A One Health perspective on bacterial zoonotic risks due to environmental contamination at public outdoor events

Plain Language Summary

Bacterial zoonotic diseases are caused by bacteria that can be transmitted between animals and humans. These diseases can spread through environmental contamination, such as water or soil polluted by animal feces. With the increasing number of public outdoor events and their growing scale, outbreaks of bacterial zoonotic diseases related to environmental contamination have become more frequent. Many events are located near agricultural areas or areas frequented by wildlife, where animal excrement can contaminate soil and water sources. Additionally, heavy rainfall can lead to the spread of pathogens into water through runoff, causing water pollution. The behaviors of participants, weather conditions, and geographical factors all contribute to the increased risk of bacterial zoonotic disease transmission at public outdoor events. Understanding these risk factors and implementing effective preventive measures are crucial for ensuring public health safety.

This review based on a search of PubMed and Scopus databases, includes studies on outbreaks of bacterial zoonotic diseases associated with environmental contamination in public outdoor events. The events were categorized into four types: festivals, freshwater sports, other sports events, and other gatherings. Basic information about each event, including scale and geographic location, was compiled. The review summarized the main pathogens involved, laboratory diagnostic methods, outbreak sources, and possible risk factors. A total of 27 studies were included. Outbreaks associated with music festivals were relatively rare since most outbreaks related to foodborne diseases, with only one instance of *E.coli* infection due to cow dung contamination of soil reported in a UK music festival. In contrast, other types of events saw more frequent outbreaks where direct or indirect contact with contaminated water and soil was the primary transmission route. The pathogens commonly identified included *E.coli*, *Campylobacter*, and *Leptospira*. The risk of bacterial zoonotic disease transmission varied among different types of events, with sports events posing higher risks due to open wounds or activities like swimming that increase exposure to contaminated environments.

Effective control measures include reducing muddy areas, monitoring changes in water quality, focusing on weather conditions during event preparation, restricting animal activity zones, and enhancing participants' hygiene awareness could mitigate the risks due to environmental contamination. More research should consider the environmental transmissions of bacterial zoonotic diseases and focus on effective prevention and control measures in public outdoor events.

Abstract

Background: Bacterial zoonotic diseases are important illnesses that can be transmitted through various routes. In addition to foodborne transmission, environmental factors play a substantial role in disease spread at public outdoor events. Currently, there is no comprehensive overview from the “One Health” perspective on the risks of bacterial zoonotic diseases due to environmental factors. This review aims to summarize the risks of bacterial zoonotic associated with environmental contamination and suggest practical prevention and control measures at outdoor gatherings.

Methods: PubMed and Scopus were searched in July 2024. Studies about the bacterial zoonotic risk due to environmental contamination at public outdoor events were included. We extracted information on events, pathogens, outbreak sources, and risk factors.
Results: 27 studies were included, 1 was related to music festivals, 12 were related to freshwater sports, 3 were related to other sports events, and 11 were related to other types of gatherings. *E. coli*, *Campylobacter*, and *Leptospira* are the most common pathogens. Swallowing and contact with contaminated water and soil caused the transmission from animals to humans. Weather conditions also a risk factor contribute to the outbreak of diseases.
Conclusion: Different types, geographical context of the event, and weather conditions can influence the risk of disease transmission. Bacterial zoonotic diseases are often transmitted through animal feces and contaminate water and soil, exposing human populations. In various events, people can contract these diseases by swallowing contaminated water or coming into contact with polluted mud. Reducing muddy areas, monitoring water environments, and controlling livestock activities may decrease disease transmission.

Keywords: One Health, bacterial zoonotic, environmental contamination, public outdoor events

Introduction

As society develops and the quality of living improves, large-scale gatherings at public outdoor events (e.g., music festivals, sporting events, petting zoos, fairs) have become increasingly common. These events, varying in purpose, size, setting, and the availability of medical facilities and contingency strategies for potential weather and environmental health hazards, provide significant recreational and economic benefits. However, they also elevate various public health risks, including the spread of infectious diseases, water- and sanitation-related illnesses, heat-related illnesses, trauma, and crush injuries (Memish et al., 2019). Studies indicate a higher incidence of infections such as *Shigella* among attendees of large open-air festivals compared to the general population (Botelho-Nevers et al., 2013). Furthermore, freshwater sports including traditional sports such as swimming, triathlon, rafting, and emerging extreme sports like adventure racing, expose participants to a variety of infection risks depending on geographic location, environmental conditions, weather, and type of sport (Delamare et al., 2024).

Zoonotic diseases are a growing global concern as their increasing prevalence and transmission pose substantial threats to public health, agricultural economies, and ecosystems. Bacterial zoonoses are infections caused by bacterial pathogens that can be transmitted between vertebrates and humans, such as *leptospirosis*, *salmonellosis*, nosocomial anthrax, anthrax, and tuberculosis (World Health Organization, 2020). Transmission routes are complex and varied, encompassing direct or indirect contact with infected animals or their feces, contaminated food, water, or soil, and airborne transmission through aerosols (Chikeka et al., 2015). The diversity and complexity of these transmission routes make the control and prevention of these diseases extremely challenging. Pathogens could be discharged into the environment through skin secretions and excretions of animals, or even transmitted by air and contaminate the surrounding environment. Thus, populations are exposed to contaminated environments, causing infections through contact with or swallowing of contaminated water and soil. Besides, inadequate sanitation and the lack of hygiene make it difficult to maintain personal hygiene and increase the risk of infection. Reports from

