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A review of risk factors at the human-animal-environmental interface of garbage dumps that are driving current and emerging zoonotic diseases

Nareerat Sangkachai [a,b,c], Bruce Gummow [c,d], Orachun Hayakijkosol [c], Sarin Suwanpakdee [b,e], Anuwat Wiratsudakul [b,e,*]

[a] ASEAN Institute for Health Development, Mahidol University, Salaya, Nakhon Pathom, Thailand
[b] The Monitoring and Surveillance Center for Zoonotic Diseases in Wildlife and Exotic Animals, Faculty of Veterinary Science, Mahidol University, Salaya, Nakhon Pathom, Thailand
[c] College of Public Health, Medical and Veterinary Sciences, James Cook University, Townsville, Queensland, Australia
[d] Department of Production Animal Studies, Faculty of Veterinary Science, University of Pretoria, Pretoria, South Africa
[e] Department of Clinical Sciences and Public Health, Faculty of Veterinary Science, Mahidol University, Salaya, Nakhon Pathom, Thailand

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ABSTRACT

An increasing trend in zoonotic and emerging infectious diseases (EIDs) has been observed worldwide. Most EID outbreaks originate from wildlife, and these outbreaks often involve pathogen–host–environment interaction. Garbage dumps act as an interface between humans, animals, and the environment, from which EIDs could arise. Therefore, this review considers the presence of important pathogens associated with animals and vectors at garbage dumps from a One Health perspective, looking at animal, human, and environmental factors that play a role. A narrative review was performed focusing on four key points, including garbage dumps, animals, waste pickers, zoonoses and EIDs. Articles addressing the presence of terrestrial animals, insects in garbage dumps, and infectious diseases among waste pickers were included in this study. There were 345 relevant articles covering 395 species of terrestrial animals and insects, consisting of 4 species of amphibians, 180 species of birds, 84 species of insects, 114 species of mammals, and 13 species of reptiles. Furthermore, 97 articles (28.12 %) addressed pathogens found in those populations. About half of the articles were interested in bacterial diseases (52.58 %), followed by parasitic diseases (30.93 %) and viral diseases (30.93 %). Zoonotic pathogens were described in 53.6 % of all articles, while 19.59 % focused on drug-resistant microbes, 13.40 % on rodent-borne diseases, and 7.21 % on vector-borne diseases. Garbage dumps would play a role in the emergence of diseases. The relevant factors at garbage dumps that may increase the risk of disease emergence include increased animal populations and density, increased vector population, newly evolved strains of pathogens, increased interaction between humans, domestic animals, wildlife, and vectors, and socio-economic factors. Therefore, sustainable waste management will reduce waste generation, and improve waste collection, and disposal which helps reduce the emergence of new diseases.

1. Introduction

A growing trend of zoonotic and emerging infectious diseases (EIDs) has been observed in the past two decades. EIDs can impact global health, socioeconomic conditions, and the environment [1]. Most EID outbreaks originate from wildlife, and these outbreaks often involve pathogen–host–environment interaction [2]. Consequently, increasing the human–animal–environmental interface increases the risk of zoonotic and emerging disease outbreaks. Furthermore, a highly integrated global economy, the accelerating increase in trade and travel, and an increase in urbanisation are helping drive EID incidents [3–5].

Increasing population density and demands of urban environments can intensify air pollution and result in insufficient water availability, poor water quality, high resource consumption, and waste disposal problems [6–8]. Waste management is one of the most challenging issues in many cities. By 2050, it is estimated that cities will generate more than six million tons of solid waste per day [8]. Waste management deserves special attention due to its impact on the environment and

* Corresponding author at: Department of Clinical Sciences and Public Health, Faculty of Veterinary Science, Mahidol University, 999 Phuttamonthon 4 Road, Salaya, Nakhon Pathom 73170, Thailand.
E-mail address: anuwat.wir@mahidol.edu (A. Wiratsudakul).

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potential health effects. Expanded waste accumulation potentially increases the risk of interspecies disease transmission [9] because garbage dumps contain a massive amount of organic waste, which can be a food source for various species of animals and insects [10,11]. Given the presence of animals and vectors in garbage dumps, zoonotic disease transmission will likely occur in these areas. In addition, waste management is closely linked to waste workers in many processes such as collection, recycling, and disposal. They have to work under unhygienic and unhealthy conditions and are likely exposed to various harmful hazards, especially in low-income countries [12]. Garbage dumps, therefore, act as an interface between humans, animals, and the environment, from which EIDs could arise, a significant public health concern as conceptualised in Fig. 1. This review aims to examine factors that play a role in the human-animal-environment interface at garbage dumps from a One Health perspective.

