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Drivers of zoonotic disease risk in the Indian subcontinent: A scoping review

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ABSTRACT

Literature on potential anthropogenic drivers of zoonotic disease risk in the Indian subcontinent is sparse.

We conducted a scoping review to identify primary sources, published 2000–2020, to clarify what research exists and on which areas future research should focus. We summarised findings thematically by disease.

Of 80 sources included, 78 (98%) were original research articles and two were conference abstracts. Study designs and methods were not always clearly described, but 74 (93%) were quantitative (including one randomised trial), five (6%) were mixed-methods, and one was qualitative. Most sources reported research from India (39%) or Bangladesh (31%), followed by Pakistan (9%), Nepal (9%), Bhutan and Sri Lanka (6% each). Topically, most focused on rabies (18; 23%), Nipah virus (16; 20%) or leptospirosis (11; 14%), while 12 (15%) did not focus on a disease but instead on knowledge in communities. People generally did not seek post-exposure prophylaxis for rabies even when vaccination programmes were available and they understood that rabies was fatal, instead often relying on traditional medicines. Similarly, people did not take precautions to protect themselves from leptospirosis infection, even when they were aware of the link with rice cultivation. Nipah was correlated with presence of bats near human habitation. Official information on diseases, modes of transmission and prevention was lacking, or shared informally between friends, relatives, and neighbours. Behaviour did not correspond to disease knowledge.

This review identifies various human behaviours which may drive zoonotic disease risk in the Indian subcontinent. Increasing community knowledge and awareness alone is unlikely to be sufficient to successfully change these behaviours. Further research, using interdisciplinary and participatory methods, would improve understanding of risks and risk perceptions and thus help in co-designing context-specific, relevant interventions.

1. Introduction

Emerging zoonotic diseases represent a growing threat to global health, particularly in countries that may lack the finances and infrastructure to address them effectively [1]. Globally, over 60% of human infectious diseases are caused by pathogens shared with wild or domestic animals [2,3]. Investigating the human-animal interface is essential to understanding the emergence of zoonotic diseases and possible prevention mechanisms [4]. Concentrated small mammal densities, different species living in close proximity, and anthropogenic encroachment on habitats that disturb existing ecosystems all affect the dynamics of emerging zoonotic disease [5,6]. Synanthropic rodents are associated with fragmented and human-dominated landscapes, increasing the likelihood of zoonotic spillover [7].

Threats posed by zoonotic diseases are global but especially pertinent in low-income countries, where a range of socio-economic, environmental and other contextual factors often converge to increase risks of, and vulnerability to, disease outbreaks. These factors include fragile and poorly resourced health systems, rapid population growth, increased urbanisation, variable literacy, economic vulnerability, consumption of

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bushmeat, and anthropogenic encroachment on wildlife habitat associated with agriculture and other land use changes [2,6,8–11]. In addition, spillover events are likely to be under-reported in resource-poor settings as communities have little access to healthcare and diagnostics, government-recommended disease prevention measures are not widely followed, and surveillance mechanisms are either poor or non-existent [12,13].

Working within existing cultural beliefs and practices is essential to reducing incidence of emerging zoonotic diseases, including leptospirosis (i.e. rodents as primary reservoir, but many other host animals potentially involved), rabies (i.e. dogs as primary reservoir, bats also recognised), and Nipah virus (NiV; i.e. fruit bats as primary reservoir). Leptospirosis and rabies are serious issues throughout the subcontinent while NiV, with a case fatality rate of 70%, is present in India and Bangladesh [14–16] and one of the ten highest-priority pathogens globally [17]. A recent study found that risk of zoonotic disease spread was increased in tropical areas, including the Indian subcontinent, that are undergoing changes in land use related to agriculture, and with high wildlife biodiversity [8].

This review aimed to synthesise existing evidence on anthropogenic, behavioural and environmental drivers of zoonotic disease risk in the Indian subcontinent. Objectives were to: (i) summarise the scope (i.e., extent and nature) of the literature focused on this geographical area; (ii) synthesise major anthropogenic and environmental drivers of zoonotic disease risk; and (iii) identify key areas for further research.

2. Methods

2.1. Study design

We conducted a scoping review, adapting Arksey and O'Malley's classic six-stage scoping framework with later revisions [18–21]. Scoping reviews are preferable to a systematic review when the existing literature has not been reviewed comprehensively or 'exhibits a complex or heterogeneous nature not amenable to a more precise systematic review' [21].

2.2. Stage 1: Defining the research question

Our primary research question was: 'Which environmental, cultural, and behavioural factors may drive potential zoonotic disease spillover in the Indian subcontinent?' The review included all primary research related to factors that may drive risk of zoonotic disease in the chosen geographical area. Our working definitions are presented in Table 1.

2.3. Stage 2: Identifying relevant studies

First, we searched six electronic databases systematically (Global Health, Global Index Medicus, MEDLINE, EMBASE, PsycINFO and Web of Science) to ensure comprehensiveness. We used relevant terms and related terminology for the topic, adapted to the subject headings for each database as applicable. For example, Box 1 shows the MEDLINE search. Second, we hand-searched reference lists of all eligible papers purposively. Third, we asked stakeholders to identify any additional sources (Stage 6).

Table 1
Working definitions.

