=1.85, 95%CI: 1.48–2.30) and unclassified diarrhea groups ($RR_{cumulative}$=1.18, 95%CI: 0.59–2.34). The result of the single-day effect subgroup analysis was similar to the result of the cumulative effect. And the sensitivity analysis proved that the results were robust. This systematic review and meta-analysis support that temperature will increase the risk of ID, which is helpful for ID prediction and early warning in the future.

Keywords Ambient temperature · Infectious diarrhea · Bacterial dysentery · Subgroup analysis · Meta-analysis

Introduction

Diarrheal disease is one of the major diseases with the highest incidence in the world, especially among children and the elderly (James et al. 2018). It is estimated that more than 10 million years lived with disability (YLD) due to diarrhea (James et al. 2018). Infectious diarrhea (ID) is an intestinal infectious disease caused by a variety of pathogens, including salmonella, shigella, vibrio cholera, and rotavirus (Lin and Dong 2008; National Health Commission of the People's Republic of China 2007). ID is an infectious disease that must be reported in accordance with the Law of the People's Republic of China on the Prevention and Control of Infectious Diseases, of which cholera is a category A infectious disease, and bacterial and amebic dysentery, typhoid and paratyphoid fever are category B infectious diseases (National People's Congress of the People's Republic of China 2013).

The pathogen of ID is very obviously affected by weather and climate (Leddin and Macrae 2020; Oh et al. 2021), and it is easier to grow and reproduce under suitable temperature and relative humidity (Asadgol et al. 2020; Ma et al. 2020). Therefore, a large number of epidemiological studies have explored the relationship between meteorological factors and ID. Campbell-Lendrum et al. reported that due to changed climate, the incidence of infectious diseases such as malaria, diarrhea, and cholera causes more than 3 million deaths each year (Campbell-Lendrum et al. 2015). Wang et al. study suggested that low temperatures could increase the risk of ID in

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China taking the median temperature as a reference (Wang et al. 2020). In the study of Liu et al., a mean daily temperature increases of 1 °C would increase the relative risk of BD by 1.7% (Liu et al. 2020). Wang et al. investigated and found the low temperature (RR = 1.057, 95% CI: 1.030–1.084) will increase the risk of infectious diarrhea (Wang et al. 2019).

The results of the meta-analysis are also not consistent. Carlton et al. have proved that ambient temperature will increase the incidence of all-cause diarrhea (incidence rate ratio:1.07, 95% CI: 1.03–1.10), but the association with viral diarrhea is not significant (IRR 0.96, 95% CI 0.82, 1.11) (Carlton et al. 2016). A study conducted in South Asia showed that lower temperatures in mid-latitudes will increase the risk of rotavirus infection (Jagai et al. 2012). The study by Levy et al. also supported that temperature reduces the incidence of rotavirus (Levy et al. 2009). Recently, more studies on the risk of temperature to ID have been published. In these studies, the cumulative effect and single-day effect of temperature on ID also become available. Due to the limitations of previous reviews and the new data available, we aimed to systematically review and conduct a meta-analysis to assess the impact of ambient temperature on the incidence of ID.

Methods

Identification and selection of studies

This systematic review is based on the Systematic Reviews and Meta-Analysis (PRISMA) statement. Before going through all the necessary procedures, we registered on the PROSPERO system and passed the registration (CRD42021225472).

For this meta-analysis, a comprehensive search strategy was carefully designed to find all eligible studies from multiple electronic databases, including Chinese National Knowledge Infrastructure (CNKI), VIP (Chinese) database, Chinese BioMedical Literature Database (CBM), and PubMed, Web of Science, Cochrane Library. The time limit is from 1 January 1990 to 12 December 2020. The following combined search terms were used in the search: ("infectious diarrhea" OR "Cholera" OR "bacillary dysentery" OR "amoebic dysentery" OR "typhoid fever" OR "paratyphoid fever") AND ("temperature" OR "ambient temperature"). Relevant Chinese technical terms for the Chinese databases were used to search for published articles (the detailed search strategy is shown in Appendix file 1).

References provided by all relevant articles were also searched to get other studies that met the inclusion criteria. After deleting duplicate studies, two reviewers read the abstract and title to screen respectively. We downloaded and read the full text of the studies to evaluate whether they could be included in meta-analysis. If the above two reviewers are still not sure whether an article meets the standard after discussion, a third party is required to establish a consensus.