2. Material and methods

A narrative review was performed focusing on four key points: garbage dumps, animals, waste pickers, and zoonotic and EIDs. Three databases were Scopus, ScienceDirect, and PubMed. Search terms included “garbage dump,” OR “landfill,” OR “dump,” OR “rubbish,” OR “dumping ground,” OR “waste disposal,” OR “dumpsite”, and combined with the term “animal”. Articles in English addressing the presence of terrestrial animals and insects in garbage dumps without restriction on year or geographic localisation were included in this study. This is because most zoonotic pathogens are strongly related to the diversity and abundance of terrestrial mammals [13]. However, fish and sewage were outside the scope of this review and were excluded. Furthermore, additional searches using the terms “waste picker,” “zoonoses,” and “infectious disease” were also carried out (Fig. 2.). Articles that met the search criteria were further screened to ensure the focus remained on the interaction of humans, terrestrial animals, and insects with garbage dumps (Fig. 2.). We illustrated the host-pathogen network to visualize the importance of the species being studied. In this network, a round vertex represents a species, a square one indicates the pathogen type, and an edge between the vertices points out that the species and the pathogen are identified in the same article. The host’s vertex size is proportional to the number of articles identifying the species.

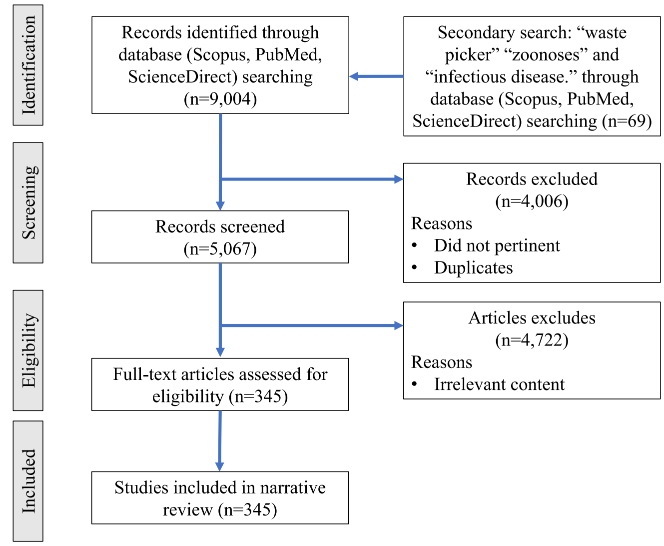


Fig. 2. Flow diagram of narrative review of literature.

3. Result

There were 345 relevant articles, of which 313 addressed terrestrial animals and insects related to garbage dumps. Thirty-four articles were associated with infectious diseases in waste pickers [11,14–46]. Studies have been conducted in 69 different countries or territories (). According to the World Bank’s classification, using income per capita data [47], the majority of these studies focused on high-income countries (47.82 %), as shown in Fig. 3.

3.1. *Anthropogenic waste-associated species*

In total, there were 395 species of terrestrial animals and insects reported at garbage dumps worldwide (Table S1 in the Supplementary Material 1), consisting of 4 species of amphibians, 180 species of birds, 84 species of insects, 114 species of mammals, and 13 species of reptiles. Amphibians reported at garbage dumps comprised 4 species in one