Anthropogenic	Anthropogenic effects, processes, objects, or materials are those that are derived from human activities, as opposed to those occurring in natural environments without human influences [22]
Behavioural	The way in which one acts or conducts oneself [23]
Cultural	Shared patterns of behaviours, interactions, cognitive constructs, and understanding that are learned by socialisation [24]
Driver	Any natural or human-induced factor that directly or indirectly causes a change [25]
Environmental	The conditions in which a person, animal or plant lives or operates or in which an activity takes place [26]
Indian subcontinent	Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka (https://en.wikipedia.org/wiki/Indian_subcontinent)
Spillover	Process in which an infectious agent is transmitted into a novel host species [6]
Zoonotic disease	Disease passed from a vertebrate non-human animal to a human (https://www.who.int/news-room/fact-sheets/detail/zoonoses)

2.4. Stage 3: Selecting studies

We established eligibility criteria iteratively, with initial criteria based on the research question and geographical area. Studies had to meet all criteria to be included. Documents in English and French were included as most relevant, as other publishing languages (e.g., Chinese, German) are not typically associated with such research on the Indian subcontinent. We included studies from 2000 to September 2020 (the search date) to keep the number of studies identified manageable and of contemporary relevance. All study designs, interventions and participants were included as applicable. As there is little research on this area, drivers and risk factors did not need to be a primary objective of the study but primary data on environmental, behavioural, or cultural factors in the context of zoonotic risk had to be presented for the paper to be eligible for inclusion. Studies that did not include human participants were included if they discussed pertinent data (for example, if they included information about bat roosting sites and the proximity of such sites to human habitation, or potential effects of different factors on disease risk for human populations). Studies that focused solely on wildlife sampling without discussing potential effects on human populations and habitations were not included. All authors agreed final inclusion criteria: primary research articles published since 2000 in English or French, which focused on the Indian subcontinent and examined behavioural, cultural or environmental factors, defined in Table 1, in the context of zoonotic disease risk.

Documents were imported into EndNote (Version X9; Clarivate Analytics), where duplicates were removed. The remaining documents were imported into Covidence systematic review software (Veritas Health Innovation, Australia) where titles and abstracts were first screened to assess potential relevance. Articles included at this stage then underwent full-text screening against eligibility criteria. Finally, reference lists of all eligible articles were iteratively checked for any additional documents to assess for eligibility, resulting in the total number included (Fig. 1).

2.5. Stage 4: Charting data

Information was extracted from included sources into an Excel spreadsheet with the following headings: (i) source identifiers: i.e., lead author, publication year; (ii) source characteristics: i.e., country, disease focus, study discipline, primary objective, study design, study population; and (iii) key findings in relation to drivers of zoonotic risk.

2.6. Stage 5: Collating, analysing and reporting results

Documents were summarised by publication year, country, and disease focus. Extracted data on evidence and findings across studies were then analysed thematically using deductive and inductive coding as described by Braun and Clarke [27].

2.7. Stage 6: Consulting stakeholders

We contacted three zoonosis experts from the region to obtain their feedback on our initial findings and any suggestions for additional studies that might meet eligibility criteria. Two provided feedback, stating our findings made sense in terms of regional context but neither suggested additional studies for inclusion.

Box 1
. MEDLINE search strategy.

1 (Zoono* or reservoir* or “animal-to-human” or “human-to-animal” or “animal-human” or “human-animal”).mp

2 Zoonoses/

3 1 or 2

4 (spillover* or outbreak* or emerging or emergence or emergent or emerged or reemerging or re-emerging or re-emergent or reemergent or re-emergence or interfac* or interaction* or contact* or exposure*).mp

5 Disease outbreaks/

6 communicable diseases, emerging/

7 4 or 5 or 6

8 (Bangladesh or Bhutan or India or Maldives or Nepal or Pakistan or Sri Lanka or Indian subcontinent).mp

9 exp. Bangladesh/ or Bhutan/ or India/ or Maldives/ or Nepal/ or Pakistan/ or Sri Lanka/ or Indian subcontinent/

10 8 or 9

11 3 and 7 and 10

12 11

13 limit 12 to yr = “2000 -Current”.