Inclusion and exclusion criteria

The studies meeting the following criteria were included: (1) concerning the relationship between ambient temperature and incidence of ID; (2) diagnosis of ID must have clinical evidence; (3) providing the relative risk (RR) or incidence rate ratio (IRR) and 95% confidence interval (CI) of ID when the temperature increases, or complete data for calculating RR or IRR with 95% CI; (4) study design is correct and appropriate (epidemiological and statistical methods used in the study could achieve its research purposes); (5) no language restrictions applied. The exclusive criteria were as follows: (1) insufficient data; (2) conferences/meetings abstracts, case reports, editorials, and review articles; (3) duplicate publication or overlapping studies.

Data extraction and assessment of study quality

The following information was extracted according to predesigned data extraction form by two independent reviewers: first author, year of publication, country, duration, total number of ID cases, diarrhea type, effect type, maximum lag days, study design, statistical model, and main findings of the study. Another reviewer checked the extracted data for completeness and accuracy.

Due to the heterogeneity of studies and the desire to understand the impact of the individual methodological components of studies, we focused on certain items that are reflective of methodological and reporting quality of the studies as delineated in the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement (http://strobe-statement.org) (Ip et al. 2009). The quality of each study was evaluated in reference to the STROBE statement from 22 items, and the score reflects the potential bias in the included studies.

Statistical analysis

The association of temperature and subsequent ID was assessed with RR and 95% CI. The RR refers to how many times the incidence of infectious diarrhea in the exposed group is that of the control group. Simultaneously, the P values less than 0.05 were considered statistically significant. Groups were separated according to different types of infectious diarrhea. Considering the potential for between-study heterogeneity, subgroup analyses were carried out based on stratification by different regions, how much temperature increased, and different lag days. The heterogeneity of meta-analysis was assessed using the I^2 statistic.

In order to promote the results of our study beyond the included studies and take other factors into consideration, we use random-effects to conduct a meta-analysis model (Borenstein et al. 2010; Deeks et al. 2019; DerSimonian and Laird 1986). The fixed-effect model was used to perform sensitivity analysis.

To test for publication bias in the results, the method for quantitative analysis of potential publication bias used Begg's and Egger's tests (*P* value greater than 0.05 indicated that no significant bias was found in this meta-analysis) (Begg and Mazumdar 1994; Egger et al. 1997). The process of meta-analysis was performed using Stata (version 16.0; Stata Corp, College Station, TX) software.

Result

Characteristics of eligible studies

Figure 1 showed a flow chart of the literature search and screening process. After literature search, we initially found 4915 records, and 27 eligible studies were included (Cheng et al. 2017; D'Souza et al. 2008; Dewan et al. 2013; Gao et al. 2020; Hao et al. 2019; Hashizume et al. 2008; Hu et al. 2019; Li et al. 2016; Li et al. 2019; Li et al. 2014; Li et al. 2013; Liu et al. 2019; Liu et al. 2020; Luque Fernández et al. 2009; Min et al. 2019; Qiang et al. 2013; Thindwa et al. 2019; Trærup et al. 2011; Wang et al. 2019a; Wang et al. 2021; Wang et al. 2018; Wang et al. 2011; Wu et al. 2018; Xu et al. 2017; Zhang 2019; Zhang et al. 2021). The total population exceeds 7.07 million. Among the results of these studies, not only some report the single-day effect of temperature (17 studies reported on the single-day effect of temperature, and a total of 28 estimates and effect intervals were collected), but some report the cumulative effect of temperature over multiple days (16 studies reported on the cumulative effect of temperature, and a total of 30 estimates and effect intervals were collected).

Among the studies that met the inclusion criteria, 11 studies focus on bacillary dysentery, 3 cholera, 3 typhoid or paratyphoid, and 2 rotavirus diarrhea studies. The other eight studies did not clearly indicate which specific ID they studied. All studies included were observational studies (Table 1). Regarding the location of the research, 3 studies use national data, 5 in northern China, and 12 in southern China. The remaining 7 studies are located in Australia, Bangladesh, Tanzania, Zambia, and other countries. The quality evaluation found that inter-rater agreement among the reviewers was strong. Appendix Tables S1 and S2 summarized the STROBE statement of the included studies.

