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Research article

The effect of temperature on infectious diarrhea disease: A systematic review

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ABSTRACT

This study aimed to ascertain the delayed effects of various exposure temperatures on infectious diarrhea. We performed a Bayesian random-effects network meta-analysis to calculate relative risks (*RR*) with 95 % confidence intervals (95 % CI). The heterogeneity was analyzed by subgroup analysis. There were 25 cross-sectional studies totaling 6858735 patients included in this analysis, with 12 articles each investigating the effects of both hyperthermia and hypothermia. Results revealed that both high temperature (RRsingle = 1.22, 95%CI:1.04–1.44, RRcum = 2.96, 95% CI:1.60–5.48, $P < 0.05$) and low temperature (RRsingle = 1.17, 95%CI:1.02–1.37, RRcum = 2.19, 95%CI:1.33–3.64, $P < 0.05$) significantly increased the risk of infectious diarrhea, while high temperature caused greater. As-sociations with strengthening in bacillary dysentery were found for high temperatures (RRcum = 2.03, 95%CI:1.41–3.01, $P < 0.05$; RRsingle = 1.17, 95% CI:0.90–1.62, $P > 0.05$), while the statistical significance of low temperatures in lowering bacterial dysentery had vanished. This investigation examined that high temperature and low temperature were the conditions that posed the greatest risk for infectious diarrhea. This research offers fresh perspectives on preventing infectious diarrhea and will hopefully enlighten future studies on the impact of temperature management on infectious diarrhea.

1. Introduction

Diarrhea is the primary symptom of infectious diarrhea (ID), and intestine infectious disease has been widely brought on a number of pathogens including bacteria, viruses, fungi, and parasites. (Zhang et al., 2017). In general, it refers to intestinal diseases brought on by microorganisms, such as Class A cholera, Class B bacterial and amoebic dysentery, typhoid and paratyphoid fever, and Class C infectious diarrhea. In China, bacillary dysentery (BD) result in Shigella flexneri and other infectious diarrhea (OID) induced by a variety of bacteria are most common[1,2]. The National Health Commission's Statistical Bulletin on the Development of China's

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Health Cause in 2021[3] revealed that bacillary dysentery is still a significant national public health issue, although the number of cases has significantly decreased from 1.3 million in 1991–50403 in 2021, and provided information on the morbidity and mortality of Class C infectious diseases in that year, OID's incidence and death toll came in second among Class C infectious diseases, which is a major factor in the poor health and loss of life of Chinese citizens.

Infectious diarrhea is spread through fecal-oral transmission, which is influenced by a number of factors, including temperature and environmental changes, in addition to factors including population density, access to healthcare, personal habits, and other factors [4,5]. Although the findings from many research are inconsistent, some have shown that infectious diarrhea and temperature are connected. As an illustration, in East China[6], using the daily average temperature of 18 °C(P50) as reference, the risk of norovirus infection reduced with the increase in temperature, and the daily average temperature below 0°Cwas a risk factor for norovirus infection. In North China [7],research showed that the extreme temperatures can significantly increase the risk of bacillary dysentery, regarding the median average temperature. In Malawi, the investigator [8] found that the temperature lag relationship showed a bimodal pattern for typhoid fever. Taking the monthly average temperature (23 °C) as the reference temperature, the risk of typhoid fever increased at lower and higher temperatures. Previous research has shown that the incidence of infectious diarrhea is affected differently by various temperatures.The mechanism behind the connection between temperature and infectious diarrhea remains unclear, but there were some potential etiologies and meteorological explanations. First, the temperature may directly or indirectly affect the replication and survival of pathogens that cause diarrhea [9]. Infectious diarrhea, such as that caused by norovirus and rotavirus, is frequent in children during the winter and spring. Because temperatures are favorable for the development and propagation of viruses throughout the winter and spring seasons, and temperature variations can cause difficulties with the body's immunological function, it is easier to catch viral infectious diarrhea. However, bacteria and protozoa thrive in warm climates [10], bacterial infectious diarrhea caused by Salmonella, Shigella, Vibrio parahaemolyticus, Escherichia coli, and *Staphylococcus aureus* is often prevalent in the summer and fall. , The combination between climatic elements and variations in social, sanitary, and sanitation status between urban and rural areas may explain why the effect of temperature on raised diarrhea risk is more severe in rural than in urban settings [11]. Third, eating habits and hygiene practices may change according to the weather. On warmer days, for instance, there is a larger need for water, which may encourage the spread of germs and other infections. Additionally, warm weather increases the likelihood of food spoilage, which increases the risk of infectious diarrhea and food poisoning. Second, geographical differences in temperature and geography have a direct impact on the infectiousness of diarrhea.

Currently, only a small number of domestic studies on temperature and infectious diarrhea are carried out across different provinces or cities. In order to ascertain the effect of temperature on the incidence of infectious diarrhea and to offer baseline data and a scientific justification for the prevention and control of infectious diarrhea, this study conducted a network meta-analysis of published studies.

2. Methods

This review develops a flawless retrieval approach in exact compliance with PRISMA's [12,13], specifications (Preferred reporting items for systematic review and meta-analyses).

2.1. Search strategy

PubMed, Web of Science, the China Knowledge Network Journal Database (CNKI), and the Wan fang Database were all thoroughly searched by two researchers. Before December 1, 2022, a thorough and organized collection of all prior domestic and international publications on the topic of climatic factors and ID incidence was made. The search was conducted using the thorough keywords ("infectious diarrhea" or "cholera" or "bacillary dysentery" or "amoebic dysentery" or "typhoid fever") and ("temperature" or "environmental temperature" or "meteorological factor"). To look for published publications, relevant Chinese technical phrases for the Chinese databases were employed (the detailed search strategy is shown in Appendix file1).

2.2. Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) When there are numerous articles in the same study population or area, choose the one with the longest survey duration and big sample size; (2) The study provides a relative risk (RR) and a 95 % confidence interval (CI) of the connection between temperature and infectious diarrhea; (3) The research period is at least one year long.

These were the requirements that were exclusive: (1) Literature that does not fit the criteria for inclusion; (2) Literature that is published frequently, is of poor quality, and contains insufficient information; (3) Reviews, meta-analyses, systematic reviews, lecture notes, conference proceedings, animal experiments, etc. (4) It is impossible to extract the relative risk data (RR) or there are insufficient data to calculate the relative risk (RR).