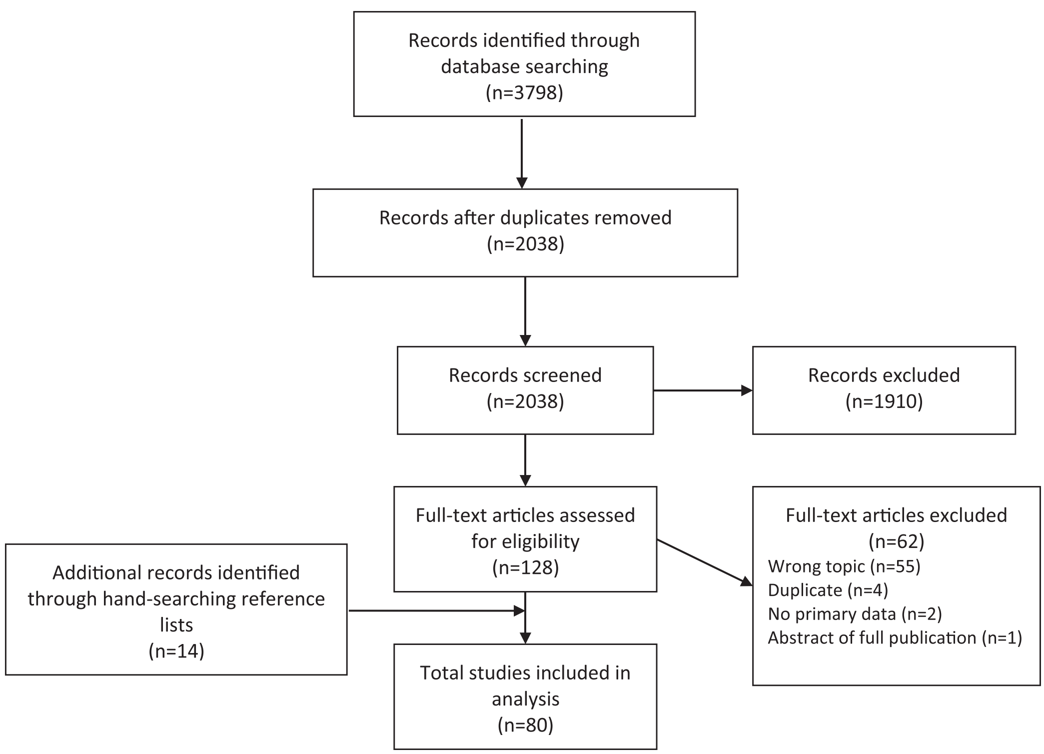

Fig. 1. PRISMA diagram.

3. Results

3.1. Extent, nature, and distribution of literature

The database search retrieved 2038 unique records after removal of duplicates, of which 66 met the eligibility criteria. A further 14 sources were identified through hand-searching the reference lists, while no additional sources were identified through stakeholder consultation, giving a total of 80 included articles (Fig. 1).

No eligible sources were published between 2000 and 2004, followed by an increase in the annual number of publications since 2005, with a peak in 2016 (Fig. 2). More details of the sources included are presented in Table 2.

With the exception of two conference abstracts, all sources were original peer-reviewed research articles. Study designs and methods were not always clearly described, but 74 (93%) were quantitative (including one randomised trial), five (6%) were mixed-methods, and one was qualitative. Quantitative studies were predominantly cross-sectional (50/74; 68%).

A few studies clearly described their sampling methods, while most provided minimal or no explanation. Fifty-three (66%) studies appeared

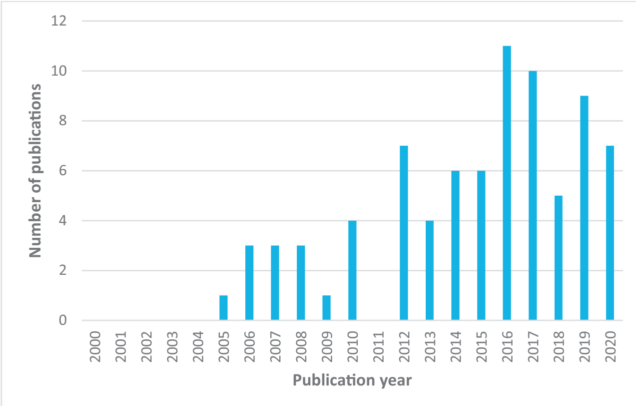

Fig. 2. Number of sources by year of publication.

to use convenience sampling although sampling methods were not clearly described in most sources.

Geographical distribution of sources was not even. Most reported research from India (31; 39%) or Bangladesh (25; 31%), followed by Pakistan (7; 9%), Nepal (7; 9%), Bhutan and Sri Lanka (5 [6%] each), and none from the Maldives. No sources reported multi-country results.

Topically, most focused on rabies (18; 23%), NiV (16; 20%) or leptospirosis (11; 14%), while 12 (15%) did not focus on a particular disease but instead on general zoonotic disease knowledge in communities. Study populations were predominantly the general public (approximately 40%), while 33% were in occupationally exposed populations, e.g., livestock farmers or bat harvesters. Sixteen (20%) sources included people with suspected or confirmed diseases of interest, e.g., NiV, rabies, leptospirosis and brucellosis. Seventeen (21%) sources examined risk factors for zoonotic disease as an explicit objective.

3.2. Findings by disease

Findings are summarised under rabies, NiV and leptospirosis - the most frequently researched diseases, and ‘other diseases’ as appropriate. Table 3 presents a summary of key drivers for, and factors associated with, zoonotic disease risk in this geographical area.

3.3. Rabies

Fifteen sources described behaviour related to rabies, particularly behaviour of people bitten by a potentially rabid animal. Ahmed and colleagues found people bitten by dogs in Pakistan did not seek post-exposure prophylaxis or vaccinate their domestic dogs even when aware of the existence of vaccination programmes. This was true despite 70% of participants knowing rabies was a vaccine-preventable disease and 75% understanding that it was fatal [28]. Similar responses were found in Bangladesh, with most participants (32%) not treating bite wounds before attending hospital for post-exposure prophylaxis, 22% applying antiseptic or water, 14% applying soap and water, and 15% applying products such as lime, soda, salt and kerosene oil [29]. Another study in Bangladesh also reported use of traditional treatments after dog bite [30], with 59% seeking treatment from healers before attending hospital and only 2% cleaning wounds properly with soap and water. In India, 64% of dog bite victims did nothing or adopted ‘religious practices’ to prevent rabies [31].

