



Review

Review of Emerging and Re-Emerging Zoonotic Pathogens of Dogs in Nigeria: Missing Link in One Health Approach

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Simple Summary: The closeness of dogs to humans, in addition to poor veterinary care and zoonotic disease awareness, poses an increased risk of zoonotic disease transmission, resulting in a significant threat to human and animal populations and food security and safety. The diversity and burden of zoonotic pathogens harbored by dogs are underreported due to poor surveillance, limited diagnostic capacity, and limited data on the disease. The purpose of this review was to assemble relevant information from published peer-reviewed literature to assess the incidence of zoonotic pathogens associated with dogs in Nigeria in order to determine the risks involved and identify priority diseases to focus on, knowledge gaps, and areas for surveillance, control, and research in Nigeria. Knowledge of the prevalence and potential role of dogs in disease outbreaks will help heighten awareness, improve veterinary care, and support policy development, including government involvement in control strategies.

Abstract: Dogs live in close contact with humans as pets, for hunting, for security, and as a source of income. In addition, the meat is also consumed by some tribes in Nigeria. Dogs could therefore serve as reservoirs, carriers, and transmitters of zoonotic diseases. This review evaluates the literature from 2000 to 2020 for the prevalence and incidence of zoonotic pathogens associated with dogs in Nigeria. The results obtained show that overall, parasites constituted a majority (64%) of the zoonotic pathogens (or species) identified in dog hosts. A good number of studies have examined the role of ticks in the transmission of tick-borne pathogens. Further, bacteria make up 22% of the zoonotic pathogens. From this study, it appears that rabies is the major pathogen in dogs for which there is reliable evidence linking contact between humans and dogs. Oyo State in southwestern Nigeria and Plateau State in north-central Nigeria were the most frequently studied states, while prevalence/disease surveillance studies constituted 80% of the overall papers assessed. Interdisciplinary collaborations as well as research and diagnosis policy amendments are missing links to fully appreciate the role of dogs in the transmission of zoonotic diseases in Nigeria. Policies should integrate a one health approach in the Nigerian health system, whereby diagnostic screening of humans and animals by physicians and veterinarians includes zoonotic pathogens for more accurate diagnosis and control.

Keywords: *Canis familiaris*; emerging; pathogen; zoonoses; Nigeria; One Health



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1. Introduction

Globally, many new and re-emerging infectious diseases have been reported in recent years [1]. An infectious disease appearing and affecting a population for the first time or rapidly spreading within or to a new geographical area where it previously existed is termed an emerging infectious disease while re-emerging infectious diseases are diseases that were once a major health challenge within a country or globally and then declined significantly

but are now becoming a health problem for a notable proportion of a population [1,2]. In addition, increased international travel, urbanization, changes in human lifestyle, increased global population, climate change [1,2], animal movement, ecological disruption, habitat encroachment, human recreational activities, and increasing contact between animal and human populations either for socioeconomic or cultural reasons [3–5] are some of the factors considered to enhance the evolution and spread of novel and re-emerging infectious pathogens. Some of these newly emerging infectious diseases have altered epidemiological and clinical characteristics, thus exerting huge public health concerns in both developed and developing countries [6].

Zoonoses have the ability to cross the species barrier; hence, humans are continually affected by a wide range of zoonotic and vector-borne pathogens [4]. On the other hand, zooanthroponoses originate from humans and animals [7]. Gebreyes et al. reported that pathogens affecting humans are increasing and that 75% of emerging diseases are zoonotic, mainly originating from wildlife [8]. Disease transmission can occur through a number of different pathways. Food-borne zoonotic pathogens are transferred directly via the feco-oral route as well as through improper food handling and inadequate cooking of contaminated food products [9]. Zoonotic pathogens can also be transferred to humans through animal bites and scratches, vectors (either actively or passively) such as fleas, lice, mosquitoes, and ticks [10], soil, water contaminated with manure, or, for example, occupational hazards due to exposure at work for abattoir workers, animal handlers, zoo-pet-shop workers, veterinarians, and farmers [11]. The emergence and re-emergence of zoonotic diseases and the increased prevalence rates of endemic and neglected zoonoses such as rabies, tuberculosis, salmonellosis, brucellosis, and other diseases in Nigeria call for greater attention.

A wide variety of animal species, including dogs (*Canis familiaris*), are kept as companion animals by households globally [12]. An estimated population of 470 million dogs [13] is kept as pets worldwide. On the other hand, approximately 2 million dogs have been recorded in Nigeria [14]. They may be domesticated or free-roaming dogs, and they may also provide security as well as a source of animal protein [15]. In Nigeria, besides companionship, dogs are consumed as food in some parts of the country by diverse ethnic groups in some states, including Akwa-Ibom, Bauchi, Cross Rivers, Gombe, Kaduna, Kebbi, Nasarawa, Niger, Ondo, Plateau, and Taraba [16–18]. Dog trading is a customary practice in areas of Nigeria where dog meat is consumed and is thus a source of income for some people [19]. Dogs are transported intra- and inter-state to slaughterhouses in trucks alongside other animals and humans, a practice that enhances the risk of disease transmission between dogs and from dogs to other species, including humans [18], either directly or indirectly [12].

The role of wildlife in disease spread and multi-host infections cannot be ignored. The increasing human population and fragmentation of natural habitats compels wildlife into significant contact, both direct and indirect, with humans and their livestock or pets, resulting in more opportunities for transmission of infection between and within populations [20]. Domestic animals, wildlife, and humans share many similar pathogens. Seventy-seven percent of livestock pathogens and 91% of domestic carnivore pathogens are known to infect multiple hosts, including wildlife [7]. Dogs may impact native wildlife through predation, competition, disturbance, hybridization, and disease transmission [21]. The interaction between dogs and wildlife not only potentially causes problems for wildlife but also connects wildlife with the local human population [22]. The potential of the use of geomatics and satellite remote sensing as useful analysis tools to achieve a better understanding of the relationships between the environment and zoonoses is being advocated [23,24]. Hence, the relationship between environmental patterns and disease spread could be investigated to assess the best way to prevent the spread of diseases in ecosystems as well as play an important role in the comprehension of pathosystem dynamics, including host, pathogens/vectors, and environment [24].

Previous studies have established the significant role that domestic dogs play in the clinical presentation of developing zoonotic diseases and hospitalization [25,26]. Emerging zoonoses such as brucellosis, *Bordetella bronchiseptica* infections, arthropod-transmitted rickettsioses, bartonellosis, and leishmaniasis [27–31] and re-emerging zoonoses such as rabies, influenza, echinococcosis, onchocercosis, sporotrichosis, salmonellosis, leptospirosis, etc. [27,32] have been reported globally. Various studies in Nigeria have associated companion animals (dogs included) with zoonotic infections such as rabies [18,33], salmonellosis [34], *Escherichia coli* [35], and toxoplasmosis [36]. However, certain zoonotic infections were reportedly endemic in Nigeria. Some of these include rabies, trypanosomiasis, toxoplasmosis, and taeniasis. Emerging infections included cryptosporidiosis and food contamination with *Campylobacter*, *Salmonella*, and *Escherichia coli* O157:H7 [37], while cases such as strongyloidiasis, ascariasis, leptospirosis, scabies, pentastomiasis, and African histoplasmosis were sporadic [37].