2.3. Study selection

Note Express document management software is used to manage document retrieval records. The publications were initially examined by the two researchers independently based on the titles; if in question, these articles were included to the abstract review stage. All of the articles that had been chosen in the first step were examined by two different researchers in the second stage. Two independent researchers independently assessed the abstract of the remaining publications using preset inclusion criteria in the final step. If required, get in touch with the primary researcher by phone or email. If there are any disagreements, they must be settled through dialogue or outside consultation.

2.4. Outcomes and data extraction

The following information is included in the extraction: (1) the study's basic facts, such as the research topic, the first author, the study location, the duration of the study, and the sample size; (2) the study site's baseline characteristics and the temperature studied; (3) the major components of the risk assessment for bias; and (4) the effect of the temperature on infectious diarrhea disease and the outcome indicators in question.

Extraction method: According to the criteria outlined by Atkinson et al. (2012), we choose lag days for analysis in our study [14]. The analysis is based on this effect if an article's results are based on a one-day lag. If an article is based on several lag days, we choose the outcomes for the analysis based on the following standards.

(1) Only extract the data for single lag days.
(2) Only single pollutant model data are selected.
(3) If multiple single-day impacts are mentioned in the article, pick the most significant or statistically significant one.
(4) Instead of using the stratified effect values, the total effect values listed in the text were chosen.
(5) The longest research period was chosen in cases when various studies included the same city with ID incidents related to air pollution.

2.5. Quality and risk of bias assessment

Strengthening the Reporting of Observational Studies in Epidemiology [15] (STROBE) statement (http://strobe-statement.org) sets the scoring criteria for cross-sectional studies. Finally, we only included articles with a STROBE score of 15–20 to ensure that all included studies were of medium or high quality.

2.6. Statistical analysis

We initially used the random effects model to run a pairwise meta-analysis for each comparison. The relative risk of disease in a pair of comparisons was computed with a 95 % Confidence Interval (CI). Network meta-analysis calculations were performed using the

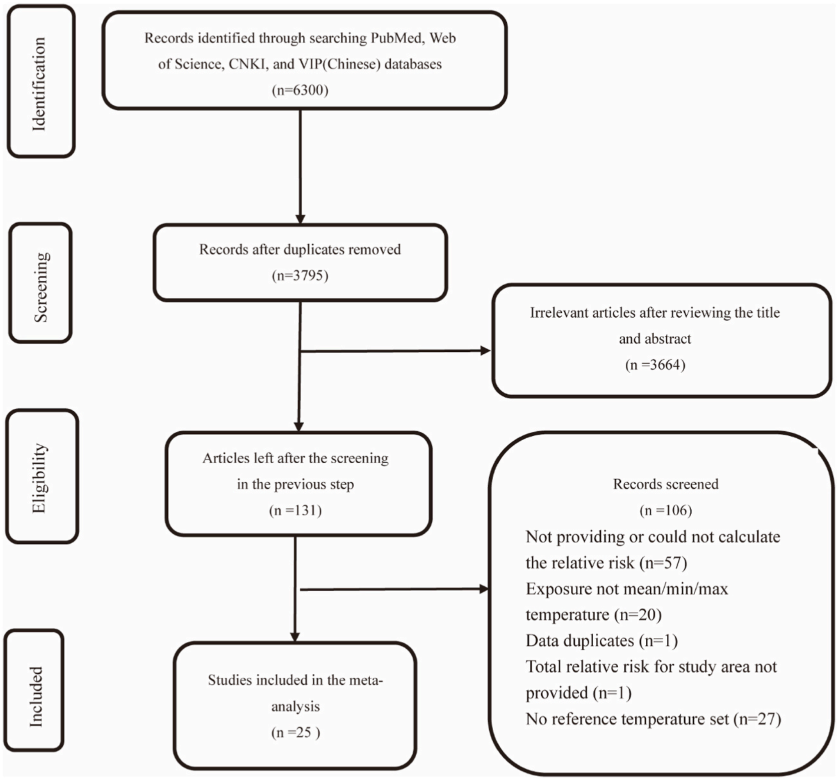

Fig. 1. Flow chart of study search progress.

Table 1
Characteristics of the studies included in the analysis and summary literature quality assessment.