public gatherings frequently document different types of bacterial zoonotic events, underscoring the critical importance of implementing effective prevention and control measures in such settings. Considering that environmental factors are very critical factors in public outdoor activities, it is essential to analyze bacterial zoonotic disease outbreaks from the "One Health" perspective to control outbreaks. One Health is an integrated, unified approach that emphasizes the interconnection between humans, animals, and the ecosystems, aiming to sustainably balance and optimize their health (Joint Tripartite (Food and Agriculture Organization of the United Nations, World Organization for Animal Health, and World Health Organization) and United Nations Environment Programme, 2021). Natural environments, such as water and soil, contain a large number of pathogens, including bacteria, viruses, and fungi. These infectious microorganisms may be present and spread before or during an event. Heavy rainfall or flooding can create favorable conditions for pathogens by forming mud, while wildlife or livestock activities can introduce pathogens into soil or water sources, causing contamination. These pathogens can then spread further during public gatherings (DeNizio et al., 2019). In adventure racing, athletes are highly likely to be infected through the skin in polluted mud or water. Additionally, many infections at gatherings occur through direct contact with animals, animal feces, or the habitats when the events' site is near the agricultural area. Therefore, continuous monitoring and analyses of environmental samples could be effective in identifying potential risks and reducing the risk of disease occurrence. Effective transmission control and prevention also require coordination and cooperation across multiple fields and sectors. The human health sector, the environmental sector, the veterinary sector, and specialized areas such as food, energy, and biology are working together from their respective perspectives to formulate and implement regulations to deal with the development of diseases and to promote common health. Despite several studies linking bacterial zoonotic disease outbreaks to environmental contamination, there are still some studies that lack the analysis of environmental samples and trace the source with evidence (Melinda et al., 1990; Sejvar et al., 2003; Brockmann et al., 2010; Hochedez et al., 2011; Centers for Disease Control and Prevention (CDC), 2011; den Boogert et al. 2017). Addressing this gap through comprehensive environmental monitoring and analysis can lead to a better understanding and reduction of the risks of bacterial zoonoses in public outdoor events, and it is essential for the development of evidence-based control and prevention strategies.

The objective of this review is to synthesize current knowledge, analyze the risks, identify knowledge gaps and recommendations for future research associated with bacterial zoonoses in public outdoor activities due to environmental contamination. We aim to explore the outbreak sources and transmission pathways of these risks, explaining how environmental contamination increases the risk of disease and its transmission. Emphasizing the important role of the One Health concept in studying bacterial zoonoses, this review seeks to enhance understanding of the human-animal-environment interconnection. It aims to provide insights into risk assessment and suggest practical prevention and control measures for bacterial zoonoses at outdoor mass gatherings.

Methods

Definition of mass public outdoor events

This study defines public outdoor events as activities held within a specified period for a particular

purpose, where more than 50 people gather in a specific area. These include music festivals, sports events, large gatherings, and fairs. Populations displaced due to natural disasters, conflicts, and wars were not included in this review.

Search Strategy

To conduct a narrative review of existing research, this study performed a literature search using PubMed and Scopus databases to collect relevant literature on environmental hygiene conditions and bacterial transmission at mass public outdoor events. Search keywords included: “Hygiene at festivals”, “mass gatherings”, “sports”, “bacterial”, “outdoor”, and the following combinations: (“zoonotic diseases”[Title/Abstract] OR “zoonoses”[Title/Abstract]) AND (“festivals”[Title/Abstract] OR “public events”[Title/Abstract]); (“bacterial”) AND (“zoonotic” OR “outbreak”) AND (“one health” OR “environmental”) AND (“mass gatherings” OR “sports” OR “festival” OR “public events”). The literature search was conducted on 5th July 2024. Only studies published in English were included in this review, with no restrictions on the time of publication. Subsequently, the full text of the included articles was reviewed, and the results section reports the included articles based on the type of event.

Inclusion and exclusion criteria

Inclusion criteria: (1)studies involving bacterial zoonotic diseases related to environmental transmission at (mass) public outdoor events; (2)studies involving bacterial zoonotic diseases potentially related to environmental transmission at public outdoor events.

Exclusion criteria: (1)studies involving foodborne bacterial zoonotic disease; (2)studies involving populations that do not meet our definition of public outdoor events; (3)non-original research publications (eg. review studies). Assessment of the quality of the included articles was based on the guidelines for writing outbreak investigation reports (www.ecdc.europa.eu) and STROBE checklist.

Data extraction and data-analysis

General information regarding the study was extracted, such as the first author and year of publication. Also, basic information about the event was extracted, for example, type, time, location, site geography, duration, condition, and size. Furthermore, details regarding the investigation of the bacterial zoonotic diseases were extracted, including the detected pathogens, the number of infections, the number of laboratory-confirmed cases, the laboratory methods used, the outbreak sources, and the associated risk factors. This review primarily focuses on identifying the source of outbreaks in public outdoor events. Additionally, it explores major pathogens associated with different types of events and factors that could increase the risk of bacterial zoonotic transmission from one health perspective. A descriptive summary was conducted to present the outcomes of the studies based on the extracted data.