The increase in the population of stray and free-roaming dogs is a risk factor for the increase and spread of zoonoses [20]. The diversity and burden of zoonotic pathogens harbored by pets, especially dogs, may have been under-reported. The aim of this review was to evaluate the literature on zoonotic pathogens associated with dogs in Nigeria in order to determine the risks involved with transmission and to identify priority diseases to focus on, knowledge gaps, and areas for surveillance, control, and research in Nigeria. Knowledge of zoonotic pathogens and the potential role of dogs in disease outbreaks will help heighten awareness, improve veterinary care, and support policy development and government involvement in control strategies.

2. Materials and Methods

2.1. Database Selection and Pathogen Identification

Searches were carried out between October and November 2019 and between February and March 2020. Search terms were altered and refined in an iterative process within this period (Table 1). Zoonotic infections associated with companion animals were identified by searching the literature. Pathogens capable of causing clinical disease in dogs and transmissible via vectors, fomites, aerosols, close contact with humans or dogs, and pathogens with multiple transmission routes were included. Studies on dogs, vectors, and infections transmitted from dogs to humans were all included. Organisms considered normal flora were not included in this review.

Table 1. Search terms and synonyms.

Main Search Terms	Synonyms/Related Terms
Dog	Canine, puppy, <i>Canis familiaris</i>
Nigeria	Nigerian, West Africa
Man	Human/humans
Pathogen	Parasites, Viruses, Bacteria, microorganisms, gastro-intestinal parasites,
* Zoonoses	Zoono *, zoonotic viral disease, zoonotic bacterial disease, zoonotic parasitic disease, zoonotic viral infection, zoonotic bacterial infection, zoonotic parasitic infection, <i>Brucella</i> , <i>Campylobacter</i> , <i>Cryptosporidium</i> , <i>Echinococcus</i> , <i>Giardia</i> , Hookworm, <i>Leptospira</i> , Rabies, Rotavirus, Roundworm, Ringworm, <i>Salmonella</i> , Scabies, Methicillin resistant <i>Staphococcus aureus</i> , Tapeworm, Tuberculosis

*: No affix shown.

2.2. Search Strategy

Potentially relevant articles were identified by searching for literature in selected veterinary and biological databases. Seven databases, including Agricola, CAB Abstract, Google Scholar, PubMed, Scopus, Web of Science, and VedMed Resources, were utilized to ensure maximum literature search output. Grey literature was excluded from this review.

In addition, search terms were selected to answer the research question “What is the evidence that dogs in Nigeria harbor/transmit zoonotic pathogens to/from humans?”. They were designed to factor in ‘population’, ‘location’, and ‘disease’. Terms relevant to ‘population’ included dog/dogs and canines; ‘location’ was Nigeria/Nigerian. For terms relating to ‘disease’, the subject search term ‘zoono*’ was used for zoonoses, while individual disease pathogen conditions of dogs such as Brucellosis, Echinococcosis, Leptospirosis, Salmonellosis, and Tuberculosis were used as its synonyms. Search terms were combined using the Boolean operators AND/OR, while search filters, limits, and sub-headings were manipulated based on the provisions of the individual database. Zoonotic pathogens of dogs, including but not limited to *Brucella*, *Campylobacter*, *Cryptosporidium*, *Echinococcus*, *Giardia*, hookworm, *Leptospira*, rabies, roundworm, *Salmonella*, and tapeworm, were included in the search. Table 1 shows a list of basic search terms used.

2.3. Scope of the Review

The extracted and compiled published manuscripts from peer reviewed journals were quality-checked and duplicate documents were removed. Natural infections and isolates from natural infections with epidemiological details were considered. Only literature available in the English language was studied, while citations without full-text versions, such as conference proceedings, were excluded. Dissertations and articles without prevalence data were also excluded. Animal experimental studies, case-control studies, diagnostic trials, treatment trials, or pharmacological studies were also excluded. However, case reports were included for the valuable information they bring in, regardless of the possibility of an estimated prevalence. The titles and abstracts were reviewed, and articles were selected based on the predetermined criteria. Full details of inclusion/exclusion criteria for title/abstract review and full text review are highlighted in Table 2.

Table 2. Inclusion and exclusion protocol.

Considerations	Title and Abstract		Full Text	
	Include If	Exclude If	Include If	Exclude If
Study population	Study includes dogs	Species aside from dogs	Study includes dogs	Species aside from dogs
Geographical location	Data from Nigeria	Data from countries aside from Nigeria	Data from Nigeria	Data from countries aside from Nigeria
Pathogen	Zoonotic pathogens of dogs transmitted via vectors, fomites or aerosol	Potentially zoonotic Commensal	Zoonotic pathogens of dogs transmitted via vectors, fomites or aerosol	Potentially zoonotic Commensal
Date	Published between 2000 and March 2020	Published earlier than 2000	Published between 2000 and March 2020	Published earlier than 2000
Article type	Peer-reviewed journal article	Thesis, Review article. Textbooks, Newspaper articles, Conference proceeding	Peer-reviewed journal article, Full text available	Thesis, Review article. Textbooks, Newspaper articles, Conference proceedings, Only abstract was published,

Table 2. *Cont.*

Considerations	Title and Abstract		Full Text	
	Include If	Exclude If	Include If	Exclude If
Study type	Cross-sectional studies, case studies, retrospective studies	Clinical trial studies, studies without laboratory confirmation, physiological studies	Cross-sectional studies, case studies, retrospective studies	Clinical trial studies, studies without laboratory confirmation, physiological studies, molecular techniques development studies, phylogenetic studies with no epidemiological data
Language	Written in English	Not written in English	Full text available in English	Full text not available in English

Adapted from Alonso et al., 2016 [38].

2.4. Quality Assessment

The quality of the literature reviewed was assessed based on the criteria described by Alonso et al. 2016 [38], which were designed to cater to zoonoses in Africa. An assessment of the literature based on robust epidemiological studies and stringent reporting of methods and data was adopted. Table 3 shows the criteria for bias assessment as adapted from Alonso et al. 2016 [38].

Table 3. Criteria for bias assessment.

Good Quality	Medium Quality	Poor Quality
The selection of subjects was unbiased	Biased selection of subjects is acknowledged where unavoidable and fully accounted for	Biased selection of subjects not acknowledged or accounted for
Appropriate data analysis	Limitations in data analysis are acknowledged and accounted for	Use of inappropriate data analysis
Use of validated and scientifically sound methods	Use of scientifically sound methods, even though may not be the most appropriate	Use of inappropriate methods
Detailed and accurately described methods	Comprehensible methods and valid results	Unclear or incomplete methods
Reported results are accurate and complete	Accurately reported results	Incomplete or inaccurate results

Adapted from Alonso et al., 2016 [38].

3. Results

3.1. Summary

An initial search of the seven selected databases resulted in 591 citations between 2000 and March 2020. After title/abstract screening was carried out, this was reduced to 411 citations, which were further narrowed down to 225 articles after removing duplicates. A full-text screening was carried out on these publications, resulting in 146 articles meeting the inclusion criteria for review (Table S1). An illustration of the article search and selection

process is shown in Figure 1. All the papers included in the study are summarized in the Supplementary Information.