ID	Study	City	time	sample	method	illness	Maximum lag days	Single-day/ cumulative effect	Outcome measures reported	STROBEVscore
1	Ai, 2018(Siqi 2018)	Cheng du	2005–2012	52699	DLNM	OID	21	Single day & cumulative effect	When the temperature is −1.40 °C, there is a maximum protective effect, and the RR value is 0.29 (95%CI: 0.21–0.40); when the temperature is 29.90 °C, there is a maximum harmful effect RR was 3.21 (95%CI: 2.54–4.07).	22
2	Liu, 2019(Liu 2019)	Chong qing	2009–2016	68855	DLNM	BD	30	Single day & cumulative effect	The lowest risk of BD morbidity temperature value was used as a reference value. When the mean daily temperature was 36.5 °C (lagged by 0 days) the RR value was the largest, 1.11 (95 % CI: 1.07 to 1.14)	23
3	Wang, 2018a (Wang et al., 2018)	Lan zhou	2008–2015	23108	DLNM	BD	14	Cumulative effect	Specifically, the RR of rotavirus and norovirus hospitalization was 55.8 % (95 % CI 0.37–0.84),47.3 % (95 % CI 0.29–0.78) respectively, at cumulative lags 0–10 and 0–7 days, at 30 °C (97th percentile, relative to 17 °C).	19
4	Wang, 2018b (Wang et al., 2018)	Hong Kong	2002–2011	8039	DLNM	OID	30	Single day effect	Using the lowest incidence risk temperature of 17 °C as the reference temperature, when the temperature was 32.0 °C with a lag of 0 d, the RR value was 1.37 (95 % CI: 1.11 to 1.72).	19
5	Thindwa, 2019 [8]	Malawi	2000–2015	2648	DLNM	typhoid	8 months	Cumulative effect	The peak RR value was 1.17(95 % CI: 1.11–1.23) at the 95th percentile of temperature, and the peak RR value was 0.89(95%CI: 0.85–0.92) at the 5th percentile of temperature compared with the 50th percentile as reference	21
6	Wang, 2019a (Wang et al., 2019)	Guang zhou	2006–2017	167691	DLNM	OID	21	Single day affect	Compared to the reference (23 °C), At lower temperatures (19 °C), peaking at lag 2 (RR 1.47, 95%CI [1.08–2.01]), while at higher temperatures peaking at lag 5 (RR 1.36, 95%CI [1.08–1.73]).	21
7	Wang, 2019b (Wang et al., 2019)	Zhe Jiang	2014–2016	301593	DLNM	OID	30	Single day & cumulative effect	The cumulative RR values for 30 d were highest at 6.2 °C (RR = 2.298, 95 % CI = 1.527–3.459), using the temperature corresponding to the lowest risk of other infectious diarrhea in the population (16.7 °C) as the reference temperature	21
8	Zhang, 2019 (Zhang 2019)	Beijing	2014–2016	122678	DLNM	OID	21	Cumulative effect	The cumulative RR values for 30 d were highest at 3.6 °C (RR = 4.820, 95 % CI = 2.857–8.132), using the temperature corresponding to the lowest risk of other infectious diarrhea in the population (21 °C) as the reference temperature, and the cumulative RR values at P95 (30 °C) was 1.435 (95 % CI = 1.054–1.953)	26
9	Hao, 2019(Hao et al., 2019)	An hui	2010–2015	19959	DLNM	BD	4 weeks	Single day & cumulative effect	The MF values with the lowest risk were used as references, the largest separate effects occurred at the minimum level, and the estimated risk ratios (RRs) was 1.23 (95 % CI, 1.20–1.25)	22
10	Hu, 2019(Hu et al., 2019)	Southeast coast	2005–2013	2308988	DLNM	ID	3	Cumulative effect	Summarized by RRs at the 90th percentile versus the reference of 1.42 (95 % CI: 1.16, 1.75) and 2.02 (95 % CI: 1.76, 2.32), for children b5 and population of other ages, respectively, compared with the 50th percentile (P50) of weekly mean temperature (17 °C) as the reference.	18

(*continued on next page*)

Table 1 (*continued*)

ID	Study	City	time	sample	method	illness	Maximum lag days	Single-day/ cumulative effect	Outcome measures reported	STROBEVscore
11	Wang, 2020[7]	China	2014–2016	2715544	DLNM	OID	30	Cumulative effect	Using 0 °C as the reference temperature, the cumulative risk of other infectious diarrhea was greatest at a mean temperature of 26 °C, 4.616 (95%CI: 3.164–6.735); and the minimal cumulative risk of morbidity at a mean temperature of −14 °C was 0.565 (95 % CI: 0.395–0.806)	21
12	Gao, 2020a (Gao 2020)	Xi Shuang Ban Na	2005–2017	9129	DLNM	typhoid	21 weeks	Cumulative effect	Using the 50th percentile temperature as the reference temperature, the cumulative effects of low-temperature 5th percentile was RR: 0.56(0.39–0.80), the cumulative effects of high-temperature 95th percentile was RR 1.64(1.37–1.94)	18
13	Gao, 2020b [39]	Wuxi	2013–2018	835	DLNM	OID	21	Single day & cumulative effect	The temperature values with the lowest risk were used as references to estimate the effects (RR), which were 23 °C for diarrhea-like illness cases. The risk of P reached its highest at the 5th percentile of temperature, which was −6 °C (RR = 2.08, 95 % CI: 1.55–2.78)	20
14	Hao, 2021(Hao et al., 2022)	Guang dong	2014–2016	353061	DLNM	OID	35	Cumulative effect	The peak RR value was 1.732 (95 % CI: 1.589–1.881) at the 81st percentile of temperature, compared with the 50th percentile as a reference	21
15	Huang,2021 (Huang et al., 2021)	Jiangsu	2015–2019	3147	DLNM	OID	21	Single day effect	The Maximum RR of Tmax on infectious diarrhea cases in the age group “age≤2” was 1.04 (95 % CI: 1.03–1.05), while in the age group “2<age≤5” was 1.02 (95 % CI: 1.00–10.6).	20
16	Wang, 2021a [7]	Jilin	2008–2018	14532	DLNM	BD	7	Single day & cumulative effect	For the low temperature, RR reached the maximum at lag20 (RR = 1.046, 95 % CI: 1.035–1.058), and for the high temperature, RR reached the maximum at lag15 RR 1.006(0.998–1.014), with the 50th percentile (P50) of daily mean temperature as the reference	22
17	Liu, 2021 (LiuMeng 2021)	Jiangjin	2017–2019	3456	DLNM	OID	7	Single day & cumulative effect	The temperature of 15.5 °C corresponding to the minimum CRR value for infectious diarrhea was used as the reference value. The RR value was 1.276 (95 % CI:0.975–1.670) at a lag of 0 d from 4.5 °C, Within 7 days of lag, the CRR value at 4.5 °C is the largest, which is 2.016 (95%CI 1.370–2.968)	19
18	Wang, 2021b [42]	North China	2014–2016	101584	DLNM	BD	7	Single day effect	The risk of bacillary dysentery peaked when the lag period was day 3. Using the median (14.7 °C) as the reference temperature, the value for the RR of bacillary dysentery was 1.05 (95 % C/ :1.03–1.07) when the temperature was at P75 (22.4 °C).	22
19	Zhou, 2021[6]	Shanghai	2012–2019	21148	DLNM	OID	7	Cumulative effect	The cumulative effects of high temperatures 95th percentiles [27 °C]) on bacillary dysentery was 2.19 (95 % CI: 1.51–3.18),	21
20	Wang, 2021c [7]	Shao xing	2014–2016	42480	DLNM	OID	30	Single day & cumulative effect	Compared with 0 °C, the overall cumulative RRs of extreme hot and extreme cold were 1.88 (95 % CI 1.51–2.34) and 0.70 (95%CI 0.56–0.86)	18
21	Wang, 2021d [7]	Beijing-Tianjin-Hebei	2010–2012	29639	DLNM	BD	21	Single day & cumulative effect	Taking the median temperature (18 °C) as the reference temperature, the total population had the greatest effect when the low temperature was delayed by 2 days (RR = 1.15, 95 % CI: 1.02 ~	19