Results

A preliminary search identified a total of 1096 articles. After screening titles and abstracts, articles unrelated to the research question and duplicates were excluded, resulting in 18 articles. These 18 articles were further screened by full-text reading, and an additional 9 articles that met the

inclusion criteria were identified through snowballing. In the initial database search, there could be missing keywords due to the lack of specific bacterial species. By full-text reading through the 18 included studies, references that met the inclusion criteria were also included. Thus complementing the missing articles and collecting as comprehensively as possible. In summary, a total of 27 articles were included in this narrative review. The complete flowchart of the study selection process is shown in Figure 1.

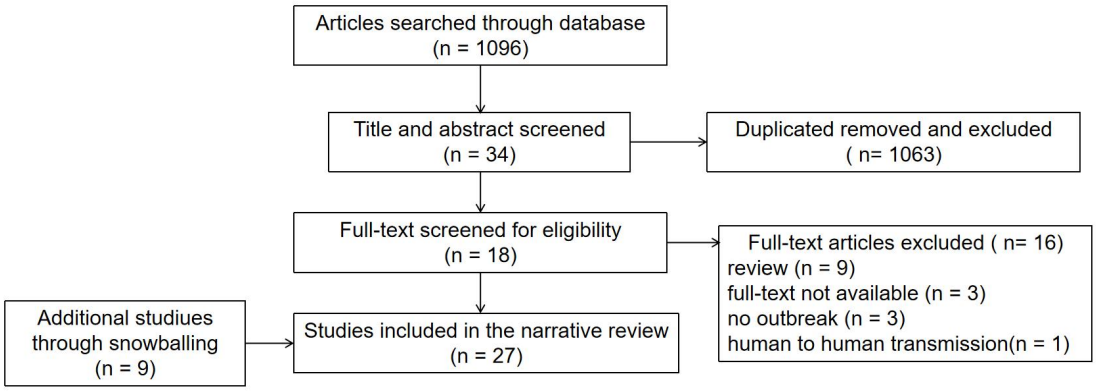

Figure 1. Flowchart of the study selection process.

The basic information of mass public outdoor events is shown in Table 1, including event type, year, location, geographical conditions, duration, environmental conditions (covering animals and climate), and event size.

Bacterial zoonotic diseases that occurred during mass public outdoor events are categorized into four types based on the event category: (1)festivals such as music festivals; (2)freshwater sports; (3)other sports events, including seawater swimming; (4)other gatherings, including fairs. Table 2 lists disease-related information during each event, including pathogens, suspected cases, laboratory-confirmed cases, laboratory methods, outbreak sources, and risk factors. Among the 27 analyzed articles, 1 was related to music festivals, 12 were related to freshwater sports, 3 were related to other sports events, and 11 were related to other types of gatherings. *Escherichia coli* (*E. coli*), *Campylobacter*, and *Leptospira* are the most common pathogens (14, 6, and 5 studies, respectively). The vast majority of outbreaks were spread through direct contamination of water and soil by animal feces, while some outbreaks at sporting events were transmitted by pathogens brought into the event site by surface runoff related to heavy precipitation.

Festivals

Non-foodborne outbreaks at festivals are rare based on our search results. One non-foodborne outbreak related to mass outdoor public music festivals was identified. However, a notable case occurred during the Glastonbury Festival in the United Kingdom in 1997, marking one of the few documented non-foodborne outbreaks associated with a large outdoor music festival (Crampin et al., 1999). This three-day event attracted approximately 80,000 attendees and took place on two dairy farms. Two days before the festival began, a large number of cows grazed on the site.

Researchers conducted laboratory analyses by collecting fecal and blood samples from the festival attendees and utilizing polymerase chain reaction (PCR), pulsed-field gel electrophoresis (PFGE), and antibody detection methods. They also collected rectal swabs from the cows and soil samples to investigate the event environment. The results revealed that eight individuals were

laboratory-confirmed to be infected with *Vero cytotoxin producing Escherichia coli* (*VTEC O157*). Additionally, the same strain of *E. coli* was detected in one rectal swab from 180 cow samples, while no such bacteria were found in the soil samples. Further interviews were conducted to assess the patients' specific festival activities, food histories, and contact with soil and animals. The findings indicated no common food source among the patients, and their camping locations were dispersed. Based on the laboratory results, it is reasonably inferred that the most likely route of infection was contact with mud contaminated with *E. coli O157* from the infected cows' feces.

Freshwater sports

A total of 12 studies on zoonotic disease outbreaks related to freshwater sports were included. Freshwater sports are defined as activities conducted in non-saltwater environments, such as lakes, rivers, ponds, and activities involving soil and mud contact, including triathlons, mud soccer, mountain biking, and obstacle races. Contact with contaminated environments is the primary source of outbreaks. Hot weather provides conditions for the rapid reproduction of pathogens, and heavy rainfall leads to surface runoff and flooding, standing water and the creation of mud, which allows animal feces to diffuse or accumulate in surrounding environment, increasing the risk of exposure and transmission.