Fourteen sources described drivers of rabies related to lack of awareness and understanding of the disease, its causes and prevention. Communities often reported low awareness of rabies, in terms of preventing bites and behaviour following a bite or other contact with potentially infected animals [28,29,31–45]. Some sources discussed community beliefs and the use of traditional medicines as prevention or post-exposure prophylaxis [29]. Studies in India found some participants had heard about rabies, but knowledge of first-aid following a bite was poor, with application of chillies, turmeric or kerosene and visiting traditional healers recommended [33,35,37]. In two Pakistan studies, most participants stated there had been no rabies awareness campaign in their community [28,38], with similar findings in India [32,35]. People reported getting their information from friends, family and neighbours, with women who had received no formal education likely to be less aware of the disease [32]. Other common sources of information included media and television [30,37]. One study in Pakistan found that half of participants were informed about rabies by community elders or neighbours and only 1% learnt of the disease from an animal health official [38]. Brookes and colleagues found that 73% of participants in India received information on rabies from friends and neighbours, with few having been made aware by a public health official or at school (6%); none of the interviewees had heard rabies mentioned in the media or in a specific awareness campaign [32].

Although 93% of study participants in Pakistan knew dogs were the main transmitters of rabies, only 40% said they would visit hospital if bitten by a dog [38]. Brookes and colleagues found Indian farm workers who learnt about rabies from a veterinarian were more likely than non-farm workers to use traditional prevention remedies [32]. A study of cattle owners in Bhutan found most who had heard of rabies had heard from a neighbour and only 22% had participated in animal health or rabies training [34]. In Bhutan, most community participants said they would report a suspected rabid dog to the authorities, although 50% of them admitted allowing their dogs to interact with feral dogs. Another study in Bhutan indicated most people had received rabies education from veterinarians and public health officials [39].

The role of human or animal rabies vaccination was not commonly understood. An Indian study found only 43% of participants were aware of a human vaccine while 57% stated vaccinating dogs would help prevent rabies [37]. In two other studies in India, 70–75% of participants believed rabies was curable [31,36]. Knowledge of rabies symptoms in dogs was low among participants in a study in Bangladesh [29]. The main environmental driver of rabies, identified in three sources, was the presence of stray dogs in communities [29,46].

3.4. Leptospirosis

Ten sources described behaviour relevant to leptospirosis. A cross-sectional study in Pakistan found people exposed to rice paddy water, e.g. through rice cultivation, had almost 7 times higher odds (p-value not calculated) of being seropositive for leptospirosis than those unexposed [47]. In India risk factors including working in mines, exposure to cattle, and open defecation were significantly associated with leptospirosis seropositivity [48]. A study in Sri Lanka identified residing on or working close to a farm and handling cattle as risks significantly associated with leptospirosis infection [49], while another, examining behaviour of secondary school students, found only 18% involved in cultivating rice used gloves or boots while doing so and 13% bathed in stagnant water [50].

Two sources studied awareness of leptospirosis in Sri Lanka. Paddy field farmers were significantly more aware of leptospirosis than were other community members, as were people living in endemic areas. Most participants knew rats were a reservoir (94%), whereas only 3% knew cattle and buffalo could also act as reservoirs [51]. Sources of leptospirosis information mentioned by secondary schoolchildren living in a rural endemic area included television, school, newspapers, and educational programmes, with 50% having accurate knowledge of the disease [50].

Eleven sources examined environmental drivers of leptospirosis. Studies in India identified rat infestation of housing and proximity to water bodies as significant risks for leptospirosis [48,52–55], while in Nepal associations were found between leptospirosis and contact with livestock [56]. Working in paddies was identified as a high-risk

Table 2
Sources included in the analysis.