(*continued on next page*)

Table 1 (*continued*)

ID	Study	City	time	sample	method	illness	Maximum lag days	Single-day/ cumulative effect	Outcome measures reported	STROBEVscore
									1.29), the cumulative effects of low temperature(-6 °C) was RR = 3.06, 95 % CI: 1.49–6.30.	
22	Chang,2022 (Chang et al., 2022)	Beijing-Tianjin-Hebei	2014–2019	147001	DLNM	BD	7	Single day effect	The lag effect, based on a reference temperature of 10 °C, when the daily mean temperature was 28 °C, the number of BD cases on lag 5d increased by 16 %(RR = 1.16, 95 % CI: 1.12–1.21), when the daily mean temperature was −7 °C, the RR was 0.835 (0.751–0.927)	21
23	Su, 2022[35]	Hebei	2017–2020	231008	DLNM	OID	30	Cumulative effect	Taking the median temperature (18 °C) as the reference temperature. The cumulative RR was greatest when the average daily temperature was −5.4 °C (RR = 3.33, 95 % CI 2.22–5.01), and the cumulative RR at the highest temperature was 1.87, 95 % CI 1.37–2.56	21
24	Wang, 2022[1,2]	North China	2014–2016	101213	DLNM	BD	7	Cumulative effect	Using the median of the mean temperature and relative humidity as a reference. The cumulative risk of bacillary dysentery was highest at 1.74 (95 % CI = 1.38 to 2.19) when the mean temperature was 31.5 °C	20
25	Wu, 2022(Wu et al., 2022)	Lanzhou City	2010–2019	8700	DLNM	BD	3 weeks	Cumulative effect	The cumulative effect of high temperature (P95) was greatest at a lag of 3 w, with a cumulative relative risk (RR) of 1.52 (95 % CI: 1.12–2.04), The cumulative relative risk (RR) with low temperature (P5) was 0.58 (95 % CI: 0.41–0.81).	20

DLNM: Distributed lag non-linear model; ID: infectious diarrhea BD: bacillary dysentery; OID: other infectious diarrhea.

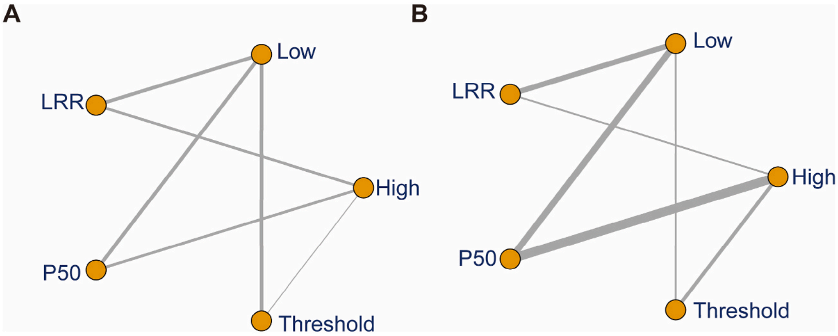

Fig. 2. Network meta-analysis maps of the studies examining the effect of temperature on infectious diarrhea (A) Network diagram of the single-day effect of temperature on infectious diarrhea (B) Network diagram of the cumulative effect of temperature on infectious diarrhea.
High: ambient temperature above the 75th percentile; Low: ambient temperature below the 25th percentile; P50: the percentile for ambient temperature; LRR: the minimal risk temperature determined by a time series analysis of the examined diseases and ambient temperature; Threshold: the temperature above which the risk of ID increases noticeably.

statistical software package R 4.2.1, and bayesian network meta-analysis was performed using gemtc package. The heterogeneity between different studies was assessed on the basis of the I-square test.

To demonstrate that all therapies can be directly compared, create a network evidence map in which each node represents a distinct intervention, and each connection indicates the number of studies on the two interventions; the more studies that are included, the thicker the connection. The "node analysis model" is used to examine the discrepancy when there is a closed loop in the reticular evidence map. Node splitting and the Bland Altima technique were used to confirm the homogeneity and consistency assumptions.

To assess the model's convergence, a trajectory map, density map, and Brooks-Gelman-Rubin diagnostic map are utilized. Track diagram is shown in the iterative operation chain of Markov Chain Monte Carlo chain (MCMC) wave process diagram, and the density map is a pattern of posterior parameter values, and if the curve tends to resemble a normal distribution and the Bandwidth value tends to zero and reaches stability, the model fully – connected. The prospective scale reduction factor (potential scale reduced factor, PSRF) is used in the Brooks-Gelman-Rubin diagnostic map evaluation method to assess the model's convergence. If the PSRF value is in the range of 1 and 1.05, it indicates that the analysis model is broadly stable; if it is not, it is required to keep adding operations to the model.

The surface under the cumulative ranking curve (SUCRA) is calculated and drawn based on the Bayesian method to directly reflect the relative advantages and disadvantages of different temperatures on ID. The value range of SUCRA is 0~1, and the higher the SUCRA value is, the smaller the influence is. The qualitative exam and quantitative test make up the publishing bias test. Drawing a contour-enhanced funnel plot is used to accomplish the former, and the Egger method is used to accomplish the latter [16]. If the test results indicate a publishing bias, the bias is rectified using the clipping procedure before recombining the effect value.

3. Results

A total of 6300 articles were searched in the database, 2321 articles from PubMed, 2104 articles from Web of Science, 1166 pieces from China Knowledge Network, 709 articles from Wanfang. After all, a total of 3795 articles in total were qualified for titles/abstracts

Table 2
Comparison of temperatures. Relative hazard (95 % CI) Temperature per row compared to temperature per column.