Two outbreaks were associated with triathlon events. Laboratory testing of patients' serum samples identified *Leptospira* as the main pathogen. Epidemiological and environmental investigations indicated that both events took place under high temperatures and heavy rainfall, which facilitated the contamination of freshwater sources with *Leptospira*. Participants' exposure to contaminated water, skin barrier disruption, open wounds, and ingestion of contaminated freshwater were identified as key risk factors (Morgan et al., 2002; Brockmann et al., 2010). In June 1998, a one-day event held at an artificial lake in Springfield, Illinois, within an agricultural area, had 876 registered athletes, with 98 reporting illness (Morgan et al., 2002). Serological testing of patients' samples, including antibody and microscopic agglutination test (MAT) , as well as bacterial culture and PCR identification of blood and urine samples, confirmed 52 cases. Lake water samples and serum samples from farm animals, petting zoo animals, and trapped wild animals were also collected for PCR and MAT testing, but no *Leptospira* was detected in the lake water and animal samples, with only two wild animal samples testing positive. In 2006, during a triathlon in the Neckar River, Germany, five participants tested positive serologically, with skin barrier disruption being the primary risk factor (Brockmann et al., 2010). MAT identification suggested that the outbreak source was *Leptospira* excreted by rodents near the river, although no environmental or animal investigations were conducted.

The remaining ten studies occurred in mountainous, forested, and muddy environments, involving mud exposure. Five reports documented *Campylobacter* infections (Stuart et al., 2010; Griffiths et al., 2010; Mexia et al., 2013; Zeigler et al., 2014; den Boogert et al., 2019), two reported *Leptospira* infections (Stern et al., 2010; Hochedez et al., 2011), and the other three reported infections with *E.coli O157* (Sharp et al., 2020), Burkholderia (Smith et al., 2023), and *Aeromonas hydrophila* (Vally et al., 2004). All outbreaks were associated with contaminated mud, although Hochedez and den Boogert did not test environmental samples. Similar to triathlon events, heavy rainfall and high temperatures increased the risk of environmental contamination and infection. Additionally, four outbreaks were linked to animal activities, where animal feces contaminated water sources or event sites (Griffiths et al., 2010; Mexia et al., 2013; Zeigler et al., 2014; Sharp et

al., 2020).

Other sports events

Three outbreaks related to other sporting events were identified. These events included a pool party in Georgia in 1996 (Friedman et al., 1999), the "Eco-Challenge" multisport competition held in the jungle and seawater environments of Malaysia in 2000 (Sejvar et al., 2003), and a triathlon held on the Danish coast in 2010 (Harder-Lauridsen et al., 2013). The primary pathogens were identified as *E.coli O157*, *Leptospira*, and *diarrheagenic E. coli* and *Campylobacter*.

Swimming pools are often used for water sports events. In Friedman's study, ten patients who attended a pool party were serologically confirmed to be infected with *E.coli O157*. The investigation revealed that the pool had not been chlorinated as required, allowing bacterial proliferation and resulting in the outbreak (Friedman et al., 1999).

The other two outbreaks were associated with seawater contamination. Heavy rainfall during event preparation caused sewer overflows and surface runoff, which introduced contaminants into the ocean, increasing the risk of infection during water sports. Harder-Lauridsen's study confirmed infections with *diarrheagenic E.coli* and *Campylobacter* through fecal sample testing. The flooding caused by heavy rains might brought contaminated animal feces into the ocean. This study monitored bacterial contamination levels in open waters around Copenhagen and compared the incidence rates of triathlon participants in highly polluted seawater after heavy rainfall in 2010 (43%) with those in unpolluted seawater in 2011 (8%). The results indicated a lower incidence of illness associated with exposure to unpolluted water, with illness correlated to swallowing contaminated water, and the risk increasing with the frequency of ingestion (Harder-Lauridsen et al., 2013). The study of the "Eco-Challenge" event in Malaysia revealed that participants engaged in prolonged jungle trekking before coming into contact with the Segamat River, which led to cuts and abrasions, increasing the risk of *Leptospira* infection. However, this study lacked environmental sampling and testing of the Segamat River water (Sejvar et al., 2003).

Other gatherings

Eleven outbreaks related to various gatherings were identified, encompassing fairs, markets, and summer camps (Melinda et al., 1990; De Schrijver et al., 2000; Warshawsky et al., 2003; Howie et al., 2003; Smith et al., 2004; Varma et al., 2003; Durso et al., 2005; CDC, 2005; CDC, 2005; CDC, 2012; Curran et al., 2018). These events, often held in small towns or agricultural areas, were characterized by their extended duration, high population density, limited sanitation facilities, and frequent and substantial contact with animals. Laboratory testing of fecal samples identified *E.coli* as the primary pathogen. The sources of the outbreaks were predominantly contaminated water sources and animals. However, studies of the Rainbow Family Gathering by Melinda et al. and the CDC investigation of a gathering in North Carolina did not include environmental sampling (Melinda et al., 1990; CDC, 2012).

In other gatherings, except for the Rainbow Family Gathering in the United States in 1987 and the international fair in Belgium in 1999, there was direct or indirect contact with animals, their feces, and their living environments. Additionally, unhygienic behaviors, such as inadequate hand hygiene, increased the likelihood of bacterial infections. Prolonged stays in areas shared with animals raised the infection probability, which increased with the length of exposure. Insufficient sanitation facilities were a significant factor contributing to gastrointestinal infections.

During the Rainbow Family Gathering, inadequate sanitation facilities led to water source contamination and a large-scale outbreak of *Shigellosis* (Melinda et al., 1990). At the international fair in Belgium, an outbreak of Legionnaires' disease occurred. The source of the outbreak was identified as contaminated whirlpool aerosol water therapy pools. Working near aerosol-generating equipment or visiting specific exhibition booths increased the risk of infection (De Schrijver et al., 2000).