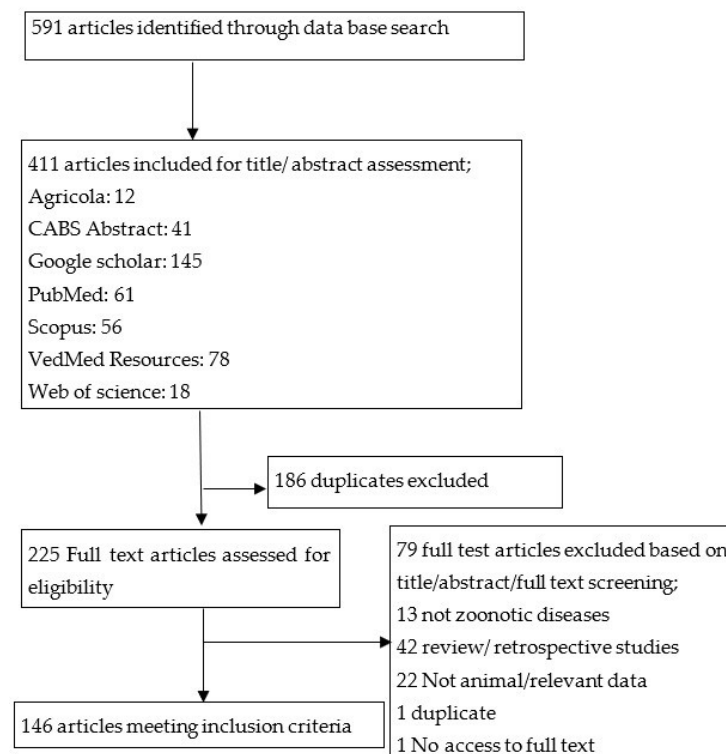


Figure 1. Article search and selection strategy.

The number of publications increased over the study period, with four papers published between 2000 and 2005, 30 between 2006 and 2010, 49 between 2011 and 2015, and 63 between 2016 and March 2020. The proportions of identified zoonotic pathogens in each class of infectious agent are shown in Figure 2.

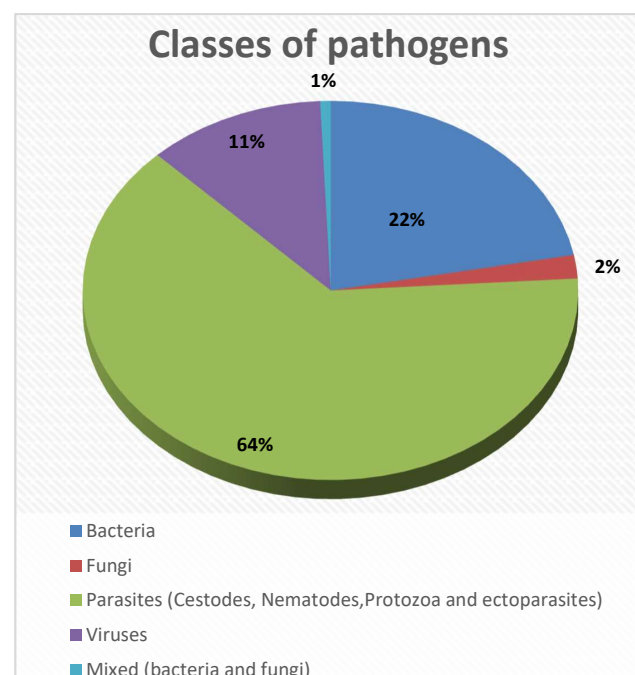


Figure 2. Percentages of zoonotic pathogens identified.

Overall, thirty potential zoonotic pathogens (or species) were identified in dog hosts in the 146 papers reviewed. Of these pathogenic species, 17 were parasites (endoparasites and ectoparasites), seven were bacteria, and three were fungi and viruses (Table 4). Five pathogens were identified in ticks from dog hosts. One study screened for bacteria, fungi, and a range of parasites in ticks from dogs. Six dog-associated zoonoses were reported in humans (Table 4). A large number of papers (42) were studied on gastrointestinal parasites, constituting 29% of the total 146 eligible papers. The most frequently reported pathogen was *Toxocara canis* (23%), while the next most frequently reported pathogen was *Ancylostoma* spp. (22%). Studies on ticks constituted 17%, with the next being the rabies virus (9%). Four papers presented evidence of probable human exposure to potentially zoonotic dog pathogens.

Table 4. Zoonotic pathogens from dogs, vectors, and humans.

Infectious Agent	Host
Parasites: <i>Ancylostoma</i> spp., <i>Cordylobia anthropophaga</i> , <i>Dipylidium caninum</i> , <i>Dirofilaria immitis</i> , <i>Echinococcus granulosus</i> , <i>Ehrlichia canis</i> , Filarioid worms, <i>Leishmania</i> spp., <i>Linguatula serrata</i> , <i>Rickettsia</i> spp., Scabies, <i>Toxocara canis</i> , <i>Toxoplasma gondii</i> , <i>Trichuris</i> spp., and <i>Trypanosoma</i> spp. Bacteria: <i>Brucella</i> spp., <i>Campylobacter</i> spp., <i>Clostridium</i> spp., <i>Cryptosporidium</i> spp., Enterobacteria, <i>Salmonella</i> spp., <i>Leptospira</i> spp., and <i>Staphylococcus</i> spp. Fungi: <i>Candida</i> spp., <i>Microsporum</i> spp., and <i>Trichophyton</i> spp. Virus: Influenza virus, Mokola virus, and Rabies virus.	Dog
<i>Anaplasma</i> spp., <i>Ehrlichia</i> spp. and <i>Rickettsia</i> spp.	Ticks (from dog host)
<i>Ancylostoma</i> spp., <i>Ascaris lumbricoides</i> , <i>Cordylobia anthropophaga</i> , <i>Cryptosporidium</i> spp., and <i>Toxocara canis</i> .	Human (infection with dog strain of pathogen/evidence of transmission from dog)

A wide range of parasites were reported in various studies, as shown in Table 5 below. These parasites were reported alongside other zoonotic gastro-intestinal parasites and thus have the potential to infect human hosts via the fecal-oral route.

Table 5. List of other endoparasites parasites reported in eligible studies.

Parasite	Number of Studies Reported
<i>Alaria</i> spp.	1
<i>Ascaris lumbricoides</i>	2
<i>Baylisascaris procyonis</i>	1
<i>Coccidia</i> spp.	2
<i>Dipylidium caninum</i>	1
<i>Dipylidobothrium latum</i>	4
<i>Entamoeba histolytica</i>	1
<i>Fasciola</i> spp.	1
<i>Filaroides osleri</i>	1
<i>Giardia</i> spp.	2
<i>Gongylonema pulchrum</i>	1
<i>Graphidium strigosum</i>	1
<i>Isospora</i> spp.	11

Table 5. *Cont.*

Parasite	Number of Studies Reported
<i>Necator americanus</i>	1
<i>Nanophytus salmincola</i>	1
<i>Sarcocystis</i> spp.	2
<i>Spirocerca lupi</i>	2
<i>Strongyloides</i> spp.	7
<i>Taenia</i> spp.	17
<i>Taenidae</i> spp.	1
<i>Trichostrongylus</i> spp.	1
<i>Troglostrongylus salmincola</i>	1
<i>Toxoscaris leonina</i>	4
<i>Uncinaria</i> spp.	6

Ecto-parasites of zoonotic importance were reported in various studies, as shown in Table 6. *Rhipicephalus* spp. was the most frequently identified tick species in the eligible studies (24/25).

Table 6. Ectoparasites reported in eligible studies.