Comparison of temperatures. Relative hazard (95 % CI) Temperature per row compared to temperature per column					
Single day effect					
	High	Low	LRR	P50	Threshold
High		0.96 (0.80, 1.15)	**0.82 (0.69, 0.96)**[a]	0.90 (0.75, 1.06)	0.95 (0.76, 1.20)
Low	1.05 (0.87, 1.24)		**0.86 (0.73, 0.99)**[a]	0.94 (0.80, 1.10)	0.99 (0.81, 1.22)
LRR	**1.22 (1.04, 1.46)**[a]	**1.17 (1.01, 1.38)**[a]		1.10 (0.91, 1.34)	1.16 (0.92, 1.48)
P50	1.11 (0.94, 1.33)	1.06 (0.91, 1.26)	0.91 (0.75, 1.10)		1.05 (0.83, 1.35)
Threshold	1.05 (0.84, 1.32)	1.01 (0.82, 1.24)	0.86 (0.67, 1.09)	0.95 (0.74, 1.20)	
Cumulative effect					
	High	Low	LRR	P50	Threshold
High		0.74 (0.44, 1.25)	**0.34 (0.18, 0.62)**[a]	0.63 (0.42, 0.92)[a]	0.91 (0.51, 1.64)
Low	1.35 (0.80, 2.25)		**0.46 (0.27, 0.75)**[a]	0.85 (0.54, 1.32)	1.23 (0.64, 2.36)
LRR	**2.96 (1.60, 5.48)**[a]	**2.19 (1.33, 3.64)**[a]		**1.85 (1.01, 3.41)**	**2.68 (1.25, 5.80)**[a]
P50	**1.60 (1.08, 2.36)**[a]	1.18 (0.76, 1.86)	**0.54 (0.29, 0.99)**[a]		1.45 (0.76, 2.78)
Threshold	1.10 (0.61, 1.98)	0.82 (0.42, 1.57)	**0.37 (0.17, 0.80)**[a]	0.69 (0.36, 1.32)	

[a] $p < 0.05$.

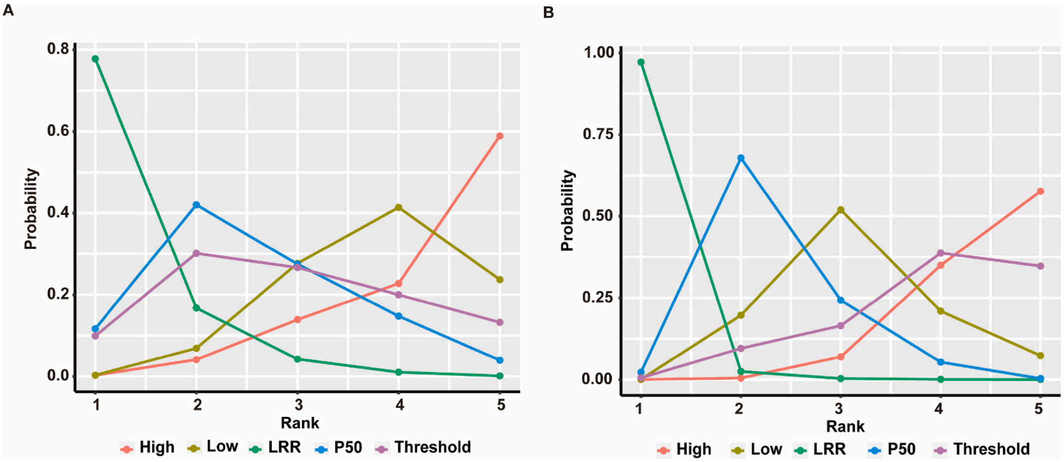

Fig. 3. The rank probability of temperatures using SUCRA-score in networks A, and B. (A)Ranking of the single-day effect of temperature on ID (B) Ranking of the cumulative effect of temperature on ID.

screening after removing duplicates. Following review by title and abstract, 131 studies progressed to full manuscript review of these, 20 publications did not offer mean, maximum, or lowest temperatures, 27 research did not include reference temperature ranges, one article repeated time, and one journal did not include total impact estimates for the study area. 57 papers were also missing RR values. Finally, the study comprised a total of 25 papers. Fig. 1 depicts the flow chart for publishing in the literature.

3.1. *Characteristics of included articles*

Time series research that is included is summarized in Table 1. The research period was from 2000 to 2020, and the chosen articles were published between 2018 and 2022. Using a distributed lag nonlinear model (DLNM), all twenty-five investigations assessed how the environment's temperature affected infectious diarrhea. Twenty-five studies totaling 6858735 people were examined. Two (8 %) of them examined the effect of ambient temperature on typhoid, thirteen (52 %) looked at the impact of ambient temperature on OID, nine (36 %) examined the effect of ambient temperature on BD, and one investigated at the impact of ambient temperature on ID without focusing at the kind of ID. Nine studies (36 %) reported both the single-day lag effect and the cumulative lag effect of temperature on ID, while five studies (20 %) reported only the single-day lag effect of ambient temperature on ID, eleven studies (44 %) reported only the cumulative lag effect of ambient temperature on ID.

We used the STROBE statement assessment criteria to rate the quality of each study that was a part of this Network-Meta analysis. The 25 articles that made up this research's analysis ranged in quality from 18 to 22, which is a relatively high grade (the detailed search strategy is shown in Appendix file2).

3.2. *Characteristics of temperature*

To evaluate the effects of high temperature (ambient temperature above the 75th percentile) and low temperature (ambient temperature below the 25th percentile), we utilized the three reference temperatures listed below: P50: the percentile for ambient temperature; LRR: the minimal risk temperature determined by a time series analysis of the examined diseases and ambient temperature; Threshold: the temperature above which the risk of ID increases noticeably. Threshold, the LRR, and the P50 were the three reference temperatures utilized in five research (20 %), seven studies (28 %) and eleven studies (52 %) respectively. In these articles, the median P50 was 16.93 °C (IQR13.75°C-22.55 °C), the median Threshold was 10 °C (IQR 0°C-16.85 °C), and the median LRR was 17 °C (IQR 15.5°C-23 °C).

Table 3
SUCRA value of the effect of temperature on infectious diarrhea.