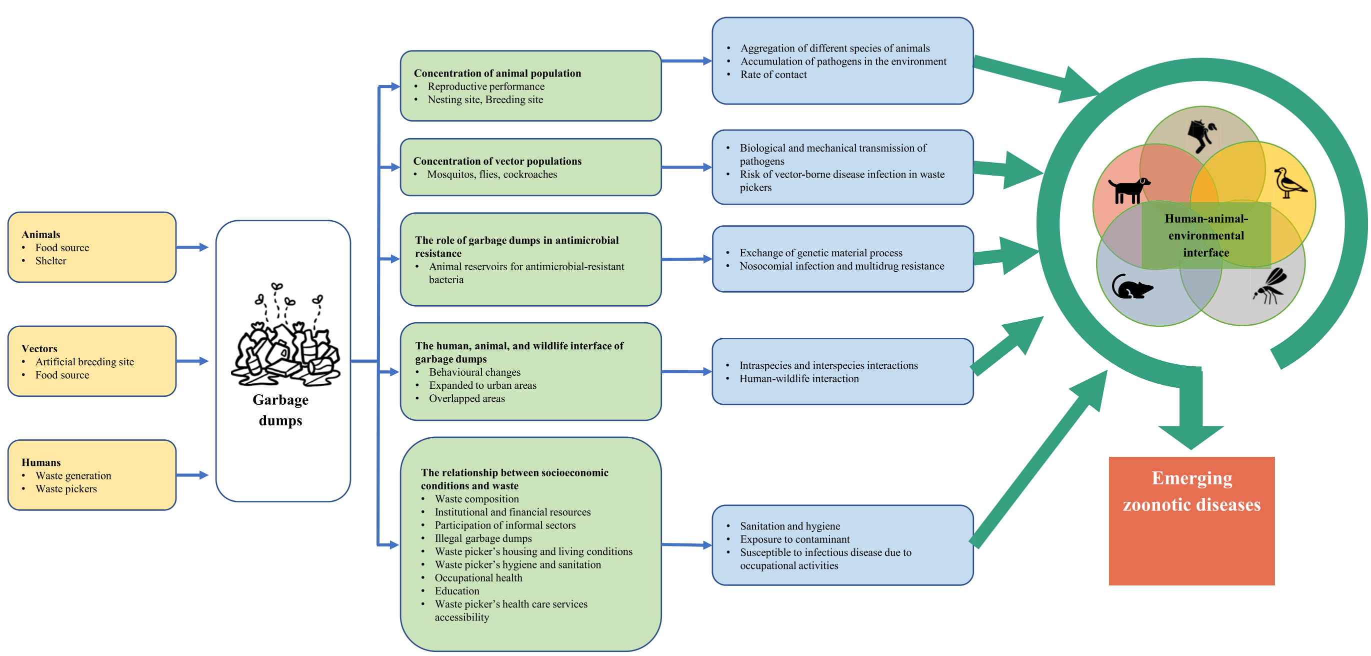


Fig. 1. Driving factors for current and emerging zoonotic diseases of the human-animal-environmental interface at garbage dump.

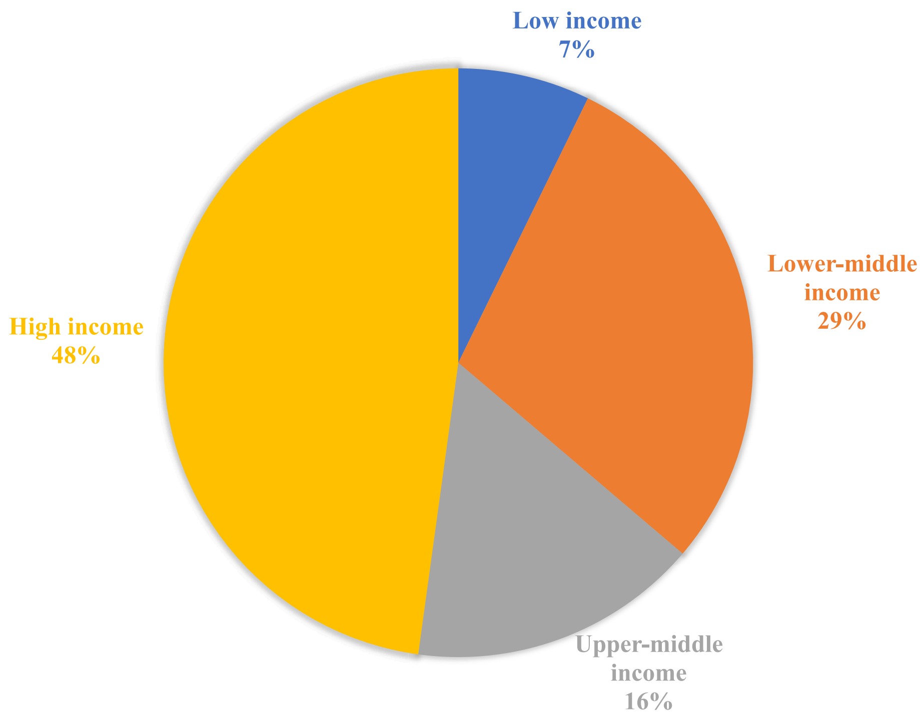


Fig. 3. The proportion of articles classified by the economic level of the country where the study was conducted.