Discussion

Knowledge synthesis

In this review, our objective is to analyze and discuss the risks of bacterial zoonoses related to environmental contamination during public outdoor events from a One Health perspective. By reviewing existing studies, we aim to summarize the sources, transmission routes, and risk factors of these diseases, highlighting the critical role of the One Health perspective. We included 27 studies related to bacterial zoonotic outbreaks associated with environmental contamination at public outdoor events, categorizing them into four main types: festivals, freshwater sports, other sports events, and other gatherings. The study results indicate that different types of public outdoor events are associated with various bacterial zoonotic pathogens, with *E.coli*, *Leptospira*, and *Campylobacter* being the most common pathogens. The transmission routes are complex and varied, including swallowing and contact with contaminated water, soil, animals, or their excreta, as well as aerosol transmission. Environmental factors such as geographic location, specific weather conditions, and inadequate sanitation significantly increase the risk of disease outbreaks across different activities. These findings underscore the close relationship between bacterial zoonoses and environmental factors, demonstrating the necessity of analyzing these issues from a One Health perspective.

Risk analysis

By classifying the selected literature, we found that the number of bacterial zoonotic diseases which is related to environmental contamination is lower at festival events compared to sports events, particularly freshwater activities. This discrepancy may be because many music festivals are held in city centers with favorable weather, resulting in lower risks of water and soil contamination and reduced opportunities for contact with agricultural areas and animal feces, which could minimize the transmission risk (Botelho-Nevers et al., 2013). With societal progress and increased health awareness, large music festivals often provide adequate sanitation facilities, enabling participants to maintain better personal hygiene. Moreover, participants at these events are primarily engaged in entertainment activities, resulting in lower exposure to environmental contamination sources.

In contrast, sports events are often held in forests, jungles, mountains, or near agricultural areas, where there is a potential for contact with wildlife or farm animals. Animal excrement can directly or indirectly enter water bodies or contaminate water sources through surface runoff and drainage. In some freshwater activities, participants are likely to ingest contaminated water and mud, exposing them to pathogens. Additionally, participants in these activities are prone to falls and injuries, resulting in open wounds that increase the risk of infection through contact with contaminated environments. Additionally, heavy rainfall and high temperatures created ideal

conditions for bacterial survival and reproduction. Surface runoff can carry contaminants into water, further elevating the risk of water source pollution and disease transmission. For instance, during the 2010 triathlon held on the Danish coast, heavy rain caused sewer overflows and surface runoff carried pollutants into the ocean, increasing the risk of infection among athletes (Harder-Lauridsen et al., 2013).

All of the studies have demonstrated the importance of environmental factors in the transmission of bacterial zoonotic diseases. Therefore, we believe that certain interventions can mitigate the risk of infections and transmissions during public outdoor activities. Firstly, regular monitoring of water quality and issuing water quality warnings is crucial. Sampling and laboratory analysis for microbial pathogens are conducted before and during the event at the location of the activity and nearby river or groundwater. In addition, follow-up sampling could be conducted within a week after the event. Secondly, during event preparations, attention should be paid to weather changes, and relevant monitoring should be strengthened. An early warning is issued and measures are made for the appropriate departments to investigate and deal with the contaminated environment when monitoring results exceed safety thresholds. Efforts should be made to avoid livestock activities in the area to reduce the entry of pollutants into water and soil. It is also possible to ensure that the environment is without contamination by testing prior to the event and to enhance the health management of the animals. Additionally, increasing participants' awareness of hygiene, avoiding the ingestion of contaminated water and mud during activities, and promptly treating wounds can reduce infection risks. A study on an event in Norway demonstrated that after implementing environmental control measures (such as draining tracks, spreading gravel in muddy areas, and reducing the proximity of animals to the track), the number of infection cases significantly decreased compared to the previous year when no such controls were in place (Mexia et al., 2013).

Festivals: risk analyses environmental transmission versus foodborne transmission

At large-scale festivals, people gather for celebrations and those events usually offer meals. Thus, it is important to control both foodborne transmission and transmission due to environmental contamination. The spread of foodborne diseases is more common. Foods often offered from different sources have inconsistent sanitation standards and could be contaminated during storage and transportation. Consumption of food, such as sashimi, is highly susceptible to infection. Besides, the density of the crowds and sharing food might increase the likelihood of bacterial transmission. Environmental transmission is less common at festivals since there is less exposure to sources of contamination, usually because of contact with the contaminated environment caused by animal feces. The opportunities of being exposed to the two types of transmission are different, but both require participants to focus on their hygiene and keep cleaning. In conclusion, compared to other events, festivals need to pay more attention to foodborne diseases, ensure that each part of the food supply meets standards, and train the catering staff during the preparation period. Also, the risk of environmental transmission should not be ignored. Monitoring the environmental health and increasing sanitation facilities, and increasing awareness of personal hygiene are still needed.

Strengths and Limitations

This study encompasses various types of public outdoor events worldwide, excluding foodborne

diseases and outbreaks caused by human-to-human transmission. We focus on the complexities of bacterial zoonotic diseases triggered by environmental contamination during public outdoor events. Besides, this scoping review identified publications covering studies on events that mentioned disease outbreaks related to environmental contamination but did not collect environmental samples or weather conditions. Limitations of this scoping review still exist. Since it was not specific to the bacterial species, it may have been missed in the search strategy. Furthermore, only searching the English literature on PubMed and Scopus, as bacterial zoonotic disease is a global problem.