Ectoparasites	Species
Ticks	<i>Rhipicephalus sanguineus</i> , <i>Rhipicephalus Pulchellus</i> , <i>Rhipicephalus Decoloratus</i> , <i>Rhipicephalus turanicus</i> , <i>Rhipicephalus lunulatus</i> , <i>Rhipicephalus muhsamae</i> , <i>Rhipicephalus senegalensis</i> <i>Haemaphysalis leachii</i> , <i>Haemaphysalis elliptica</i> , <i>Haemaphysalis longicornis</i> , <i>Boophilus</i> spp., <i>Boophilus annulatus</i> , <i>Ixodes scapularis</i> , <i>Ixodes</i> spp., <i>Hyalomma truncatum</i> , <i>Amblyomma variegatum</i> , <i>Amblyomma</i> spp., and <i>Dermacentor andersoni</i>
Fleas	<i>Ctenocephalides canis</i> , <i>Ctenocephalides felis</i> , <i>Pulex irritans</i> , and <i>Tunga penetrans</i>
Lice	<i>Damalina</i> spp., <i>Heterodoxus spiniger</i> , <i>Linognathus</i> spp. and <i>Trichodectes canis</i>
Mites	<i>Demodex canis</i> , <i>Otodectes</i> spp. and <i>Sarcoptes</i> <i>Sarcoptes scabiei</i>

3.2. Location of Studies

The analysis of the study location was narrowed down to states. Figure 3 shows the number of studies by state in the Federation. Oyo State in southwestern Nigeria was the most frequently studied state with 28 of the 146 entries (20%); the next state is Plateau State in north-central Nigeria with 25/146 (17%). Ogun State, also in the southwest, accounted for 12% of the papers (16/146). At the lower extreme, however, Edo, Gombe, Kano, Kogi, and Nassarawa states had just one study each. Seventeen studies involved multiple states, while one study did not specify the states covered in the study [39]. There was only one paper that screened samples from Nigeria and Uganda [40].

3.3. Study Type

The study design was assessed based on the title and/or aim of the study, and studies were categorized accordingly. Eight papers were categorized as a combination of more than one study type, while the majority of the papers were principally one study type.

Prevalence/disease surveillance studies constituted 80% of the overall papers assessed. Eight studies (5%) were a combination of disease surveillance and risk evaluation; eleven studies (7%) were on pathogen characterization; and eight studies (5%) dealt with case reports. One study concerned risk evaluation, while another dealt with both disease surveillance and pathogen characterization.

A number of these studies (17) were cross-sectional in design, although a majority of the studies (86 papers) did not indicate the chosen sampling technique for their study. Random sampling was employed in 27 papers, while stratified random sampling was applied in one study. Convenience sampling was reportedly employed in six studies, while cluster and purposive sampling were used in one study each.

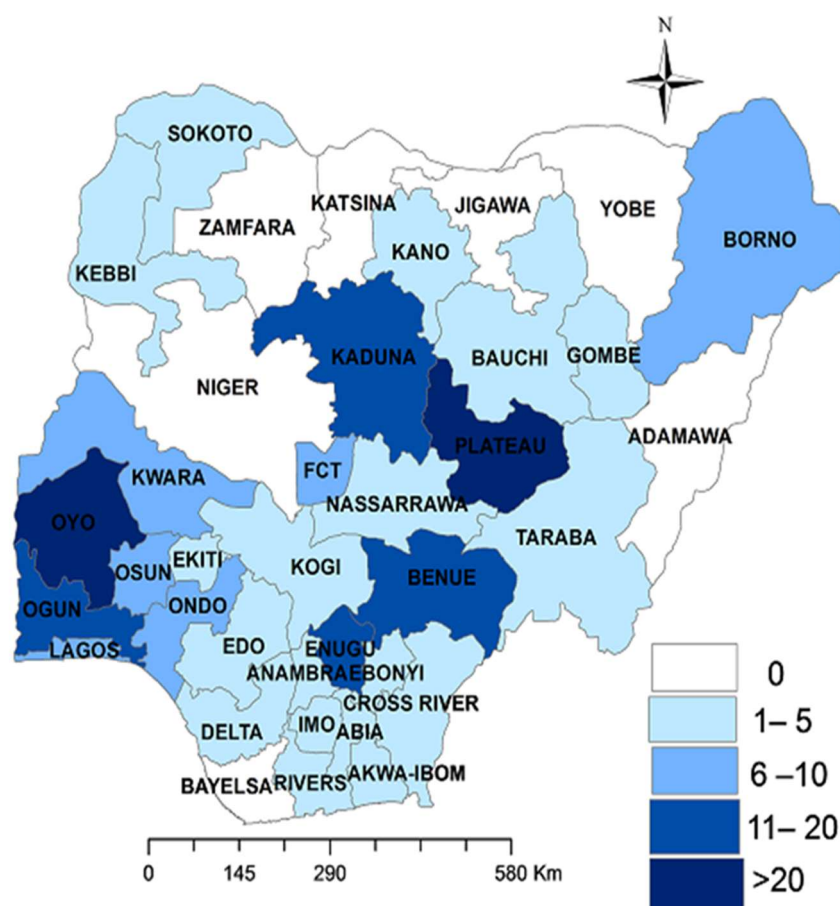


Figure 3. Number of studies by states.

3.4. Bias

Fifty-nine studies (40%) were accessed as being of good quality, suggesting a low risk of bias, while 86 (59%) were of medium quality. One (1%) paper was deemed poor quality. Major sources of bias for most of the medium-quality papers were the lack of evidence of randomization during sample collection, appropriate diagnostic methods that were well described, complete results, and appropriate data analysis where necessary. Hence, a poorly described method was the most critical source of bias for a medium-quality paper.

4. Discussion

4.1. Overview

Companion animals, including dogs, have been implicated in the transmission of many zoonotic infections of significant economic and public health importance [41]. An increase in dog zoonoses research was observed in this review, with less than ten eligible papers published between the years 2000 and 2005, increasing to above 60 between 2016 and early 2020. This may perhaps be attributed to the increased awareness of the role of pets as disease hosts or reservoirs of zoonotic pathogens [42]. Wildlife has been identified as zoonotic sentinels for novel pathogens, and the subsequent tendency for companion animals to further harbor, multiply and transmit acquired pathogens to their owners [43] necessitates research into pathogens with zoonotic potential in dogs. This is seen in the increasing number of studies on zoonotic pathogens in this review. In addition, with the emergence of the 'One Health' concept in 2004 [44], there has been an increasing desire to better understand the causes and consequences of human activities/behaviors, globalization, migration, and climate change [41] on infection trends (both in humans and animals) and disease epidemiology.

In Nigeria, the estimated dog population was approximately 5 million in 2017 [45], as compared to the about 2 million dogs estimated during the 2006 census [14]. In this review, the number of research studies on zoonotic dog pathogens is represented by the states of the federation, as shown in Figure 3. Oyo State in southwest Nigeria had the highest number of dog research studies, with 28/146 (20%) papers. Ibadan, the capital of Oyo State, is arguably one of the largest cities in West Africa [46], with a human population of above 2 million [47], thus suggesting a large dog population will be present since dog populations can be correlated in size and distribution to human populations [14]. In southwestern Nigeria, Oyo is considered one of the top three states in the dog breeding business, where people intentionally breed dogs to produce puppies for sale [48].

The breeding and sale of exotic breeds of dogs is deemed a lucrative business, yielding a good profit, and, as such, young and educated people are increasingly venturing into the trade [47,48]. This ambition to produce healthy puppies may be considered a motivation for research into infections in dogs, with a good number of studies carried out in Oyo State. Further, the southwesterners are well-trained, having a number of the oldest higher-education institutions sited there and a history of research. This may account for its good representation in the research literature.