order, Anura [48,49]. Birds reported at garbage dumps comprised of 180 species belonging to 18 orders and 48 families. Passeriformes were the largest order of birds, with 74 species (41.1 %) observed. There were 8 threatened species that were considered critically endangered species [11,50–66]. Nine orders of insects were reported at garbage dumps, comprising 39 families. Seventy percent of all insect species were in the order Diptera. Mammalia comprised 12 orders, classified into 31 families. Rodentia was the order most frequently found in reviewed articles (54 species, 47.37 %). Most rodent species were in the family Cricetidae (20.18 %, 23 species), followed by the family Muridae (20 species, 17.54 %).

Ninety-two percent of the studies were focused on wildlife with the remaining 8 % of studies focused on domestic animals including cattle (*Bos taurus*) [11,43,67–69], buffalo (*Bubalus bubalis*) [11], goats (*Capra hircus*) [11,43,70], sheep (*Ovis aries*) [43,71,72], pigs (*Sus domesticus*) [11,14,43,73,74], dogs (*Canis familiaris*) [11,43,44,67,69,75–84], cats (*Felis catus*) [49,67,69,76,85–89], donkeys (*Equus africanus*) [43], and horses (*Equus caballus*) [44]. Four species of mammals reported were endangered [69,90–93]. Additionally, there were 6 vulnerable species [67,69,94–97]. Two orders of Reptilia were reported at garbage dumps, namely *Crocodilia* [49,98] and Squamata. The majority of reptile species belonged to the family Varanidae in the order *Squamata* [69,99–105].

Animals may consume organic residues directly from garbage or use the dumps as hunting ground for prey, like small animals or insects. Sixty-four percent of articles (223) reported that numerous species used garbage dumps as food sources, including 103 species of birds [50–67,69,98,106–230], 18 species of insects [231], 54 species of mammals [68–82,84,85,88–96,98,158,188,232–276], and 7 species of reptiles [69,98–100,102–105]. Garbage dumps can be significant sources of various toxins and pollutants, posing significant risks to the environment and the health of living creatures. Based on our review, sixty articles reported that toxins and contaminants in garbage dumps affect animal health. Categorising pollutants using their chemical composition, they can be grouped into organic compounds (48.33 %), heavy metals (26.67 %), synthetic polymers (13.33 %), radioactive pollutants (6.67 %), biological contaminants (3.33 %), and inorganic pollutants (1.67 %) [48,59,60,65,67,68,71,93,95,125,130,132, 136,140,142,143,146,147,157,160,170,179,180,183,188,199,213, 214,216,217,225,229,257,275,277–304]. The most frequently observed species in garbage dumps across different continents are shown in Table 1.

3.2. Waste-borne pathogens

Only 97 articles (28.12 %) addressed pathogens found in humans and animals. Of the 97 articles, 95 studies were designed to examine pathogens in a particular species. Of these, 31 articles surveyed pathogens from birds, 28 from humans, 26 from mammals, nine from insects, and one from reptiles. Only three studies looked at pathogens in multiple species in the same study [14,43,305]. Furthermore, when classifying articles by pathogen type, about half of the articles were interested in bacterial diseases (52.58 %, 50 articles), followed by parasitic diseases (30.93 %, 30 articles) and viral diseases (30.93 %, 30 articles). Zoonotic pathogens were described in 53.6 % of all articles, while 19.59 % focused on drug-resistant microbes, 13.40 % on rodent-borne diseases, and 7.21 % on vector-borne diseases. Fig. 4 shows the relationships between animal hosts and pathogens. The largest vertex in the network is purple, representing the Brown rat (*Rattus norvegicus*) in the Mammalian group. In the Aves group (green vertex), the most studied species was the European herring gull (*Larus argentatus*) and House fly (*Musca domestica*) was the biggest vertex in the Insecta group (orange vertex). Most studies of bacteria have been carried out in birds. Antimicrobial-resistant bacteria were the most frequently highly discussed bacteria. Gulls were the most common species used to monitor antimicrobial-resistant bacteria and various foodborne zoonotic bacteria such as *Salmonella* spp., *Campylobacter* spp., and *Listeria* spp. In parasitic studies, most articles belong to the Insecta group, whereas viral diseases were primarily detected in mammals.