Single day effect		Cumulative effect	
temperature	SUCRA%	temperature	SUCRA%
High	17.65	High	12.51
Low	34.99	Low	46.05
LRR	93.26	LRR	99.19
P50	63.01	P50	66.62
Threshold	41.09	Threshold	25.63

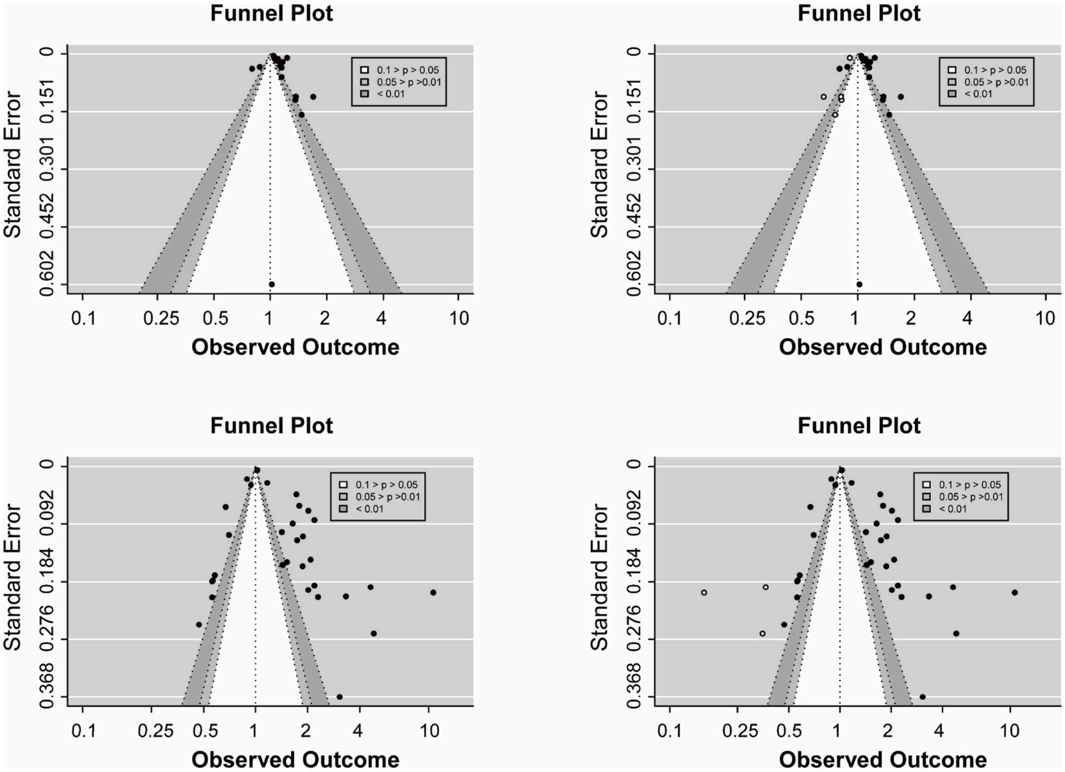

Fig. 4. Contour-enhanced funnel plot comparing the effect of temperature on infectious diarrhea (A): Single-day effect (B): Single-day effect combined with "cut-and-complement method" (C): Cumulative effect (B): Cumulative effect combined with "cut-and-complement method".

3.3. *Temperature-related effects of infectious diarrhea*

In total, 25 studies were included. With the proper instructions, their effect size (lnRR) and standard error (SE lnRR) values were computed. The "mtc.network" command from the "gemtc" package of R software was used to create the network of treatments. In this network meta-analysis, the effects of temperature on infectious diarrhea involved two networks, network A and network B (Fig. 2).

After literature collation, 14 single-day impacts involving 1201089 patients with infectious diarrhea were included in Network A. In Fig. 2(A), the network diagram was also displayed. The statistical heterogeneity in this network, as stated by the random effects model, was 11.0 %. The results of the network meta-analysis performed on this network are shown in Table 2. When the temperature corresponding to the lowest risk of developing ID (LRR) was used as the reference temperature, analysis of the single-day lagged effect of temperature on ID revealed that both high and low temperatures significantly increased the relative risk of ID ($P < 0.05$), with high temperatures causing an increased relative risk of infectious diarrhea (RR = 1.22, 95%CI:1.04–1.46), and low temperatures can also increase the relative risk of infectious diarrhea (RR = 1.17, 95%CI:1.01–1.38). The rest of the differences between the pairwise comparisons were not statistically significant (P > 0.05). The single-day lag effects of various temperatures on ID were ranked in the following order: High > Low > Threshold > P50>LRR (Fig. 3(A)). These temperatures' respective SUCRA scores were 17.65 %, 34.99 %, 41.09 %, 63.01 %, and 93.26 % (Table 3).

Twenty cumulative effects involving 5657646 patients were included in Network B. In Fig. 2(B), the network diagram was also displayed. The statistical heterogeneity in this network, as stated by the random effects model, was 6.0 %. The results of the network meta-analysis done on this network are shown in Table 2. According to the cumulative effects of temperature on ID, both high and low temperatures considerably raised the relative risk of ID ($P < 0.05$), whereas the median ambient temperature (P50) and threshold temperature (Threshold) significantly reduced the relative risk of ID ($P < 0.05$). The high temperature increased the risk of ID (RR = 2.96, 95%CI:1.60–5.48); low temperature increased the risk of ID (RR = 2.19, 95%CI:1.33–3.63); P50 increased the risk of ID (RR = 1.85, 95%CI:1.01–3.41); Threshold increased the risk of ID (RR = 2.68, 95%CI:1.25–5.80). The single-day lag effects of various temperatures on ID were ranked in the following order: High > Threshold > Low > P50>LRR (Figur3B). These temperatures' respective SUCRA scores were 12.51 %, 25.63 %, 46.05 %, 66.62 %, and 99.19 % (Table 3).

3.4. *Assessment of bias and sensitivity analysis*

Using Egger's test, the publication bias was examined. The findings suggest that both single-day effects and cumulative effects may be discovered to potential publication bias ($P < 0.05$). The cut-and-complement method of analysis then reveals that the

Table 4
Subgroup Analysis of the lag effects of Air temperature on ID.