The studies included provided the background information which is crucial for a comprehensive understanding of environmental contamination in bacteria zoonotic diseases and filling the existing gaps in environmental sampling and analysis. However, these studies have several limitations. Variations in sample types and laboratory diagnostic methods across studies might lead to incomplete analysis and interpretation of the sources and transmission routes of environmental contamination. Some of them just took the water samples or animal samples. We believe it should be a more comprehensive sampling, including air as well as weather monitoring. Besides, the study may not have detailed documentation of the intervention measures, which makes it difficult to accurately assess the effectiveness.

Future recommendations

With the increase in population, the global demand for agricultural products has increased, resulting in the rapid growth of the livestock industry. Economic development has also led to the organization of large-scale events and sporting events. However, these improvements have also caused new public health challenges, such as the prevention and control of disease outbreaks, and emerging diseases. First, the development of the livestock industry has to be accompanied by strong health management to ensure the hygiene and safety of animals and their environment. The monitoring of pathogens carried by animals should be strengthened to control the pathogens, thus not contaminating the environment and transmitting into the population. Secondly, more and larger public outdoor events mean that the risk and scope of disease transmission increase. It is important to focus on sanitation facilities and hygiene management for each event, to strengthen the awareness of organizers and the public, and to monitor food, water, and soil safety. In addition, disease prevention and control departments should promote disease surveillance and research, actively control existing diseases, and respond to emerging diseases.

Conclusion

Humans are typically infected with bacterial zoonoses through contaminated water and soil sources. Both direct and indirect exposure to these contaminants, with heavy rainfall and high temperatures, can significantly contribute to disease outbreaks. Additionally, the different types and the geographical context of the event can also influence the risk of disease transmission.

In summary, this narrative review provides a comprehensive analysis of past bacterial zoonotic outbreaks from a One Health perspective, comparing the differences in the risk among different types of activities and potential effective preventive measures. These findings establish a theoretical foundation for future research and the development of preventive measures. Future studies should emphasize the importance of One Health, enhance environmental sample collection

and analysis, and explore preventive and control measures to increase the practical application value of the research. More thorough environmental monitoring and targeted intervention strategies are expected to improve the prevention and control of bacterial zoonotic diseases at public outdoor events.

Declaration of generative AI in scientific writing

For this project, I used DeepL to translate text. I first wrote the thesis in Chinese and then used the translation tool to complete some sentences. After translation, I rewrote the sentence and changed some words to words I knew and used frequently. The tool reference is DeepL. "DeepL Translator." DeepL, 2024, www.deepl.com.

Table 1. Outbreaks of bacterial zoonotic risks at mass public outdoor events.

Reference	Event	Time	Location	Site geography	Duration	Condition	Size
Festivals							
Crampin, M., et al.(1999)	Glastonbury Music Festival	1997	England	The site comprises two diary farms	3 days	approximately 650 cows grazed on the site up to 2 days prior to the start of the festival	80,000
Freshwater sports							
Morgan J., et atl(2002)	Triathlon	1998	Springfield, Illinois	A man-made lake, located in the heavily used agricultural area	1 day	The lake receives runoff from many local livestock farms; June was the month of peak precipitation	876
Vally H., et al.(2004)	Mud football	2002	Southwest Western Australia	Mud football fields	1 day	The field was irrigated with river water; temperatures were warm, with maximum generally >25°C	~100
Stern EJ., et al.(2010)	Endurance-length swamp race	2005	Florida	Outside of Tampa, swamp in Hillsborough River State Park	2 days	Swamp race; Hurricane passed over 2 weeks before which brought heavy rains and flooding; Mammalian species around the park	200
Brockmann, S., et al.(2010)	Triathlon	2006	Germany	Neckar River	1 day	Heavy precipitation; Rising temperatures	507
Stuart, T.L., et al.(2010)	Mountain bike race	2007	British Columbia	A small community in muddy conditions	1 day	Muddy conditions	787
Griffiths SL., et al.(2010)	Mountain-bike event	2008	Wales(UK)	Road and off-road	2 days	Heavy rain; Sheep faeces in places	947
Hochedez P., et al.(2011)	Race in the tropical forest	2009	Caribbean island of Martinique	Tropical forest	1 day	Heavy rainfall and flooding; Shallow rivers and muddy trails	230
Mexia R., et al.(2013)	Cycling event	2010	Norway	Mountains in the southeast of Norway	2 days	Wet and muddy conditions; Grazing animals in area; Heavy rainfall	~19,000

Table 1. Outbreaks of bacterial zoonotic risks at mass public outdoor events (continued).