Ambient temperature and risk of infectious diarrhea

After summarizing 30 cumulative effect estimates (Figure 2) and 28 single-day effect estimates (Figure 3), the relationship

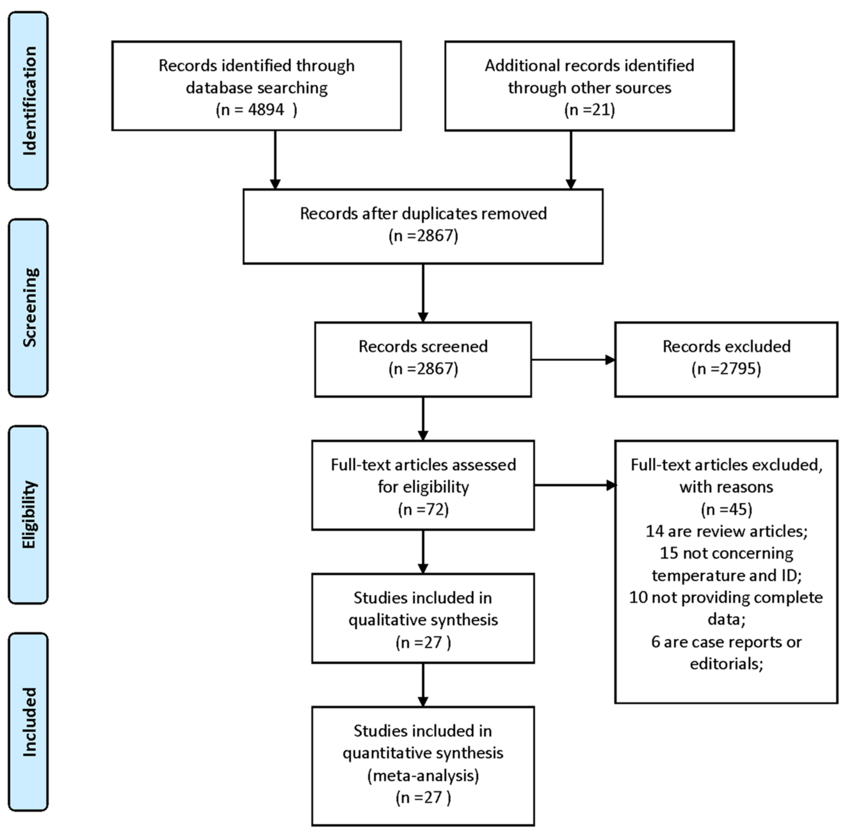


Fig. 1 Systematic search and study selection

Table 1 Characteristics of included studies

	Author	Year	Country	Region	Duration	Total number of cases	Diarrhea type	Single-day/cumulative effect	Maximum lag days	Statistical model	Main finding
1	Gao	2020	China	Southern China	2013–2018	835	Infectious diarrhea	Single-day & cumulative effect	21	DLNM	Research has discovered the effect of temperature on infectious diarrhea and diarrhea-like illness.
2	Liu	2020	China	China	2014–2016	396,134	Bacillary dysentery	Cumulative effect	8	DLNM	The positive association between temperature and BD in different climatic regions of China, and the projection for increased risk due to climate change, support efforts to mitigate future risks.
3	Wang	2020	China	China	2014–2016	2,715,544	Infectious diarrhea	Cumulative effect	30	DLNM	The overall positive pooled associations between temperature and category ID in China suggest the increasing temperature could bring about more category infectious diarrhea cases, which warrants further public health measurements.
4	Zhang	2020	China	Southern and northern China	2013–2017	710,202	Bacillary dysentery	Single-day effect	-	BSTHM	In northern and southern China, a 1 °C increase in the average temperature led to an increase of 1.01% and 4.26% in bacillary dysentery risk, respectively.
5	Hao	2019	China	Southern China	2010–2015	72,649	Bacillary dysentery	Cumulative effect	4 weeks	DLNM	In Anhui, BD morbidity risk increased with increasing weekly mean temperature.
6	Hu	2019	China	Southern China	2008–2017	2,308,988	Infectious diarrhea	Cumulative effect	3	DLNM	High temperature could increase the risk of infectious diarrhea in the southeast coastal areas of China.
7	Li	2019	China	Northern China	2008–2016	1218	Infectious diarrhea	Cumulative effect	14	DLNM	Temperature might be one of the important reasons for other infectious diarrhea outbreaks in Jiayuguan City, and it plays an important role in the occurrence and prevalence of infectious diarrhea in the population.
8	Liu	2019	China	Northern China	2005–2013	11,738	Bacillary dysentery	Single-day & cumulative effect	7	DLNM	Each 5 °C rise in temperature caused a 19% (RR = 1.19, 95% CI: 1.14–1.24).
9	Thindwa	2019	Malawi	Blantyre	2011–2015	2648	Typhoid	Single-day effect	8	DLNM	The relative-risk function of temperature for typhoid was bimodal, with higher risk at both lower (with a 1-month lag) and higher (with a ≥4 months lag) temperatures, possibly reflecting the known patterns of short and long cycle typhoid transmission.
10	Wang	2019a	China	Southern China	2006–2017	167,691	Infectious diarrhea	Single-day & cumulative effect	21	DLNM	Compared with the lowest ID risk values, low mean temperature, relative humidity, and precipitation were associated with an increased risk for ID.
11	Wang	2019b	China	Southern China	2014–2016	42,480	Infectious diarrhea	Single-day & cumulative effect	30	DLNM	Both high temperature and low temperature increase the risk of other infectious diarrhea, and the attributable risk of low temperature is more obvious.
12	Wang	2019c	China	Southern China	2014–2016	301,593	Infectious diarrhea	Single-day effect	30	DLNM	Both high temperature and low temperature increase the risk of ID, and both have a lag effect.