First author (year)	Country	Disease	Population	Type of study	Study design
Agampodi (2010)	Sri Lanka	Leptospirosis	General population	Knowledge and awareness	Cross-sectional study
Ahmed (2020)	Pakistan	Rabies	General population	KAP	Cross-sectional study
Alam (2020)	Bangladesh	Rabies	Dog bite victims	Knowledge	Cross-sectional study
Arif (2017)	Pakistan	Brucellosis	Dairy farmers	KAP	Cross-sectional study
Arunkumar (2019)	India	Nipah	Suspected cases	Outbreak investigation	Mixed-methods: interviews and laboratory data
Biswas (2015)	India	Non-specific	Farmers	Knowledge	Survey
Br (2019)	India	Non-specific	Bat harvesters	Risk mapping	Ecological study
Brookes (2019)	India	Rabies	Farmers	Outbreak investigation	Survey
Chakraborty (2016)	Bangladesh	Nipah	Cases and controls	Outbreak investigation	Mixed-methods: surveys and interviews
Chakraborty (2017)	Bangladesh	HPAI H5N1	Cases	Outbreak investigation	Mixed-methods: interviews and laboratory data
Chattopadhyay (2006)	India	Campylobacteriosis	General population	KAP	Cross-sectional study
Chinchwadkar (2020)	India	Non-specific	Female farmers	KAP	Cross-sectional study
Cortes (2018)	Bangladesh	Nipah	Not applicable	Outbreak investigation	Ecological study
Datta (2010)	India	HPAI H5N1	Rural population	KAP	Cross-sectional study
Deka (2020)	India	Brucellosis	Dairy farmers	KAP	Cross-sectional study
Dhakal (2012)	Nepal	Japanese encephalitis	Pig farmers	KAP	Cross-sectional study
Dhakal (2014)	Nepal	Japanese encephalitis	Pig farmers	KAP	Cross-sectional study
Ghosh (2016)	Bangladesh	Rabies	General population	KAP	Cross-sectional study
Gupta (2014)	India	Canine echinococcosis	General population	KAP	Cross-sectional study
Gurley (2017)	Bangladesh	Nipah	Cases and controls	Outbreak investigation	Case-control study
Hahn (2014)	Bangladesh	Nipah	Outbreak villages	Outbreak investigation	Ecological study
Hahn (2014b)	Bangladesh	Nipah	Outbreak villages	Outbreak investigation	Ecological study
Haider (2017)	Bangladesh	Hepatitis E	Pig handlers	Outbreak investigation	Case-control study
Haleem (2018)	Pakistan	Cystic echinococcosis	Livestock farmers	KAP	Cross-sectional study
Hegde (2016)	Bangladesh	Nipah	Cases and controls	Outbreak investigation	Case-control study
Herbert (2012)	India	Rabies	Slum dwellers	KAP	Cross-sectional study
Homaira (2010)	Bangladesh	Nipah	Cases and controls	Outbreak investigation	Case-control study
Hundal (2016)	India	Non-specific	Livestock farmers	KAP	Cross-sectional study
Ichhpujani (2006)	India	Rabies	General population	KAP	Cross-sectional study
Ichhpujani (2008)	India	Rabies	General population	KAP	Cross-sectional study
Islam (2013)	Bangladesh	Anthrax	Livestock farmers	Outbreak investigation	Mixed-methods: interviews and observation
Islam (2016)	Bangladesh	Nipah	Cases	Outbreak investigation	Case-control study
Kapoor (2019)	India	Rabies	Exposed	Knowledge	Cross-sectional study
Kelly (2018)	Nepal	Non-specific	Smallholders	KAP	Cross-sectional study
Khadayata (2020)	India	Non-specific	Livestock farmers	KAP	Cross-sectional study
Khan (2012)	Bangladesh	Nipah	Sap harvesters	Intervention study	Randomised controlled trial
Khan (2013)	Bangladesh	Nipah	Not applicable	Outbreak investigation	Ecological study
Khan (2017)	Pakistan	Leptospirosis	Occupational exposure	Risk mapping	Cross-sectional study
Khan (2019)	Pakistan	Rabies	General population	KAP	Cross-sectional study
Khattak (2016)	Pakistan	Tuberculosis	Livestock workers	KAP	Cross-sectional study
Kochar (2007)	India	Brucellosis	Cases of brucellosis	Epidemiological investigation	Observational study
Kothalawala (2018)	Sri Lanka	Brucellosis	Dairy farmers	KAP	Cross-sectional study
Luby (2006)	Bangladesh	Nipah	Cases	Outbreak investigation	Case-control study
Luby (2009)	Bangladesh	Nipah	Cases	Outbreak investigation	Ecological study
Madhusudhana (2015)	India	Leptospirosis	Cases	Outbreak investigation	Mixed-methods: interviews and laboratory data
Manandhar (2013)	Nepal	Avian influenza (H5N1)	General population	Awareness	Cross-sectional study
Mangalgi (2015)	India	Brucellosis	General population	Epidemiological investigation	Cross-sectional study
Mangalgi (2016)	India	Brucellosis	Occupational exposure	KAP	Cross-sectional study
Masali (2007)	India	Leptospirosis	General population	Epidemiological investigation	Cross-sectional study
Massei (2017)	Nepal	Non-specific	Dog owners	KAP	Cross-sectional study
Matibag (2007)	Sri Lanka	Rabies	General population	KAP	Cross-sectional study
Mohankumar (2015)	India	Rabies	Animal bite victims	KAP	Cross-sectional study
Montgomery (2008)	Bangladesh	Nipah	Cases	Outbreak investigation	Case-control study
Nahar (2015)	Bangladesh	Nipah	General population	KAP	Cross-sectional study
Openshaw (2016)	Bangladesh	Non-specific	General population	Risk mapping	Cross-sectional study
Openshaw (2017)	Bangladesh	Non-specific	General population	Risk mapping	Cross-sectional study
Parmar (2016)	India	Leptospirosis	Suspected cases	Epidemiological investigation	Cross-sectional study
Parveen (2016)	India	Leptospirosis	Mine workers	Epidemiological investigation	Cross-sectional study
Patel (2019)	India	Non-specific	Animal handlers	KAP	Cross-sectional study
Pathak (2014)	India	Brucellosis	Occupational exposure	Risk mapping	Serological study
Rahman (2012)	Bangladesh	Brucellosis	Occupational exposure	Risk mapping	Cross-sectional study
Rahman (2012b)	Bangladesh	Nipah	Cases	Outbreak investigation	Case-control study
Rajkumar (2016)	India	Non-specific	Livestock owners	KAP	Cross-sectional study
Regmi (2017)	Nepal	Leptospirosis	Febrile patients	Epidemiological investigation	Serological study
Rinchen (2019)	Bhutan	Rabies	Cattle owners	KAP	Cross-sectional study
Roess (2015)	Bangladesh	Non-specific	General population	KAP	Cross-sectional study
Sah (2017)	Nepal	Avian influenza	School children	KAP	Cross-sectional study
Samarakoon (2013)	Sri Lanka	Leptospirosis	School children	KAP	Cross-sectional study
Schonning (2019)	Sri Lanka	Leptospirosis	Cases and controls	Risk mapping	Case-control study
Singh (2005)	India	Rabies	Rural population	KAP	Cross-sectional study
Singh (2020)	India	Rabies	Rural population	KAP	Cross-sectional study
Sohail (2018)	Pakistan	Leptospirosis	General population	Risk mapping	Cross-sectional study
Sohan (2008)	India	Leptospirosis	Cases	Outbreak investigation	Ecological study
Sultana (2012)	Bangladesh	HPAI H5N1	Poultry farmers	KAP	Qualitative: interviews and observation