Outcome	Initial Result	Disease Type		Lag Length		
	RR(95%CI)	RR(95%CI)		RR(95%CI)		
		OID	BD	≤15day	15~30day	≥30day
Single day effect						
Compare with Threshold						
High	1.08 (0.88, 1.33)	1.03 (0.58, 1.78)	1.16 (0.78, 1.72)	1.05 (0.69, 1.57)	1.43 (0.92, 2.21)	–
Low	1.04 (0.88, 1.24)	1.04 (0.68, 1.58)	0.88 (0.59, 1.31)	1.06 (0.76, 1.49)	1.04 (0.81, 1.32)	–
LRR	0.89 (0.71, 1.09)	0.87 (0.53, 1.38)	1.00 (0.59, 1.57)	0.69 (0.42, 1.15)	0.87 (0.65, 1.19)	–
P50	0.98 (0.78, 1.21)	1.02 (0.63, 1.66)	1.11 (0.64, 1.94)	0.96 (0.59, 1.57)	1.30 (0.90, 1.85)	–
Compare with P50						
High	1.10 (0.94, 1.31)	1.01 (0.70, 1.43)	1.05 (0.71, 1.55)	1.09 (0.71, 1.67)	1.10 (0.85, 1.42)	1.21 (0.95, 1.79)
Low	1.06 (0.92, 1.25)	1.02 (0.80, 1.31)	0.79 (0.40, 1.57)	1.10 (0.72, 1.72)	0.80 (0.62, 1.04)	1.13 (0.95, 1.56)
LRR	0.91 (0.75, 1.10)	0.85 (0.62, 1.15)	0.90 (0.53, 1.41)	0.72 (0.42, 1.25)	0.67 (0.49, 0.93)[a]	1.10 (0.85, 1.64)
Compare with LRR						
High	1.22 (1.04, 1.44)[a]	1.18 (0.83, 1.70)	1.17 (0.90, 1.62)	1.51 (0.96, 2.36)	1.63 (1.08, 2.44)[a]	1.10 (0.88, 1.39)
Low	1.17 (1.02, 1.37)[a]	1.20 (0.97, 1.51)	0.88 (0.49, 1.72)	1.53 (0.98, 2.42)	1.19 (0.98, 1.41)	1.04 (0.76, 1.38)
Compare with Low						
High	1.04 (0.87, 1.23)	0.99 (0.68, 1.42)	1.32 (0.76, 2.31)	0.99 (0.64, 1.48)	1.37 (0.95, 1.98)	1.06 (0.78, 1.49)
Cumulative effect						
Compare with Threshold						
High	1.10 (0.61, 1.98)	0.92 (0.36, 2.35)	1.78 (1.22, 2.70)[a]	1.35 (0.40, 4.36)	3.13 (1.08, 9.12)[a]	0.51 (0.18, 1.43)
Low	0.82 (0.42, 1.57)	0.89 (0.28, 2.89)	0.74 (0.49, 1.08)	0.97 (0.30, 3.29)	0.83 (0.29, 2.40)	0.47 (0.13, 1.83)
LRR	0.37 (0.17, 0.80)[a]	0.30 (0.08, 1.11)	0.88 (0.55, 1.43)	0.48 (0.07, 3.35)	0.18 (0.04, 0.74)[a]	0.26 (0.07, 0.97)[a]
P50	0.69 (0.36, 1.32)	0.53 (0.16, 1.70)	1.05 (0.69, 1.64)	0.81 (0.22, 2.76)	1.59 (0.53, 4.73)	0.34 (0.10, 1.18)
Compare with P50						
High	1.60 (1.08, 2.36)[a]	1.74 (0.72, 4.17)	1.70 (1.37, 2.12)[a]	1.66 (0.66, 4.33)	1.97 (1.12, 3.50)[a]	1.53 (0.74, 3.10)
Low	1.18 (0.76, 1.86)	1.68 (0.76, 3.80)	0.70 (0.46, 1.00)[a]	1.20 (0.49, 3.38)	0.52 (0.22, 1.21)[a]	1.40 (0.69, 2.91)
LRR	0.54 (0.29, 0.99)[a]	0.57 (0.20, 1.62)	0.84 (0.54, 1.25)	0.59 (0.11, 3.80)	0.11 (0.03, 0.40)[a]	0.78 (0.33, 1.83)
Compare with LRR						
High	2.95 (1.60, 5.48)[a]	3.03 (1.01, 9.11)[a]	2.03 (1.41, 3.01)[a]	2.80 (0.39, 17.96)	17.18 (4.56, 67.49)[a]	1.96 (0.87, 4.43)
Low	2.19 (1.33, 3.64)[a]	2.95 (1.38, 6.28)[a]	0.84 (0.56, 1.19)	2.01 (0.45, 8.87)	4.56 (1.80, 11.93)[a]	1.79 (0.88, 3.80)
Compare with Low						
High	1.35 (0.80, 2.25)	1.03 (0.38, 2.75)	2.42 (1.72, 3.64)[a]	1.39 (0.40, 4.40)	3.77 (1.47, 9.88)[a]	1.09 (0.45, 2.52)

[a] $p < 0.05$.

Table 5
SUCRA value of subgroup analysis of the lag effect of temperature on ID.

Temperature	Initial Result	Disease Type		Lag Length		
		OID	BD	≤15	15~30	≥30
	SUCRA%	SUCRA%	SUCRA%	SUCRA%	SUCRA%	SUCRA%
Single day effect						
High	16.05	40.20	17.32	30.98	6.40	13.19
Low	29.63	34.09	80.11	27.30	56.50	38.86
LRR	92.85	86.50	62.31	94.70	95.08	58.23
P50	60.70	41.27	34.09	52.48	23.79	89.71
Threshold	50.76	47.94	56.17	44.54	68.25	
Cumulative effect						
High	12.51	29.12	0.21	19.25	1.00	36.86
Low	46.05	30.04	95.11	43.36	65.04	41.83
LRR	99.19	95.14	68.05	81.90	99.52	90.55
P50	66.62	70.36	39.25	61.79	30.38	74.01
Threshold	25.63	25.34	47.37	43.47	54.07	6.74

supplementary studies are dispersed in statistically significant locations, demonstrating that there is no publishing bias, and that the asymmetry is not due to publication bias (Fig. 4).

The results vary when the ID effect's temperature analysis is restricted to the study of BD; when it is restricted to the study of OID, the results remain mostly unchanged. Since LRR was employed as the reference temperature, the single-day effect and cumulative effect of air temperature on BD were significantly changed (Table 4), despite the lack of a statistically significant difference ($P > 0.05$). The relative risk of BD was dramatically increased by high temperatures. At the same time, the results did not materially alter when the maximum lag day was changed to within two weeks, within one month, or more than one month. The results of SUCRA were shown in Table 5.