Reference	Event	Time	Location	Site geographic	Duration	Condition	Size
Zeigler, M., et al.(2014)	obstacle race	2012	Nevada	Cattle ranch	2 days	Muddy place with animal feces	ND
den Boogert, E.M., et al.(2019)	Obstacle runs	2017	Netherlands	Muddy place	7 months, including 17 obstacle runs	Untreated water and mud	2,900
Sharp.A., et al.(2020)	Mud-based obstacle race	2018	England	Mud-based place	2 days	Mud-based; Livestock in the place	11,500
Smith S., et al.(2023)	Sporting event	2022	Australia	School grounds with a mud pit	1 day	Dry season; The pit was dug each year and filled with chlorinated tap water	~265
Other sports events							
Friedman MS., et al.(1999)	Trailer park pool party	1996	Georgia	Trailer park, swimming pool	1 day	Not officially registered swimming pool	51
Sejvar J., et al.(2003)	“Eco-Challenge” multisport race	2000	Malaysian Borneo	Jungle, fresh and ocean water, caving, mountain	12 days	Cuts and abrasions caused by jungle vegetation; Rainfall before the race	304
Harder-Lauridsen, N.M., et al.(2013)	Triathletes sports competition	2010	Copenhagen, Denmark	Beach Park Lagoon in the sea	1 day	Heavy rainfall and severe flooding; Sewers to overflow	1,312
Other gatherings							
Melinda Wharton., et.al(1990)	Annual Rainbow family gathering	1987	Western North Carolina	The Nantahala National Forest, 40 hectares of forest and open fields	7 days	heavy pollution of surface water; surface stream used for drinking, swimming and bathing; shallow trench latrines; frequent rains	~12,700

Table 1. Outbreaks of bacterial zoonotic risks at mass public outdoor events (continued).

Reference	Event	Time	Location	Site geographic	Duration	Condition	Size
De Schrijver K., et al.(2000)	International fair	1999	Kapellen, Belgium	Small town	1 day	Had aerosol-producing devices and whirlpool; Water not changed during the fair; Poor ventilation	50,000
Warshawsky B., et al.(2002)	Annual fair	1999	Ontario	Agricultural pavilion	10 days	Had a travelling petting zoo; Livestock from local farms	290,000
Howie, H., et al.(2003)	Scout camp	2000	New Deer, Aberdeen shire	20-acre agricultural showground that was normally used for grazing	2 days	Approximately 300 sheep grazed for 6 days up until the day before the camp; Grass had not been cut prior; The site had been contaminated with sheep faeces; Heavy rainfall	337
Smith KE., et al.(2004)	Farm day camp	2000	Minnesota	campus	2 session, 5 days for each session	Direct contact with a variety of farm animals	400
Varma JK., et al.(2003)	County fair	2001	Ohio(US)	Buildings with community facility on the fairgrounds	7 days	Handled sawdust from the building's floor; Wooden frame; Animal shows	~900
Durso LM., et al.(2005)	County fair	2003	Texas	Fairground including sewage back-up area, show arena, livestock pens	9 days	Had rodeos and livestock barns; Livestock exhibition	170,307
Centers for Disease Control and Prevention(CDC)	Petting zoos visiting	2004	North Carolina	Petting zoos	10 days	Petting zoo had extensive environmental contamination; Could have extensive contact with animals and their bedding	800,000

Table 1. Outbreaks of bacterial zoonotic risks at mass public outdoor events (continued).

Reference	Event	Time	Location	Site geographic	Duration	Condition	Size
Centers for Disease Control and Prevention(CDC)	Florida Fairs and Festivals	2005	Florida	Petting zoos	2 periods, 12 and 11 days	Common animal vendor; Environmental contamination	ND
Centers for Disease Control and Prevention(CDC)	State Fair	2011	North Carolina	Mix of urban and suburban	11 days	Structure was used for housing animals during the livestock competitions	1 million
Curran K G., et al.(2018)	Dairy education school field trip	2015	Washington state	Barn at the fairgrounds	5 days	Including a petting zoo, a hay maze, milking facilities; Interactive lectures	1,300

Table 2. Detailed information of outbreaks in public outdoor events.

Reference	Pathogens	No. of reported	No. of lab-confirmed	Laboratory method	Outbreak source	Risk factors
Festivals						
Crampin, M., et al.(1999)	VTEC O157	8	8	Faecal specimens; PCR(VT2 genes), PFGE(DNA); Serum samples(antibodies); Rectal swabs from cows and soil sample	Mud contaminated with E.coli O157 from infected cattle	Cows grazed on the site up to 2 days prior to the start of the festival; Contact with mud
Freshwater sports						
Morgan J., et atl(2002)	Leptospirosis	98	52	Serum samples(titer); ELISA(IgM antibody); MAT test; PCR(pathogenic species)	Widespread leptospiral contamination of the lake	Swallows of lake water; High levels of precipitation; Animal reservoirs
Vally H., et al.(2004)	Aeromonas hydrophila	26	3	Swab samples of skin lesions; Antibiotic susceptibility testing	Exposure to contaminated mud	Mud exposure; Exposure of skin lesions to contaminated river water
Stern EJ., et al.(2010)	Leptospirosis	44	14	Blood and urine specimens; Serological testing(MAT titer); PFGE, CAAT, and DNA-DNA hybridization; Environmental samples	Contaminated water, animal activity	Swallowing river/swamp water; Being submerged in any water
Brockmann, S., et al.(2010)	Leptospirosis	5	5	Serum sample; Serological test(IgM ELISA, MAT titer)	Leptospiral contamination of the Neckar River	Open wounds

Table 2. Detailed information of outbreaks in mass public outdoor events (continued).