Next to Oyo State in literature representation is Plateau State, with 25/146 (17%) of the total eligible studies reviewed in this study. Plateau State, though located in north-central Nigeria, claims to have the highest number of dog breeders (breeders). It may be speculated here also that the availability of dogs for sampling can explain the high number of dog research studies emanating from Plateau State. Dog meat is a delicacy for Plateau State indigenes, with markets set aside specifically for the sale of dogs for slaughter [49]. As a result, researchers have access to dogs for sampling, which may influence their choice of dogs as sampling animals. Lastly, the good representation observed may be attributed to the availability of research facilities and veterinarians working at the National Veterinary Research Institute (NVRI), which is located in Plateau State.

On the other hand, few studies were recorded from the northern part of Nigeria, whereby some states such as Gombe, Kano, Kogi, and Nassarawa have only one eligible paper on zoonotic pathogens of dogs, while a few other northern states (Bauchi, Kebbi, and Sokoto) had two or three eligible studies take place there. This may be partly due to the low educational exposure and research institutions/facilities [50] when compared to the south or the country at large. More so, terrorism and the security instability in north-eastern Nigeria have had a negative impact on education and, consequently, research activity [51]. A lack of relevant research from this zone and indeed other states with poor published research output may impact policies with consequences for the wider population.

Going by the projected over 7 million human population for Oyo State, and over 4 million for Plateau State as of 2019 [52], a speculated human-to-dog ratio of 1:1 will infer a large number of people are at risk of increased interaction and the possibility of exposure and transmission of zoonoses. This high level of risk may be applicable across the nation due to increased interactions regardless of available research data, which is why the emphasis is on dog vaccination and deworming.

Published data from community-based research should form the basis for government policies on zoonotic disease management, control, and eradication in any given community [53]. To effectively achieve this, research needs to be of good quality, employing appropriate study design, diagnostic tools, and appropriate statistical analysis. The majority (80%) of the eligible papers reviewed here were studies on disease surveillance to evaluate the prevalence and incidence of zoonotic pathogens. These data will enable public health managers and decision-makers to appraise the current preventive health measures, evaluate the effectiveness of disease control measures, strategize, and improve detection and response to emerging and re-emerging zoonotic diseases in Nigeria.

The eligible papers included in this study ranged from medium to good quality, inferring minimal risk for bias. The majority of the papers reviewed were likely to be cross-sectional in design (they were predominantly prevalence studies of particular in-

fections/pathogens within population subsets at a particular time period). However, the authors did not categorically state this, and as such, a majority of these papers were assessed as medium quality (see assessment criteria in Table 3). Other than that, the diagnostic procedures of the majority of the papers accessed were duly described, and the results were fully expressed with the statistical analysis made using appropriate tools where necessary. The sampling technique was a limitation in some studies that adopted convenience sampling. This is commonly associated with biased results, especially as survey results may not be representative of the whole population and the possibility of under- or over-representation abounds [54].

4.2. Gastro-Intestinal Parasites

Parasitic diseases are commonly transmitted via the “direct fecal–oral (animal–human, human–human) route” [55,56]. Mixed farming, where crops and animals are raised, faecal pollution of water and soil by animal and human feces as well as poor general hygiene practices, are important means by which food or water can become contaminated [57]. These foodborne parasitic diseases are usually associated with diarrhea, amongst other symptoms [58], and often amount to high illness (morbidity) and death (mortality) worldwide [59]. According to the Global Burden of Disease Study 2010 diseases ranking, diarrhoeal disease is the fourth largest disease burden, accounting for 3.6% of the total disease burden globally [60].

The estimated disability-adjusted life years (DALY) for the relative impact of some important zoonotic diarrheal diseases are cryptosporidiosis (8 million DALYs) [59], hookworm disease (3.23 million DALYs), trematodiasis (1.88 million DALYs), echinococcosis (0.14 million DALYs), and trichuriasis (0.04 million DALYs) [61].

Several studies worldwide have reported high prevalences of these zoonotic parasitic infections in dogs, for instance, in Europe [62,63], the USA [64], Ethiopia [65], South Africa [66], and quite a number in Nigeria [67–69], with variances in prevalence depending on the geographical location [70].

In the present review, *Toxocara canis* and *Ancylostoma* spp. (among other parasites) were the most frequently reported, each identified in over 30 studies, accounting for over 20% of the total eligible papers reviewed. A five-year (2007–2012) retrospective study in Abia State observed a prevalence of 31.9% and 11.9% for *Ancylostoma* spp. and *Toxocara* spp., respectively, among dogs presented at the Abia State veterinary clinic. Onyenwe and Ikpegbu (2004), in another 18-year (1985–2002) review of gastrointestinal helminths of dogs treated at the veterinary teaching hospital in a South-Eastern state (Enugu), reported *A. caninum*, *T. canis*, and *D. caninum* as the most commonly encountered parasites in dogs, while a 10-year (1995–2005) review in Borno State (north-eastern) by Mbaya et al. (2008) identified *A. caninum*, *T. canis*, *D. caninum*, *Isospora canis*, and *Strongyloides canis*, respectively, as the most common parasites of dogs examined at the University of Maiduguri Veterinary Teaching Hospital. Overall, a number of gastrointestinal parasites of public health significance, including *Ancylostoma caninum*, *Cryptosporidium* spp., *Dipylidium caninum*, *Echinococcus granulosus*, and *Toxocara canis*, were identified across the various studies considered. These findings concur with the prevalence observed in previous reviews [71–73]. However, these reviews were carried out across different geographical regions of the country, while the current review retrieved reports from the entire country within the specified time period. The high prevalence observed further reiterates the need for improved sanitation, proper hygiene, and management of farms and farm produce, as well as routine deworming of dogs.

Although this review was mainly interested in zoonotic pathogens in dogs, the role of wildlife in the transmission of these pathogens to and from dogs (especially stray dogs) in a One Health context cannot be overlooked. Wildlife predation on stray dogs is said to provide an opportunity for pathogen transmission, disease emergence, or re-emergence from these domestic-wildlife interactions [74], while on the other hand, dogs are reservoirs for pathogens that may threaten endangered wildlife populations. For instance, a study

suggested that the infections transmitted by dogs to wildlife may have been responsible for the extinction of the African wild dog (*Lycaon pictus*) in Tanzania [75]. Dogs' continued contact with humans and wildlife aids the multi-directional transmission of parasites as well as zoonotic diseases among humans, livestock, and wildlife [21]. In this review, a few studies screened hunting dogs for zoonotic pathogens, but studies demonstrating these dogs' pathogens as being due to interactions between domestic dogs and wildlife are scarce or absent. Hence, there is a need for studies to investigate the transmission across the interface between humans, wildlife, and domestic animals [76], especially in communities around national parks where domestic dogs have a high likelihood of interacting with wildlife.

Noteworthy examples of important zoonotic endoparasites of dogs are *A. caninum*, which has been implicated as the etiologic agent of eosinophilic enteritis in humans [77], *T. canis*, which is the causative agent of ocular and visceral larva migrans in humans (especially children) [78], and *E. granulosus*, a major public health concern in many low- and middle-income countries [79]. Echinococcosis is a chronic helminthic disease in both animals and humans and is globally distributed [80]. In Nigeria, however, not many reports have been made of this important zoonotic helminth parasite. A review of cystic echinococcosis in both animals and humans between 1970 and 2018 identified only five studies that diagnosed hydatid cysts in humans, and only two of the five studies were reports from after the year 2000 (2007, 2017) [81]. It was observed that twenty-three studies reported echinococcosis in animals (food animals such as cattle, sheep, goats, camels, and dogs), but from this number, only two studies were conducted after 2000 (2014), and they actually diagnosed the parasite in dogs [81]. Overall, there were only six studies identifying the parasite in dogs.