Table 1 (continued)

	Author	Year	Country	Region	Duration	Total number of cases	Diarrhea type	Single-day/ cumulative effect	Maximum lag days	Statistical model	Main finding
13	Zhang	2019	China	Northern China	2014–2016	122,678	Infectious diarrhea	Cumulative effect	21	DLNM	The relationship between temperature and exposure to other infectious diarrhea is non-linear.
14	Wang	2018	China	Northern China	2008–2015	23,108	Bacillary dysentery	Single-day & cumulative effect	14	DLNM	The incidence of bacillary dysentery is affected by multiple meteorological factors, but the primary one is high temperature.
15	Wu	2018	Bangladesh	Matlab	1983–2009	9519	Cholera	Single-day effect	-	Logistic regression models	These findings suggest that heatwaves might promote the occurrence of cholera, while this relationship was modified by rainfall and tree cover.
16	Xu	2018	China	Southern China	2010–2015	44,926	Bacillary dysentery	Single-day effect	-	BSTHM	Among meteorological factors, air temperature, relative humidity, and wind speed all played a significant role in the spatial-temporal distribution of bacillary dysentery risk.
17	Cheng	2017	China	Southern China	2006–2012	12,717	Bacillary dysentery	Single-day & cumulative effect	9	DLNM	The risk of bacillary dysentery increased with the temperature rise above a threshold, and the temperature effects appeared to be acute.
18	Li	2016	China	Southern China	2006–2012	6511	Bacillary dysentery (age 0–14)	Single-day effect	6	DLNM	An increase in temperature was significantly associated with childhood BD.
19	Li	2014	China	Southern China	2006–2012	4775	Bacillary dysentery	Single-day effect	-	NBRM	Each 1 °C rise of temperature corresponded to an increase of 3.60% (95%CI, 3.03 to 4.18%) in the monthly number of BD cases.
20	Dewan	2013	Bangladesh	Dhaka	2005–2009	4355	Typhoid	Cumulative effect	4 weeks	GLPRM	Temporally, typhoid incidence was seen to increase with temperature, rainfall, and river level at time lags ranging from 3 to 5 weeks.
21	Li	2013	China	Southern China	2006–2011	36,487	Bacillary dysentery	Single-day effect	-	NBRM	A positive association was found for mean temperature (excess risk (ER) for 1 °C increase being 0.94% (95% confidence interval (CI): 0.46 to 1.43% on the lag day 2).
22	Qiang	2013	China	Northern China	2005–2010	11,218	Bacillary dysentery	Single-day effect	5	GAM	It indicates that the incidence of bacillary dysentery in Chengguan District of Lanzhou City is obviously seasonal, and high temperature is most likely to cause the disease.
23	Trærup	2011	Tanzania	Tanzania	1998–2004	-	Cholera	Single-day effect	-	NBRM	For a 1 °C temperature increase, the initial relative risk of cholera increases by 15 to 29%.
24	Wang	2011	China	Southern China	2001–2007	59,373	Typhoid and paratyphoid	Single-day effect	-	GLPRM	Based on results from panel data analysis, the incidence of typhoid and paratyphoid fever was shown to be associated with meteorological factors such as temperature, precipitation, relative humidity and 1-month lag of temperature increase.
25	Fernández	2009	Zambia	Lusaka	2003–2006	-	Cholera	Cumulative effect	6 weeks	GLPRM	A 1 °C rise in temperature 6 weeks before the onset of the outbreak explained 5.2% (relative risk (RR) 1.05, 95% CI