4. Discussion

The published domestic and international research on the impact of temperature on infectious diarrhea from 2000 to 2020 were gathered for this network meta-analysis, and the effect values were merged. The results of this study further confirm significant effects of high temperature ($RR_{\text{single}} = 1.22$, 95%CI:1.04–1.44, $RR_{\text{cum}} = 2.96$, 95%CI:1.60–5.48, $P < 0.05$) and low temperature ($RR_{\text{single}} = 1.17$, 95%CI:1.02–1.37, $RR_{\text{cum}} = 2.19$, 95%CI:1.33–3.64, $P < 0.05$) on infectious diarrhea. High temperature caused greater effect. These studies were thought to be sufficiently homogeneous, however statistical heterogeneity still existed. This could be as a result of discrepancies in the disease type researched and the maximum lag time used.

Numerous studies have demonstrated a direct relationship between the weather and infectious diarrhea, which is easily brought on by microorganisms [17–20]. As we all know, temperature can play a decisive role in the survival conditions of bacteria or viruses. Infectious diarrhea is transmitted mainly through the digestive tract, mainly by the fecal-oral route, and to a lesser extent by individual contact or respiratory droplet transmission, in which the influence of temperature is also particularly important. First, various microorganisms respond differently to changes in temperature, humidity, oxygen, light, and nutrition, which affects how long they can survive and reproduce outside of their host [21,22]. Second, the hosts that the microorganisms are hosted on are affected by climatic circumstances either directly or indirectly [23–25]. Appropriate temperatures cause the expression of pertinent genes in the hosts, which results in a successful host infection [26]. The likelihood of fecal contamination, which is a direct cause of infectious diarrhea, is similarly affected by changes in rainfall and temperature [1,2,27,28]).

In the subgroup analysis of high-quality articles, the detrimental effects of low temperatures on bacterial dysentery (BD) were no longer evident. High temperatures were associated with BD strengthening ($RR_{\text{cum}} = 2.03$, 95%CI:1.41–3.01, $P < 0.05$), whereas the statistical significance of low temperatures in lowering bacterial dysentery had vanished.

The majority of studies have found a link between temperature and BD [29]. According to Wang et al. [7], the total cumulative RR of extremely hot and extremely cold within 7 days lag, compared with 0 °C, was 1.88 (95 % CI: 1.51–2.34) and 0.70 (95%CI: 0.56–0.86), respectively. Every 1 °C increase in temperature caused a 0.78 % increase in the incidence of BD in Wuhan [30]. Every 1 °C rise in temperature increased the number of BD patients in AnHui [31] by 1.58 % (0.46 %–2.71 %). This may be the result of temperature effects on immunity and behavior in high-temperature conditions, such as how high temperatures could alter electrolyte balance and impair immunity [2,32]. The entire process of food preparation, processing, transportation, and storage was impacted by the increase in temperature, which encouraged the rapid reproduction of pathogens and raised the risk of human infection [2,32–34]. The incidence of infectious diseases among individuals was increased by the temperature's effect on BD, either directly or indirectly.

According to the findings of the subgroup analysis, OID risk was raised by both high and low temperatures. In Hebei Province [35], the risk of getting another infectious form of diarrhea increases within 30 days when the daily average temperature was either too high ($RR = 3.33$, 95%CI:2.22–5.01) or too low ($RR = 1.87$, 95%CI:1.37–2.56).

The incidence of OID typically has two peaks. The high-incidence times for viral diarrhea are winter, and spring, but the bacteria and protozoa thrive in warm climates [36–38]. The risk curve of norovirus positive rate increased first and then decreased, reaching the highest at 8 °C (RR = 1.12, 95%CI:0.55–2.28) [39]. To explore the reasons, research [14] proved that temperature was related to the effective reproduction number of rotavirus and that low temperature increases the transmission of rotavirus. While the high-incidence period for bacterial infectious diarrhea is summer [36–38]. In a South African study [40], the number of cases of diarrhea increased by 32 % for every 5 °C increase in weekly maximum temperature ($IRR = 1.32$, 95%CI:1.22–1.41). It may be because high temperature promotes the reproduction of bacteria, prolongs the survival time of bacteria in the environment and contaminated food, and food was prone to spoilage, in addition, the increased demand for drinking water at high temperatures will promote the spread of diarrhea [41–43].

The association between ID and temperature is supported by this study's data. Monitoring this meteorological component will serve as an early warning system for the occurrence and prevalence of ID and as a scientific foundation for implementing ID prevention and control strategies.

5. Limitations

This study has several limitations. Firstly, the papers included in this meta-analysis are heterogeneous. Due to the analysis of regional disparities, estimates in the literature may differ significantly, the majority of the included research were carried out in China. Second, we only looked at the temperature factors that affect the incidence of infectious diarrhea, but other meteorological factors (such humidity and air pressure) may also have an impact and more investigations are needed for further analysis. It is difficult to accurately quantify the correlation between temperature and infectious diarrhea.

6. Conclusions

The relationship between ID and ambient temperature is supported by this study's scientific evidence in the medical field. The network meta-analysis indicates that either an excessively high or an excessively low average temperature raises the risk of ID, whereas hot conditions are more likely to result in BD. Monitoring this aspect of the climate will act as an early warning system for ID and give a scientific foundation for putting ID management and preventative measures into practice.

Data availability statement

All data in this study are included in the article.

Ethics declarations

Review and/or approval by an ethics committee was not needed for this study because it was a statistical analysis of available reports, no patient privacy issues were involved.

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CRediT authorship contribution statement

Xinzhu Zhang: Writing – original draft, Visualization, Software, Methodology, Formal analysis. **Yameng Wang:** Writing – original draft, Visualization, Software, Methodology, Formal analysis, Conceptualization. **Wanze Zhang:** Writing – original draft, Visualization, Software, Resources, Methodology, Formal analysis, Conceptualization. **Binhao Wang:** Writing – review & editing, Data curation. **Zitong Zhao:** Writing – review & editing. **Ning Ma:** Writing – review & editing, Methodology. **Jianshi Song:** Writing – review & editing, Project administration. **Jiaming Tian:** Writing – review & editing, Methodology. **Jianning Cai:** Writing – review & editing, Methodology, Formal analysis. **Xiaolin Zhang:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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