Several studies in Nigeria have reported endo-parasitic infections in either animals or humans, but within the period under review, studies demonstrating infection in humans due to close association with dogs are very scarce. The only study where the prevalence of identified parasites in dogs was related to the prevalence among dog owners was carried out in Oyo State [82]. In their findings, the dogs were harboring *T. canis*, *Ascaris* spp., *Ancylostoma* spp., and *Trichuris* spp., while the dog owners were found to be infected with *A. lumbricoides*, *Ancylostoma* spp., and *Trichuris* spp. In another study, *T. canis* was identified in dogs, and visceral larva migrans (VLM) was diagnosed in children from a community in Oyo State [83]. Soil samples from playgrounds were screened for the parasite, and children from schools within the vicinity of the playground were included in this study. The study suggests a possible transmission from the contaminated soil/environment to school children, which is a typical scenario that demonstrates the 'One Health' concept of disease transmission, whereby the relevance of the human–animal ecosystem interface in zoonotic disease transmission is highlighted [44]. No other study specifically demonstrated an association between gastro-intestinal parasites in dogs and their human counterparts. This finding suggests that researchers across Nigeria are yet to adopt a 'One Health' approach in disease investigation. Authors should discuss the results and how they can be interpreted from the perspective of previous studies and the working hypotheses. The findings and their implications should be discussed in the broadest possible context. Future research directions may also be highlighted.

4.3. Ectoparasites

Ectoparasites are known to be vectors of pathogens, which they transmit to their host during feeding or, in some cases, while defecating [84]. Critical to effective and sustainable control measures against zoonotic diseases is the comprehensive elucidation and characterization of pathogens and their vectors, or reservoir hosts, in a given geographical area [85]. Although a wide range of ectoparasites and associated pathogens were identified in various papers included in this study, no study could establish a zoonotic infection in humans that was linked to an infested dog. In the only study where larvae of an ectoparasite (*Cordylobia anthropophaga*) were isolated from humans, the infection was not a result of

association with the dogs sampled, as they were random samples presented under different circumstances [86].

4.4. Haemoparasites and Spirochetes

Haemoparasites are commonly transmitted by arthropod vectors, usually during a blood meal [85]. A wide number of vector-borne diseases, such as Lyme disease, ehrlichiosis, or tick-borne encephalitis, may infect dogs. These, in turn, may serve as carriers of these vectors in the environment, thus posing a risk for the indirect transmission of these pathogens to humans [32]. In this review, there were a few studies that identified *Babesia* spp., *Ehrlichia canis*, *Rickettsia* spp., *Anaplasma* spp., *Candidatus* spp., and *Theileria* spp. in ticks as well as in blood samples from dogs.

Other zoonotic pathogens identified in sampled dogs' blood included *Dirofilaria immitis* (parasitological/antigen detection), *Leishmania* spp. (antibody detection), *T. gondii* (antibody detection), and *Trypanosoma* spp. (PCR/parasitological detection). Dogs are known reservoirs for human infections caused by both canine leishmaniasis and trypanosomiasis, but only a few studies on these important pathogens were recorded in the period under review. The prevalence of African animal trypanosomiasis (AAT) in Nigeria was reviewed from 1960 to 2017 [87], and an overall prevalence of 17.3% was reported for trypanosomes in captured tsetse flies. With a total of 74 eligible studies published between 1960 and 2017 covering the six geopolitical zones (a total of 53,924 animals), an overall prevalence of 16.1% was recorded for AAT. Interestingly, dogs were not included among the animals screened in the included studies. This may be due to the author's chosen inclusion and exclusion criteria for the meta-analysis. However, it goes to show that there is scant data available for trypanosomiasis in Nigerian dogs. It becomes challenging to infer the prevalence rates for these diseases, especially as only a few states in the country were covered.

4.5. Bacteria

The emergence of zoonotic bacterial diseases is reportedly facilitated by increased interactions with animals, intensive farming systems, antimicrobial abuse, and global climate change [11]. Of noteworthy importance to global public health is the increasing emergence of antibacterial resistance (primarily from misuse or overuse of antibacterial agents) by many zoonotic bacterial agents, especially in the immunocompromised elderly, children below five years of age, and expectant mothers [88]. Overall, there was a paucity of studies on zoonotic bacterial diseases of dogs as observed from this review, but a few are described below.

4.5.1. Brucellosis

Brucellosis is an important zoonotic bacterial disease of domestic animals, livestock, and wildlife with enormous economic consequences [89]. A range of animals, including dogs, cattle, goats, horses, pigs, and sheep, are important for the transmission of brucellosis to humans [90]. Although dogs are incapable of acting as epidemiological reservoirs of *Brucella* and, as such, are categorized as "spillover hosts or sentinels" [91], the few studies on canine brucellosis demonstrated the existence of *Brucella* in dogs. All the studies were seroprevalence studies using a variety of serological methods, with not a single study identifying *Brucella* bacteriologically in dogs. The results obtained in this review consolidate reports from a previous review covering a time period as far back as 1970 [91]. The authors in the papers also observed that prevalence studies were the dominant studies on *Brucella* conducted in Nigeria within the period covered. No reported study on *Brucella* infections in humans that was directly linked to an association with a dog was identified. However, a demonstration of seroprevalence does not necessarily mean an acute infection but rather proves exposure to the bacteria.

4.5.2. *Campylobacter* spp.

Campylobacter is another important zoonotic bacteria with huge public health significance, being a leading cause of gastroenteritis [92], with a number of studies globally demonstrating this [93,94]. However, only a very few studies were identified within the time period reviewed, across a few states. To further support the findings in this review, a review on the epidemiology of *Campylobacter* spp. in sub-Saharan Africa covering the period between 2000 and 2019 by Hlashwayo et al. (2020) reported that only two studies [92,95] out of the 25 eligible studies from Nigeria were studies on *Campylobacter* from dogs [96]. The few studies available on *Campylobacter* are obviously insufficient to establish the role of dogs as reservoirs in the transmission of *Campylobacter* to humans in Nigeria.

4.5.3. Enterobacteriaceae

Enterobacteriaceae is a large family of Gram-negative bacteria comprising about 10 genera and 25 clinically significant strains, including *Escherichia coli*, *Klebsiella*, *Salmonella*, *Shigella*, and *Yersinia* spp. [97]. Members of this bacteria family may constitute a part of the normal flora of animals' small and large gastrointestinal tracts and are hence referred to as 'enterics'. They can be opportunistic pathogens when found in certain sites, with the potential to cause significant morbidity and mortality in compromised hosts. Members of Enterobacteriaceae are known causative agents of a range of illnesses, which include gastroenteritis, hemolytic uremic syndrome, meningitis, pneumonia, septicaemia, wound infections, and urinary tract infections [98]. Antimicrobial agents have been successfully used to treat infections caused by bacteria and also in farm practice, where small doses of antibiotics are being administered as prophylaxis or growth promoters [88]. Bacteria may develop resistance to antimicrobial agents as a result of mutations or the acquisition of resistance plasmids [99]. The emergence and rapid spread of antimicrobial resistance by bacteria have gained global attention in recent years, primarily because of the risk of treatment failures associated with drug-resistant strains [100]. Resistance in Enterobacteriaceae may be due to the production of expanded-spectrum β -lactamases (ESBLs), and this has been reported in a range of Enterobacteriaceae, including *Citrobacter* spp., *E. coli*, *Enterobacter cloacae*, *Klebsiella pneumoniae*, *Klebsiella oxytoca*, *Morganella morganii*, *Proteus mirabilis*, *Salmonella* spp., *Serratia* spp., and *Shigella* spp. [101].