Table 1 (continued)

	Author	Year	Country	Region	Duration	Total number of cases	Diarrhea type	Single-day/cumulative effect	Maximum lag days	Statistical model	Main finding
											1.04–1.06) of the increase in the number of cholera cases (2003–2006).
26	D'Souza	2008	Australia	Brisbane, Canberra, and Melbourne	1993–2003	5911	Rotavirus diarrhea	Cumulative effect	1 week	Log-linear regression model	The effects of both temperature and humidity on rotavirus admissions in Brisbane differed across seasons.
27	Hashizume	2008	Bangladesh	Dhaka	1996–2001	3115	Rotavirus diarrhea	Cumulative effect	4 weeks	GLPRM	There was strong evidence for an increase in rotavirus diarrhea at high temperatures, by 40.2% for each 1 °C.

DLNM distributed lag non-linear model, *BSTHM* Bayesian space-time hierarchy model, *NBRM* negative binomial regression model, *GLPRM* generalized linear Poisson regression models, *NBRM* negative binomial regression model, *GAM* generalized additive model

between temperature and the risk of ID incidence was found ($RR_{cumulative}$=1.42, 95%CI: 1.07–1.88, $RR_{single\text{-}day}$=1.08, 95%CI: 1.03–1.14).

There is obvious heterogeneity in the pooled cumulative effect and the single-day effect results (I^2 are both >99%). Therefore, we conducted a subgroup analysis according to different ID diseases to explore the source of heterogeneity (Tables 2 and 3). For the cumulative effect, bacillary dysentery ($RR_{cumulative}$=1.85, 95%CI: 1.48–2.30), rotavirus diarrhea ($RR_{cumulative}$=1.04, 95%CI: 0.91–1.18), cholera ($RR_{cumulative}$=1.05, 95%CI: 1.04–1.06), typhoid ($RR_{cumulative}$=1.14, 95%CI: 1.04–1.25), and other unclassified infectious diarrhea ($RR_{cumulative}$=1.18, 95%CI: 0.59–2.34) respond differently to temperature increase. In the subgroup analysis of bacillary dysentery, the risk in northern China ($RR_{cumulative}$=2.24, 95%CI: 1.83–2.73, I^2=55.57%) is higher than that in other regions. When the temperature increases more than 10 °C, the BD risk will increase by 218% (RR=2.18, 95%CI: 1.63–2.90, I^2=69.80%). When the maximum lag day > 10, the RR of the bacillary dysentery is 2.16 (95%CI: 1.61–2.90, I^2=80.85%). In the subgroup analysis of unclassified infectious diarrhea, the highest risk region was found in northern China ($RR_{cumulative}$ =3.85, 95%CI: 1.94–7.64, I^2= 86.89%). In the subgroup with a lag day > 10 days, only one study was investigated in Jiayuguan, China (Li et al. 2019), and the cumulative effect of ID relative risk was 7.73 (95% CI: 4.25–14.05).