(*continued on next page*)

Table 2 (*continued*)

First author (year)	Country	Disease	Population	Type of study	Study design
Tenzin (2010)	Bhutan	Rabies	Rabies exposed	Outbreak investigation	Ecological study
Tenzin (2012)	Bhutan	Rabies	General population	KAP	Cross-sectional study
Tenzin (2017)	Bhutan	Rabies	General population	KAP	Cross-sectional study
Thapa (2014)	Bhutan	Anthrax	General population	Outbreak investigation	Ecological study
Tiwari (2019)	India	Rabies	General population	KAP	Cross-sectional study
Yadav (2020)	India	Brucellosis	Dairy farmers	Risk mapping	Cross-sectional study

occupation by 90% of participants in Sri Lanka, and 58% were aware of water being the main mode of transmission [51]. Climatic conditions were significantly associated with risk of leptospirosis in a study in Pakistan [57]. Seroprevalence was highest in humid sub-tropical climatic regions (51%), followed by semi-arid regions (44%) and lowest in hot and dry regions (28%).

3.5. Nipah virus

Ten sources described behaviour related to the risk of NiV, which is strongly associated with human-bat proximity and contact [58–67]. All sources mentioned bat contacts, with risk factors for NiV infection including proximity during bat breeding season [58], consuming raw or fermented date palm sap, and climbing trees in which bats were observed [59–64,68–70]. In one Bangladesh outbreak, those infected with NiV had almost 5 times higher odds (adjusted odds ratio 4.91, 95% CI 3.16–7.65) of having consumed raw date palm sap than controls [60]. Another study found the odds ratio to be 7.9 (95% CI 1.6–38) [62]. One of 11 NiV deaths occurred in the son of a date palm sap collector, who reported hearing bats in his trees at night and having seen bat excrement in the sap collection pot. This collector had sent fresh sap to his relatives, two of whom died from encephalitis believed to be related to NiV infection, although this infection was not confirmed [62]. Bat hunting and feeding potentially contaminated dropped fruit to livestock were frequently reported behaviours in two studies in Bangladesh [71,72]. Bats were eaten or used as medicine in rural communities [72] and 94% of households reported bats consuming fruit from trees on their property [71].

One source discussed insufficient awareness as a driver of disease risk in a NiV-endemic area in Bangladesh, finding that 50% of participants reported drinking raw sap, while only 5% were aware of NiV. However, participants who were aware of the possibility of infection from consuming raw palm sap were as likely to drink it as those who were unaware (i.e., 69% versus 67%) [68].

Twelve sources, all from Bangladesh, discussed environmental drivers of NiV. A case-control study found NiV cases were associated with living close to trees used as bat roosts (odds ratio 40.1, 95% CI 3.9–416.7) or having bats near the house during the day (odds ratio 6.5, 95% CI 1.1–37.5) [59]. Living in areas near where bats were observed was cited as a potential driver in many papers [59–64,68–70]. An outbreak investigation found villages affected by NiV were more likely to contain habitat suitable for *Pteropus* giganteus (odds ratio 2.6, 95% CI 1.2–5.8), considered the main transmitter for NiV infection, than unaffected villages [73]. Outbreaks in central and northwest Bangladesh occurred in villages with higher population densities and fragmented forests, suggesting human population density and encroachment on wildlife habitats can affect NiV spillover into humans [74]. Hegde and colleagues found that, after controlling for date palm sap consumption, age, and sex, NiV cases were significantly associated with nocturnal bats around homes in the month preceding illness [60]. Infrared photographs demonstrated that *Pteropus* bats visited date palm trees during sap collection to lick the sap [75]. Cortes and colleagues analysed data from 57 NiV spillover events (2007–2013) and found that these were associated with low temperature and lack of rainfall, accounting for 36% of variation in the total number of spillover events each winter [76].

3.6. Other diseases

Eight sources described behavioural drivers related to transmission pathways of brucellosis, including consumption of raw milk [77–79], and lack of handwashing and general hygiene, especially when milking or birthing cattle [34,77–81]. Occupational exposure was also discussed [82]. One source described behaviours related to avian influenza, including keeping poultry in the house [83,84] and close contact with sick birds [85,86]. A study on knowledge of campylobacteriosis in India demonstrated that no interviewees knew anything about the disease [87].

Other drivers included beliefs that visiting a shrine would help treat disease [77], lack of formal training on animal husbandry [88], and little awareness of disease transfer from animal to human [89–93] or animal to animal [94,95]. Knowledge of disease was shared between relatives and friends rather than through formal routes [85,96–98]. Illiterate or informally educated female smallholders had much less understanding of zoonotic disease risk than male smallholders in a study in Nepal [99]. Two sources discussed environmental drivers of Japanese encephalitis in Nepal, including proximity to water sources, poultry and pigs being raised coterminously, and the presence of wild birds close to the house [88,100].

Structural issues included lack of vaccination or access to veterinary advice as risk factors related to anthrax [101]. These were also mentioned for Japanese encephalitis [88,100], canine echinococcosis [102], brucellosis [79], hepatitis E [103] and zoonotic disease generally [84,104].