Studies on antibiotic resistance Enterobacteriaceae have been reported globally both in livestock and companion animals [101–103] and in some instances, human infections have been linked to animal isolates [98]. In this review, ten studies on enterobacteria were identified, with *E. coli* being the most common pathogen of interest. Although some of the studies reported other pathogenic bacteria besides *E. coli*, only one study tested both animals and humans for pathogenic enterobacteria. In addition to determining the prevalence of enterobacteria in sampled populations, these studies also evaluated the resistance status of isolates, including multidrug-resistant verocytotoxin-producing *E. coli* O157:H7 and ESBL-resistant enterobacteria, as well as the resistance/susceptibility patterns of a number of enteric pathogens to commonly used antibiotics. The observed interest in antibiograms of isolates is probably due to the increasing awareness and global publicity efforts to fight the emergence and prevent the further spread or development of multi-drug resistant bacteria. Hence, the role of dogs (or other animals) in the transmission of resistant bacteria strains to humans or the environment seems to be a gradually growing research interest in Nigeria.

4.5.4. Leptospirosis

Although leptospirosis is a worldwide problem, with the exception of Antarctica, it is most significant in tropical and subtropical countries [104]. The disease is often confused with endemic infections such as malaria, hepatitis, enteric fevers, and dengue fever [105], and it may have been underreported due to underdeveloped diagnostic capacity [106]. Carrier animals include rodents, cattle, pigs, and dogs [104], and infection can be acquired through direct contact and environmental contamination [107]. The disease can be consid-

ered an occupational disease affecting animal handlers, veterinarians, abattoir workers, and sewer workers [105]. Dogs (either symptomatic or asymptomatic) can shed leptospires in their urine, which can lead to human exposure [108]. Therefore, control of leptospirosis is of both animal and public health importance. For appropriate control measures, current data on strains circulating in a country is important. From this review, however, only two seroprevalence studies on leptospirosis in dogs are available in Nigeria within the period under review, with no study reporting for both animals and humans. Similar findings were observed in a review on leptospirosis (for studies published after 1970) in Sub-Saharan Africa, where out of 83 eligible animal studies, 15 were carried out in West Africa (two were studies on dogs). Three out of nine eligible studies were human and animal surveys, while 12 out of 32 human studies were conducted in West Africa [109]. The findings here show that leptospirosis is indeed a neglected zoonotic infection that needs urgent attention in Nigeria.

4.5.5. Staphylococcus Infection

Staphylococcus aureus, despite being part of the normal flora of the human skin and mucous membranes (nasopharynx, anterior nares, and perineum) [110], has been a versatile pathogen implicated in a wide range of human conditions ranging from mild skin infections to severe and complicated bacteraemia, endocarditis, septicaemia, and metastatic infections [111]. Worldwide, methicillin-resistant *Staphylococcus aureus* (MRSA) is an important cause of nosocomial and community-acquired infections in humans [111]. Although MRSA is rarely isolated from animals (with only a few cases reported in dogs), staphylococci that are more prevalent in animals may also become resistant to methicillin [112]. MRSA has been detected in some domestic animal species, including cats [113], cattle [114], chickens [115], dogs [116], and horses [117]. There have also been reports of human-to-dog transmission of MRSA, where dogs were identified as the reservoirs for reinfection in humans [118].

In the present review, results showed only three studies on *Staphylococcus*, probably because it is considered a commensal and thus an opportunistic pathogen in dogs. The studies identified were studies on either MRSA or methicillin-resistant coagulase-negative staphylococci (MR-CNS) screening in apparently healthy dogs, but no study was found that reported a link between an animal isolate and a human-confirmed infection. It may appear that researchers in Nigeria are probably more interested in studies on nosocomial or hospital-acquired MRSA in humans than they are in the role of companion/domestic animals in the transmission of MRSA in the community. Although the risk of transmission from dogs (and perhaps other domestic animals) to humans may be perceived as minimal, surveys to establish a possible link between zoonotic infections are highly recommended.

4.6. Fungi

Fungi exist ubiquitously in the environment or are present as part of the microbiota and thus may rarely cause disease in healthy humans and animals [119]. In recent years, however, there has been an upsurge in the number of fungal diseases in animals caused by opportunistic and pathogenic fungi [120]. Opportunistic fungi may penetrate intact skin or, when host immunity is compromised, cause a wide range of diseases, including aspergillosis, candidiasis, cryptococcosis, mucormycosis, and infections caused by melanized fungi [120]. *Microsporum canis* and *Trichophyton* species are zoonotic in dogs [121], while opportunistic fungal agents such as *Aspergillus terreus*, *Penicillium* sp., *Paecilomyces* sp., *Chrysosporium* sp., or *Pseudallescheria boydii*. [122] have been reported in dogs.

There is a paucity of data on fungal infections in dogs in Nigeria, as observed from the results obtained in this review. With only four studies on dermatophytes and candidiasis, veterinarians and medics should be mindful of candidiasis during treatment as it sometimes occurs secondary to bacterial infections and may be responsible for resistant treatments.

4.7. Viruses

Dogs may harbor and transmit a number of viral infections to humans. Viruses such as canine parvovirus, canine coronavirus, canine distemper, canine Kobuvirus, canine influenza, infectious canine hepatitis, canine herpes virus, canine rotavirus, canine sapovirus, etc., may cause mild to severe symptoms in dogs [123–125], while rabies virus and norovirus are considered the most common zoonotic infections in dogs that can be transmitted to humans by dogs [26].

4.7.1. Influenza Viruses

Influenza A virus (IAV) known to be endemic in the gastrointestinal tract of water birds sometimes spills over and infects terrestrial bird populations (domestic chickens or turkeys) or certain mammalian populations (humans, swine, horses, seals, mink, cats, and dogs) [126]. It was not until 2004 that canine influenza virus (CIV) H3N8 was first discovered in a dog in Florida, while in 2006, H3N2 CIV was first reported in South Korea and China, but epidemics in dogs with these CIV have been rare since 2016 [127]. Both H3N8 and H3N2 CIV infections in dogs are accompanied by mild respiratory tract involvement [128], but no human infection by either of the CIV subtypes has been reported. However, dogs may be occasionally infected by the human seasonal IAV subtypes, including both H1N1 and H3N2 strains [129]. Dogs co-infected with CIV and human IAVs have been hypothesized to serve as mixing vessels for possible virus re-assortment [127].

This review identified three studies where dogs were screened for CIV antibodies: a study that screened for both H3N8 and H3N2 CIV only found antibodies to H3N8 in the tested dog sera; similarly, another study that screened both dogs and humans for H3N8 CIV found no human sample to test positive. In one of the studies, dogs screened tested positive for IAV H7 antibodies. The results obtained in this review support the literature that proposes low epidemics of CIV in dogs globally.