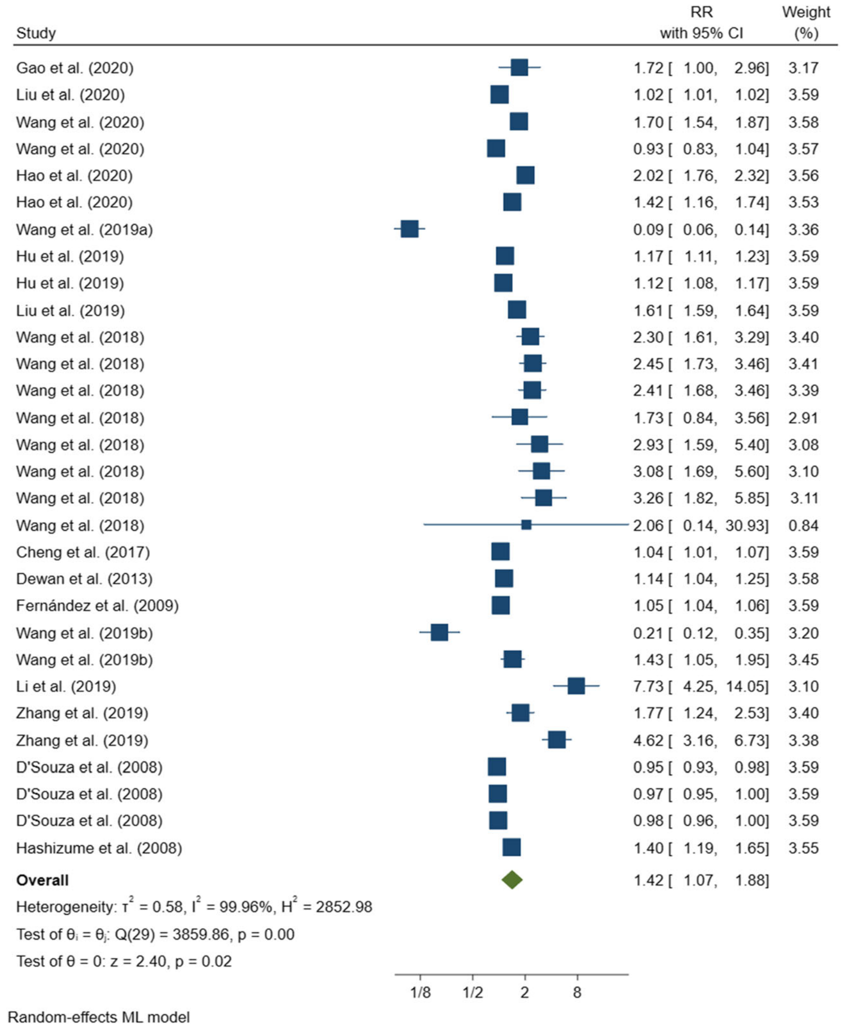
In the single-day effect analysis, the risk of bacillary dysentery was similar to the result of the cumulative effect group and statistically significant ($RR_{single\text{-}day}$ =1.10, 95%CI: 1.06–1.15, I^2= 86.89%). When the temperature rises more than 10 °C, the RR of bacillary dysentery is 1.36 (95%CI: 1.18–1.57, I^2=0.00%). But for the other unclassified of ID group analysis, some results that were not statistically significant were also found (Table 3).

The results of sensitivity analysis showed the pooled RRs without great fluctuation, indicating that the results are robust. Regarding the cumulative effect of temperature, neither Begg's test (z = 0.96, P = 0.335) nor Egger's test (z = 1.32, P = 0.188) manifested any distinct evidence of the publication bias. For the single-day effect, although Begg's test (z = −0.18, P = 1.14) did not show any obvious evidence of publication bias, Egger's test (z = 2.21, P =0.027) suggested that there may be publication bias.

Discussion

Infectious diarrhea contributes to severe malnutrition and high mortality in developing countries, especially for infants and children (Kosek et al. 2003; Navaneethan and Giannella 2008). This meta-analysis of all available articles provided the most current evidence for the relationship

Fig. 2 Forest plot of cumulative effects between temperature and ID incidence



between ambient temperature and infectious diarrhea. When the temperature rises, the risk of infectious diarrhea is significantly increased no matter for the cumulative effect or the single-day effect. This is consistent with the meta results of all-cause diarrhea by Carlton et al. (incidence rate ratio: 1.07, 95% CI: 1.03–1.10) (Carlton et al. 2016). The temperature affects the gene transcription of pathogens that affect disease, and a warm environment can help improve their adaptability (Wei et al. 2017). Checkley et al. reported that high temperature may promote bacterial growth and prolong the survival of bacteria in a contaminated environment, thereby increasing the risk of infection in susceptible individuals (Checkley et al. 2000).