4. Discussion

We aimed to synthesise existing evidence on potential drivers of zoonotic disease risk in the Indian subcontinent.

4.1. Scope of literature

For our first objective, summarising the scope of existing literature, we identified 80 sources describing primary research on potential drivers of zoonotic disease risk in this geographical area. Three diseases, rabies, NiV and leptospirosis, were most commonly researched, although disease drivers overlapped considerably. Descriptions of study designs and methods, including how populations were sampled, were often unclear. Sources were heterogeneous in terms of methods used and populations included, but some clear trends were evident, in terms of both geographical location of studies and diseases researched. Most studies focused on India and Bangladesh, with rabies, leptospirosis and NiV the most frequently researched diseases. Rabies is a fatal and widely known disease, whereas NiV and leptospirosis, which are both related to occupational hazards such as raw palm sap harvesting and paddy planting, are potentially more likely to disproportionately affect rural communities with fewer resources rather than urbanised populations.

4.2. Major potential drivers

For our second objective, synthesising major potential drivers of zoonotic disease risk, the most recurrent was ‘lack of awareness’. Information was usually shared informally between friends, relatives, and neighbours, with little available from official channels. Importantly, even when official information was available, and communities were aware of disease transmission, this was not reflected in behaviour

Table 3
Summary of key drivers for, and factors associated with, zoonotic disease risk.

Disease	Number of studies	Driver		
		Behavioural/cultural	Environmental	Other
Rabies	18	Limited impact/lack of knowledge/awareness Incorrect wound care Do not seek medical care after bite Do not vaccinate dogs Limited hygienic behaviour after a bite Use of traditional medicine as prevention/cure Consuming meat from suspected rabid animals Contact with sick animals	Exposure to stray/'community' dogs Domestic dogs roam free	
Nipah virus	16	Limited impact/lack of knowledge/awareness Consuming raw/fermented date palm sap Consumption of dropped fruit Bat hunting Climbing trees	Contact with infected bat Exposure during harvesting time Low precipitation/low temperature Bat roosts near human habitation High human population density Fragmented forest Poor housing Seasonal patterns: winter and spring Proximity to bat feeding sites	Bat excreta found in pots used for fermenting sap
Leptospirosis	11	Limited impact/lack of knowledge/awareness Rice cultivation practices Consumption of contaminated food and water Contact with animals Exposure to cattle Open defecation Use stagnant water to bathe Do not use boots or gloves in paddy field Walking barefoot	Exposure to paddy field Domestic rat infestation High density of rat population Heavy rain Salinity of soil and water logging Proximity to water bodies Exposure to contaminated/stagnant/flood water Living in rural area Exposure to rodents Living in close proximity to livestock	Occupational exposure: agricultural/ forestry/ fisheries
Non-specific	12	Limited impact/lack of knowledge/awareness Lack of hygienic behaviour Lack of hygiene around cattle birthing Bat harvesting Consumption of raw/unpasteurised animal products No contact with veterinarians Direct contact with animal waste Animals kept in home	No private water source/toilet Humans and animals share water sources	
Brucellosis	9	Limited impact/lack of knowledge/awareness Consumption of raw milk Lack of hygienic behaviour Handling of infected material Animal handlers Animals unvaccinated Self-medicate livestock	Share housing with livestock Overcrowded housing	Occupational exposure: dairy workers
Avian influenza	5	Limited impact/lack of knowledge/awareness Direct contact with infected poultry Poultry living in house Lack of hygienic behaviour Unhygienic carcass disposal		
Anthrax	2	Limited impact/lack of knowledge/awareness Consumption of meat from sick animals Lack of vaccination Unhygienic carcass disposal Contact with infected carcasses Animals fed with infected kitchen waste		Moribund animals killed to be eaten as dead animals cannot be eaten
Japanese encephalitis	2	Limited impact/lack of knowledge/awareness Lack of hygienic behaviour	Exposure to paddy field	
Canine/cystic echinococcosis	2	Limited impact/lack of knowledge/awareness Lack of hygienic behaviour Dogs fed raw offal Animals slaughtered in housing Self-medication		
Hepatitis E	1	Limited impact/lack of knowledge/awareness Pig farming Handling raw pork		
Campylobacteriosis	1	Limited impact/lack of knowledge/awareness		
Tuberculosis	1	Limited impact/lack of knowledge/awareness Lack of hygienic behaviour		

change. For example, despite propagation of readily accessible messages about the dangers of consuming raw date palm sap by the Government of Bangladesh, including 'do not drink raw sap' and 'avoid drinking raw sap' outbreak-affected communities continued to do so [68].

Most authors did not engage critically with the issue of whether there is a need for awareness of modes of disease transmission for community behaviour change, or discuss why people may choose to not change their behaviours. One potential reason for the lack of association between awareness and behaviour change appears related to lack of access to expert knowledge on how to treat animals [41,84,89,105]. Another reason may be the preference for traditional medicines. This lack of behaviour change could be related to cultural practices, or may relate primarily to structural issues such as community poverty and lack of access to healthcare providers and veterinarians. For example, much of the population of Nepal, one of the countries covered in this review, has little to no access to qualified healthcare providers, particularly in remote and rural regions: 41% of rural communities have no access to a health post, and 80% do not have access to a public hospital within 30 min of their home by public transport [106]. Many families are unable to afford veterinary care, even when it is available, and must treat their livestock themselves. Similarly, those bitten by potentially rabid animals may self-treat to avoid the expense and effort of visiting a medical practitioner.