4.7.2. Rabies

Rabies, being a zoonotic disease with a range of animal reservoirs, continues to pose a significant threat to humans in most parts of the world [130]. Dogs shed the rabies virus in their saliva, killing over 50,000 people globally annually; approximately 95% of deaths occur in Africa and Asia [130,131]. Ninety-eight percent of human rabies deaths are as a result of a rabies-infected dog bite, and children are at greatest risk [131]. Vaccination against rabies in dogs and wildlife animals is considered the most cost-effective strategy for global control of the virus at the source [132].

Rabies is probably the most commonly studied of all the viruses in dogs, as observed in this review with rabies studies carried out across 14 states of the country. Two of the eligible studies evaluated rabies antibody titers in dogs, comparing the levels in confined dogs as against free-roaming or hunting dogs in a bid to determine the level of protection conferred (if any) by vaccines or from exposure to the virus. On the other hand, some of the studies screened for rabies antigen in brain tissues or saliva of dogs slaughtered for consumption, thus emphasizing the risk involved in the culture of dog meat consumption and the need for vaccination for high-risk individuals. Neutralizing antibodies to other Lyssa viruses, such as the Lagos bat virus and Mokola virus, were also confirmed in healthy dogs in some other studies. Overall, seroprevalence studies should be encouraged in Nigeria as post-vaccination follow-up to ensure proper protection is attained, and the data generated can also help guide policymakers in planning national control measures against rabies.

4.8. Missing Link in One Health Approach for Zoonotic Disease Diagnosis in Nigeria

The one health approach has been gaining increasing attention in recent years, with the primary aim of improving public health [133]. Articles reviewed in this study were evaluated for multidisciplinary inclusion in the individual study's design, transdisciplinary team participation, as well as resources, data, and knowledge exchange amongst human, animal, and environmental professionals. On a general assessment, the literature reviewed

lacked One Health (OH-ness) based on the adequacy of OH operations (i.e., thinking, planning, and working) and OH infrastructures (information sharing, reciprocal learning, and systemic organization) [134]. Most critical are the conceptualization/planning and the poor interdisciplinary and transdisciplinary approaches to research. This is most evident in the lack of communication between the human and veterinary medicine sectors.

A long history of poor cooperation and coordination exists among professionals in domestic and international public health and animal health agencies [135]. The majority of the studies reviewed identified the pathogens in animals, whereas the pathogens present clinical symptoms in humans when they get infected. This goes to show that the health system in Nigeria has yet to appreciate and put into practice the one health approach to disease diagnosis and management. As such, actual disease prevalence in humans may be underreported. Strong collaboration between medical and veterinary professionals is therefore encouraged in the areas of diagnosis, surveillance, and control of zoonotic diseases in Nigeria [136]. With the establishment of the Nigerian Center for Disease Control and Prevention (NCDC), the link between the medical and veterinary professions can be fostered and nurtured to allow for information transfer and the sharing of ideas, knowledge, and facilities on matters relating to zoonosis for the benefit of society. Greater integration of health policy across sectors, i.e., not just better communication but genuinely integrated approaches to health, is advocated for. There is also a need for Nigerian policymakers to prioritize public health by funding the human health and veterinary sectors to ensure the equipping of healthcare facilities and continuous training of personnel for proper diagnosis of zoonotic infections, especially as differential diagnosis seems to be a major challenge whereby diseases such as leptospirosis (among many other zoonotic diseases) that mimic febrile illnesses may tend to be misdiagnosed.

4.9. Limitations

This current review has some limitations. The exclusion of theses/dissertations, gray literature, and review articles may have already introduced a bias. In addition, searches were limited to the post-new Millennium period, thereby excluding studies prior to the year 2000. Of note is also the fact that many research articles are published in local journals that are not visible on the internet and are therefore not accessible for evaluation.

It was observed that certain states of the federation (6/37) did not have a single eligible article within the period under review; this is a major limitation as current data on zoonotic diseases of public health interest is supposedly lacking for such states, and hence disease intervention policies may have to be based on speculations or outright denial, as was observed with the COVID-19 pandemic in a north-central state of Nigeria. It is thus a challenge to give an overall zoonotic disease status for the whole country.

As all eligible studies were included in this review regardless of quality assessment (poor/medium/good), there is already a bias as randomization was not demonstrated by a good number of these studies; hence, the sample sizes used may not be a clear representation of the general population of interest. In addition, some papers evaluated disease prevalence using molecular techniques; this may be prone to reporting bias as amplification of nucleic acid does not necessarily mean an on-going infection, hence the possibility of an overrated prevalence report. However, the detection of pathogens by molecular methods plus sequencing in healthy animals (either as healthy carriers or as reservoirs of infection) is noteworthy as it can aid disease surveillance.

5. Conclusions

This review highlighted the potential role of dogs in the transmission of a range of zoonotic diseases to their owners, the environment, and other animals. Seventeen zoonotic pathogens were identified in dogs in Nigeria; a majority of the studies were on zoonotic gastrointestinal parasites of public health importance.

Studies on a number of zoonotic pathogens of dogs, such as *Bordetella bronchiseptica*, *Coxiella burnetii*, *Capnocytophaga* spp., Norovirus, *Pasteurella* spp., and *Yersinia* spp. [26], were

missing, while studies on some important zoonotic pathogens of dogs, such as *Leptospira* spp., *Salmonella* spp., *Borrelia burgdorferi*, and *Leishmania* spp., were scarce. The majority of the data consists of seroprevalence studies, but none are for validation and standardization of diagnostic techniques. The bulk of the prevalence studies or characterizations of identified pathogens considered dogs, with only a few studies actually considering both dogs and humans. It was thus difficult to ascertain the zoonotic impact of the implicated zoonotic pathogen.

Although this review was aimed at identifying zoonotic infections in humans that were directly linked to contact with a dog, very few case reports established an association between diagnoses in humans and contact with a dog. However, the current review identified the various zoonotic infections/pathogens endemic to dogs in Nigeria. The top five zoonotic diseases widely studied/identified in Nigerian dogs are toxocariasis, ancylostomiasis, tick infestation, tick-borne parasite infection, and rabies. The tick *Rhipicephalus sanguineus* is the most common tick implicated in tick-borne infections in dogs in Nigeria.

The veterinary extension services will need to enhance awareness among farmers, herders, abattoir workers, animal handlers, and the community at large on the need for animal vaccination and deworming, prompt reporting of animal bites for post-exposure care, and environmental and personal hygiene. Addressing these would considerably mitigate zoonoses transmission and, consequently, their fatal impediments. The government urgently needs to institute and enforce laws to govern the use of and access to antibiotics. Many countries have laws that ban or restrict the use of antibiotics as growth promoters or prophylaxis in farm animals [137,138], thereby minimizing the risk of the emergence of antibiotic resistance. Nigeria should adopt these international standards for responsible antibiotic use, as the abuse of antibiotics abounds in the country, whereby people self-medicate without a doctor's prescription, a practice that certainly increases the chance of pathogens developing antibiotic resistance over time.

The findings in this study's report should stimulate researchers to adopt interdisciplinary research strategies for assessing zoonotic disease burden and distribution across the country. There is obviously an urgent need for more research work at the dog-wildlife interface to both protect wildlife and also monitor for emerging and zoonotic diseases that may be transmitted through the wildlife-dog-human route of transmission. To support public health in general, the global "One Health" approach, which employs interdisciplinary collaborations and communications in all facets of animal and human health care and the environment, is highly recommended.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/zoonoticdis3020012/s1>, Table S1: Summary of 146 reviewed papers between 2000 and March 2020 [139–262].

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