Eleven studies of bacterial dysentery were included in this study. The temperature increases in the subgroup analysis have significant results on both the cumulative effect and the single-day effect. Previous studies suggested that the increased risk of BD can be explained by changes in microorganisms in contaminated food or water caused by increased temperature (Kotloff et al. 1999). Higher temperatures prolong the survival of BD pathogens (Black and Lanata 1995; Kovats et al. 2004). In addition, preference for cold food or cold drinks can also increase the risk of food-borne BD outbreaks under high temperature conditions (Kovats et al. 2004). For other unclassified infectious diarrhea, although there were significant results for cumulative effects, the subgroups did not show significant single-day effects. This may be related to the fact that temperature has the indirect effects on immunity and thermoregulation (Fang et al. 2021; Min et al. 2019), leading to the single-day effect of ID is often not obvious, and it is easy to be overlooked in some studies. This may also be the reason for the publication bias in Egger's test. In addition, Wang et al. investigated meteorological factors and infectious diarrhea incidence, and they found that elevated temperature (31.85 °C vs. 3.49 °C) was a protective factor for ID (RR=0.81, 95% CI: 0.80–0.83). This may indicate the differences in meteorological conditions and physical geography between regions. According to the inclusion and exclusion criteria, we only focused on those studies of infectious diarrhea caused by pathogens. Only 4 articles

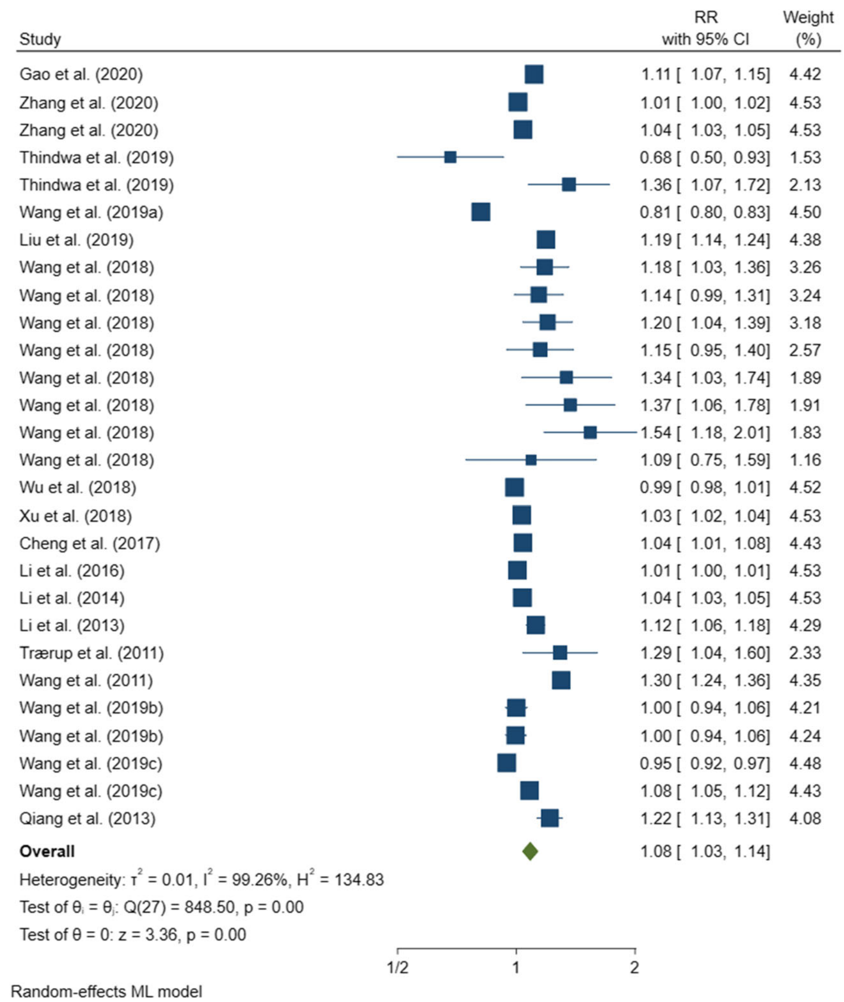


Fig. 3 Forest plot of single-day effects between temperature and ID incidence

on infectious diarrhea caused by the virus were included in the study. The results showed that the relationship between the increase in temperature and the ID of the virus infection was not significant. This is similar to that in the studies of Jagai et al. and Levy et al.; there was no positive relationship between rotavirus infection and temperature found (Jagai et al. 2012; Levy et al. 2009).

This study is a meta-analysis to investigate the impact of temperature increase on ID, which would help to further understand the relationship between meteorological factors and intestinal infectious diseases, but the limitations should be acknowledged. First, most of included studies use ecological study methods, so ecological fallacies in the studies might be unavoidable. The behavioral and demographic factors may affect the relationship (weakened or enhanced) (Pitzer et al. 2011) between the detected ambient temperature and infectious diarrhea. This may require further research in related fields. However, the duration of these studies is often several years or even longer and therefore does not affect the evaluation of ID's long-term trends (Jelinski and Wu 1996; Zhang et al. 2020).