In terms of other drivers identified in the review, the use of traditional medicines and particular food and drink are deeply ingrained cultural practices. For example, production and consumption of date palm sap has been part of community life in Bangladesh for generations [62]. Communities may be understandably resistant to changing these behaviours, both because they are likely to have been preserved for many years as culturally significant and because those recommending such changes (e.g., politicians, national and foreign experts) may not be perceived as legitimate, e.g., not trusted or respected within communities, highlighting the importance of producing solutions with communities [107]. In terms of seeking healthcare, many communities are poor and may necessarily prioritise food and shelter over attending healthcare centres, even if these are available. These underlying issues may partly drive why communities may appear to 'ignore' official advice, e.g., to stop consuming raw palm sap, or to visit healthcare providers after being bitten by an animal, and add a layer of complexity to research. We need to take a critical perspective that can help to interrogate this complexity, elucidating what non-explicit processes underly observed behaviours, before we can claim to know what is actually driving behaviours [108]. A recent study that examined human-animal interactions and the spillover potential of coronavirus in China interviewed 1585 people who were likely to have been exposed to bats or other wildlife, including workers at live animal markets, animal breeders, or people involved in the wildlife trade [13]. Li and colleagues found that, although the majority of the respondents were aware of zoonotic disease spread, and stated that they were concerned about possible disease emergence from animals sold at wet markets, they did little to protect themselves from potential exposure, e.g., washing hands or sourcing meat from supermarkets rather than wet markets [13]. Despite awareness of potential drivers of zoonotic disease spread, interviewees did not modify their behaviour to protect themselves from possible contamination. This supports our position that community attitudes to behaviours perceived as 'risky' by experts or people in higher-income countries, and what drives these, are likely to be complex and influenced by many factors that must be understood before any awareness or behaviour change interventions are initiated.

A recent study in communities at high risk of zoonotic disease in Uganda found that most people were not aware of zoonotic disease, and that although this was partly a failure of communication, other factors, e.g., consumption of (free) bushmeat, had to be taken into account. Authors suggested that interventions should involve sustainable solutions that do not impinge on communities' livelihoods, rather than just providing educational interventions [109]. However, solutions such as increasing domestic livestock production in resource-poor countries brings its own complications: disease control is often basic or non-existent in agricultural communities, and may encourage emergence of other pathogens [2].

4.3. The way forward and future research

National strategies are key to preventing future zoonotic outbreaks and protecting the health of communities [6]. However, designing strategies remains a complex issue due to lack of effective surveillance and the many socio-ecological factors that influence disease spread. A One Health approach, involving collaboration between human health, animal health and environmental sectors at all levels of government, is likely to be crucial for implementing effective surveillance, prevention and mitigation strategies. Such an approach was not widely discussed in the sources, but should involve medical professionals, veterinarians, and environmental specialists working with community members to foster a concerted grassroots approach to research and practice. Communities could be involved in pinpointing what is likely to work in their context, which could influence disease surveillance and reporting mechanisms, and enforcement of regulations. Policy and legislation need to be put into place, although these processes take much political will and effort and are predicated on consistent governance and co-production with communities to design effective and workable strategies. Encouraging this type of initiative may have become easier following the Covid-19 pandemic, as policymakers and communities alike have been made aware of the importance of zoonotic disease transmission, and the potential ramifications of the spread of these diseases. Further research should focus on encouraging a coherent One Health response, working with and in communities to identify their priorities, their requirements, the barriers and enablers to effectively addressing risk factors around zoonotic disease, and how behaviour change initiatives could be supported by governmental and multilateral bodies.

5. Limitations

Several limitations should be considered. Only English and French sources were included, and although unlikely considering publishing trends favouring English since 2000, some relevant studies published in other languages may have been missed. For similar reasons, we may have missed some studies not indexed in the databases we searched. We did not critically appraise source quality as this was a scoping review designed to identify and synthesise the extent and nature of existing research, and was not a systematic review. The heterogeneity of the studies included in terms of methods, outcomes, populations and objectives precluded a comprehensive and useful quality appraisal. It was beyond the scope of this review to include studies solely focused on prevalence and dynamics of zoonotic agents within animal reservoir populations (e.g., wildlife sampling surveys). If these did not incorporate discussion of these factors with regard to effects on disease risk in human populations they were excluded.

6. Conclusions

Our review provided evidence from 80 primary research sources of behaviours and environmental factors that may drive zoonotic disease risk in the Indian subcontinent. Three diseases, rabies, NiV and leptospirosis, were the main focus of this research, although respective drivers overlapped considerably. Potential drivers included lack of awareness, cultural practices such as use of traditional medicines, and insufficient hygiene behaviours (e.g., hand-washing, use of protective clothing). We contend that behaviour change is essential to preventing spillover events from animals to humans. Future research should focus on working within communities to design context-specific interventions that are tailored and not generic. However, advocacy around the need for governments to invest time and financial resources into working with communities may be difficult, particularly when many outbreaks of zoonotic disease may not be reported or recognised as a key issue to be addressed.

Author contributions

All authors conceived the study and contributed to design. ADB conducted the search, analysed data with help of all authors, and drafted the manuscript. JWR, SRB and NH provided critical review. All authors agreed the version submitted.

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Declaration of Competing Interest

None declared.

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