Reference	Pathogens	No. of reported	No. of lab-confirmed	Laboratory method	Outbreak source	Risk factors
Stuart, T.L., et al.(2010)	Campylobacter jejuni	537	25	Stool and environmental sampling; PCR; MLST	Contaminated mud	Direct ingestion mud; Other food/drink during
Griffiths SL., et al.(2010)	Campylobacter	161	10	Stool specimen	Mud/water which had been contaminated with sheep faeces from the rural course	Inadvertent ingestion of mud
Hochedez P., et al.(2011)	Laptospirosis	20	10	Blood sample; Serological test(MAT); PCR	Environmental contamination	Cuts on the skin
Mexia R., et al.(2013)	Campylobacter; Salmonella	572	8	Stool specimen; Mud samples	Faecally contaminated mud	Exposure to faecally contaminated mud
Zeigler, M., et al.(2014)	Campylobacter coli	22	4	Stool specimen; PFGE	Muddy surface water contaminated with cattle or swine feces	Inadvertent swallowing of muddy surface water
den Boogert, E.M., et al.(2019)	Sapovirus; Norovirus; Shigella spp.; Enterohaemorrhagic E.coli; Campylobacter jejuni; Giardia lamblia	76	13(5, 4, 1, 1, 1, 2, respectively)	Stool specimen; RT-PCR; Water sample	Mud contamination	Ingesting mud; Rinsing off in a hot tub
Sharp.A., et al.(2020)	E.coli O157:H7	11	9	Faecal specimen; Whole-genome sequencing	A failure to remove livestock from the course prior to the event	Contact contaminated mud

Table 2. Detailed information of outbreaks in mass public outdoor events (continued).

Reference	Pathogens	No. of reported	No. of lab-confirmed	Laboratory method	Outbreak source	Risk factors
Smith S., et al.(2023)	Burkholderia pseudomallei	7	7	Swab sample Faecal specimen Environmental sample; MALDI-TOF; Whole-genome sequencing; MLST	Mud pit	Existing abrasions and minor skin trauma sustained; Repeated use and subsequent ground shrinkage and water pooling
Other sports events						
Friedman MS., et al.(1999)	E.coli O157:H7	18	10	Blood specimens; ELISA(IgM and IgG antibody)	Pool had little to no chlorine added	Swimming in the pool
Sejvar J., et al.(2003)	Leptospirosis	80	26	Serum samples; ELISA(IgM antibody); MAT(titer)	Environmental contamination	Swimming in the Segama River; Swallowing river water; Kayaking; Spelunking
Harder-Lauridsen, N.M., et al.(2013)	Diarrhoeagenic E.coli; Campylobacteriosis; Giardia lamblia	351	11(5, 3, 3, respectively)	Stool specimen	Water contamination	Unintentionally swallowed contaminated water
Other gatherings						
Melinda Wharton., et.al(1990)	Shigella sonnei	185	88	Stool specimens; Disk diffusion method; Alkaline lysis method	Food, water contamination from surface streams	Poor sanitation, food, unboiled water
De Schrijver K., et al.(2000)	Legionella pneumophila	93	41	Urinary antigen analysis(EIA, ICT); ELISA(IgM and IgG); PCR	Legionella from whirlpool aerosol spa	Working near aerosol producing devices

Table 2. Detailed information of outbreaks in mass public outdoor events (continued).

Reference	Pathogens	No. of reported	No. of lab-confirmed	Laboratory method	Outbreak source	Risk factors
Warshawsky B., et al.(2002)	E.coli O157:H7	155	7	Stool specimens; Standard slide/tube agglutination; PFGE(subtyping)	The goats and sheep from the petting zoo	Direct or indirect contact with animals; Duration of stay
Howie, H., et al.(2003)	E.coli O157	70	20	Stool specimens; Faecal specimens; Culture on CT SMAC; IMS technique(environmental spcimens, sheep); PFGE(distinguish strains)	Contaminated environment and contaminated hands	Failed to wash hands before eating; Did not use cutlery; Climbed a tower; In a specific district
Smith KE., et al.(2004)	C.parvum; E.coli O157:H7; STEC	25	14(8, 4, 5, respectively)	fecal samples; PFGE(subtyping); PCR(genotyping)	Contaminated calves	Contact with calves; Getting manure on hands
Varma JK., et al.(2003)	STEC	23	14	Faecal specimens; Immunoassay; PFGE(subtyping)	Contaminated building	Visited a multipurpose community facility on the fairgrounds; Handling sawdust from the floor; Eating and/or drinking in the building
Durso LM., et al.(2005)	E.coli O157:H7	525	7	Soil, dried livestock feces, livestock bedding, standing water and surface swabs samples; Immunomagnetic separation; PCR, PFGE(subtyping)	Contaminated livestock	Livestock exhibit exposure; Contact with livestock

Table 2. Detailed information of outbreaks in mass public outdoor events (continued).

Reference	Pathogens	No. of reported	No. of lab-confirmed	Laboratory method	Outbreak source	Risk factors
Centers for Disease Control and Prevention(CDC)	STEC	108	41(38 E.coli O157:H7)	Systematic environmental sampling of the fairgrounds; PFGE	Environmental contamination	Contact with animals and their bedding; Stay longer; Touching in manure; Falling/ sitting on the ground; Sucking thumb
Centers for Disease Control and Prevention(CDC)	E.coli O157:H7	63	20	Stool samples; PFGE; Environmental samples	Animal exposure	Direct and indirect contact with animals
Centers for Disease Control and Prevention(CDC)	E.coli O157:H7	25	11	Stool specimen; PFGE	Animal contamination	Having visited for livestock competitions
Curran K G., et al.(2018)	E.coli O157:H7	60	25	Stool specimen; Environmental sample; PFGE	Exposure to a contaminated barn	Exposure to animal environments

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