Second, the inability of the diarrheal disease reporting system to capture all cases in practice, which does challenge the conclusions of the study. As a systematic review and meta-analysis study, it is difficult for us to resolve the potential selection bias in the included study. However, we report the quality assessment of the included studies to reflect these potential biases.

Third, most of the studies included in this meta-analysis occurred in southern China, northern China, and a few other countries. Although various temperature zones are involved, the studies in European and American countries are still lacking. The incidence of infectious diarrhea in these countries is also considerable (Shane et al. 2017), and further studies in these countries may further complete our conclusions in the future.

Fourth, some studies have found that various meteorological factors such as temperature, relative humidity, rainfall, and sunshine hours may also jointly affect the risk of ID (Liu et al. 2018). This study did not consider the correlation between various meteorological factors, which requires further research in the future.

Table 2 Cumulative effect of temperature increase and ID incidence

Diarrhea group	Subgroup	Number of studies	RR	95% effect interval		Heterogeneity (I^2)
Bacillary dysentery						
All studies		13	1.85	1.48	2.3	99.74%
Region	China	1	1.02	1.01	1.02	-
	Northern China	9	2.24	1.83	2.73	55.57%
	Southern China	3	1.43	1.04	1.96	95.33%
Temperature increase (°C)	1	2	1.02	1.01	1.02	0.01%
	>10	6	2.18	1.63	2.9	69.80%
	>5	5	2	1.63	2.44	56.54%
Lag days (day)	<10	2	1.29	0.96	1.75	99.71%
	>10	9	2.16	1.61	2.9	80.85%
	>20	2	1.72	1.35	2.19	74.04%
Other diarrhea						
All studies		11	1.18	0.59	2.34	99.75%
Region	China	2	1.26	0.83	1.91	96.70%
	Northern China	3	3.85	1.94	7.64	86.89%
	Southern China	6	0.64	0.27	1.52	99.78%
Temperature increase (°C)	>10	6	0.98	0.58	1.67	99.58%
	>20	4	1.54	0.29	8.23	98.09%
	>5	1	1.43	1.05	1.95	-
Lag days (day)	<10	2	1.14	1.11	1.18	6.00%
	>10	1	7.73	4.25	14.05	-
	>20	8	0.95	0.42	2.15	99.07%
Rotavirus diarrhea						
All studies		4	1.04	0.91	1.18	98.63%
Cholera						
All studies		1	1.05	1.04	1.06	-
Typhoid						
All studies		1	1.14	1.04	1.25	-

Table 3 Single-day effect of temperature increase and ID incidence

Dysentery group	Subgroup	Number of studies	RR	95% effect interval		Heterogeneity (I^2)
Bacillary dysentery						
All studies		17	1.1	1.06	1.15	98.58%
Region	Northern China	11	1.17	1.1	1.25	19.53%
	Southern China	6	1.03	1.02	1.05	90.29%
Temperature increase (°C)	1	8	1.05	1.02	1.08	98.29%
	>1	5	1.18	1.14	1.23	0.00%
	>10	4	1.36	1.18	1.57	0.00%
Lag days (day)	0	14	1.1	1.05	1.15	97.94%
	>1	3	1.1	1.01	1.2	91.56%
Cholera						
All studies		2	1.07	0.92	1.25	58.60%
Typhoid						
All studies		3	1.09	0.79	1.52	88.36%
Other diarrhea						
All studies		6	0.99	0.91	1.07	97.32%

Conclusions

This meta-analysis provided a comprehensive evidence to identify the risk of ID incidence associated with temperature. The results suggest the ambient temperature is closely related to the incidence of ID. Relevant departments should pay attention to the impact of temperature on infectious diarrhea diseases and be prepared to prevent key meteorological diseases.

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Availability of data and materials Not applicable.

Author contribution M.L.: data curation, writing, original draft preparation, software. X.D.: conceptualization, original draft preparation, methodology. Y.W.: data curation and writing—reviewing. Y.S.: supervision, writing—reviewing and editing. All authors read and approved the final manuscript.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication There is no conflict of interest that exists in this manuscript, and it is approved by all authors.

Competing interests The authors declare no competing interests.

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