In humans, the commonly reported infections in waste pickers were those caused by vectors. There were cases of malaria [15–17,33] and arboviruses such as Dengue [23,33], Zika [23,25], and Chikungunya [23,25]. In the case of bacterial infections, tuberculosis was considered an important health issue for waste pickers [17,36,42] and this could be related to occupational exposures and fomites contaminated with

Table 1
Most common species found in garbage dumps across continents.

No.	Overall	Asia	Europe	Africa	South America	North America	Australia/ Oceania
1	European herring Gull *(Larus argentatus)*	House Fly *(Musca domestica)*	White Stork *(Ciconia Ciconia)*	Dog *(Canis familiaris)*	American Black Vulture *(Coragyps atratus)*	Ring-billed Gull *(Larus delawarensis)*	Dingo *(Canis familiaris dingo)*
2	White Stork *(Ciconia Ciconia)*	Brown rat *(Rattus norvegicus)*	Yellow-legged Gull *(Larus michahellis)*	Pied Crow *(Corvus albus)*	Ring-billed Gull *(Larus delawarensis)*	European herring Gull *(Larus argentatus)*	House mouse *(Mus musculus)*
3	Yellow-legged Gull *(Larus michahellis)*	Dog *(Canis familiaris)*	European herring Gull *(Larus argentatus)*	Egyptian vulture *(Neophron percnopterus)*	Turkey Vulture *(Cathartes aura)*	Common Starling *(Sturnus vulgaris)*	Brown rat *(Rattus norvegicus)*
4	Ring-billed Gull *(Larus delawarensis)*	Cat *(Felis catus)*	Lesser Black-backed Gull *(Larus fuscus)*	Pig *(Sus domesticus)*	South American Coati *(Nasua nasua)*	Great Black-backed Gull *(Larus marinus)*	Cat *(Felis catus)*
5	Brown rat *(Rattus norvegicus)*	Cattle *(Bos taurus)*	Egyptian vulture *(Neophron percnopterus)*	Cattle Egret *(Bubulcus ibis)*	Azara's Grass Mouse *(Akodon azarae)*	Brown Bear *(Ursus arctos)*	House Rat *(Rattus rattus)*
6	Dog *(Canis familiaris)*	Golden Jackal *(Canis aureus)*	Long-tailed Field Mouse *(Apodemus sylvaticus)*	Spotted Hyena *(Crocuta crocuta)*	Southern Caracara *(Caracara Plancus)*	Bald Eagle *(Haliaeetus leucocephalus)*	Australian white ibis *(Threskiornis Molucca)*
7	Common Starling *(Sturnus vulgaris)*	Oriental Latrine Fly *(Chrysomya megacephala)*	Black-headed Gull *(Larus ridibundus)*	Marabou *(Leptoptilos crumenifer)*	Brown rat *(Rattus norvegicus)*	Glaucous Gull *(Larus hyperboreus)*	Cattle *(Bos taurus)*
8	Lesser Black-backed Gull *(Larus fuscus)*	Egyptian vulture *(Neophron percnopterus)*	Carrion crow *(Corvus corone)*	Banded Mongoose *(Mungos mungo)*	House Rat *(Rattus rattus)*	Laughing Gull *(Leucophaeus atricilla)*	Hill's Brown Blowfly *(Calliphora hilli)*
9	House Rat *(Rattus rattus)*	Common Water Monitor *(Varanus salvator)*	Griffon Vulture *(Gyps fulvus)*	Yellow Baboon *(Papio cynocephalus)*	Yellow Fever Mosquito *(Aedes aegypti)*	White-footed Mouse *(Peromyscus leucopus)*	Brown Blowfly *(Calliphora stygia)*
10	Egyptian vulture *(Neophron percnopterus)*	Cattle Egret *(Bubulcus ibis)*	Caspian Gull *(Larus cachinnans)*	Black Kite *(Milvus migrans)*	Córdoba Akodont *(Akodon dolores)*	Red-winged Blackbird *(Agelaius phoeniceus)*	Dog *(Canis familiaris)*

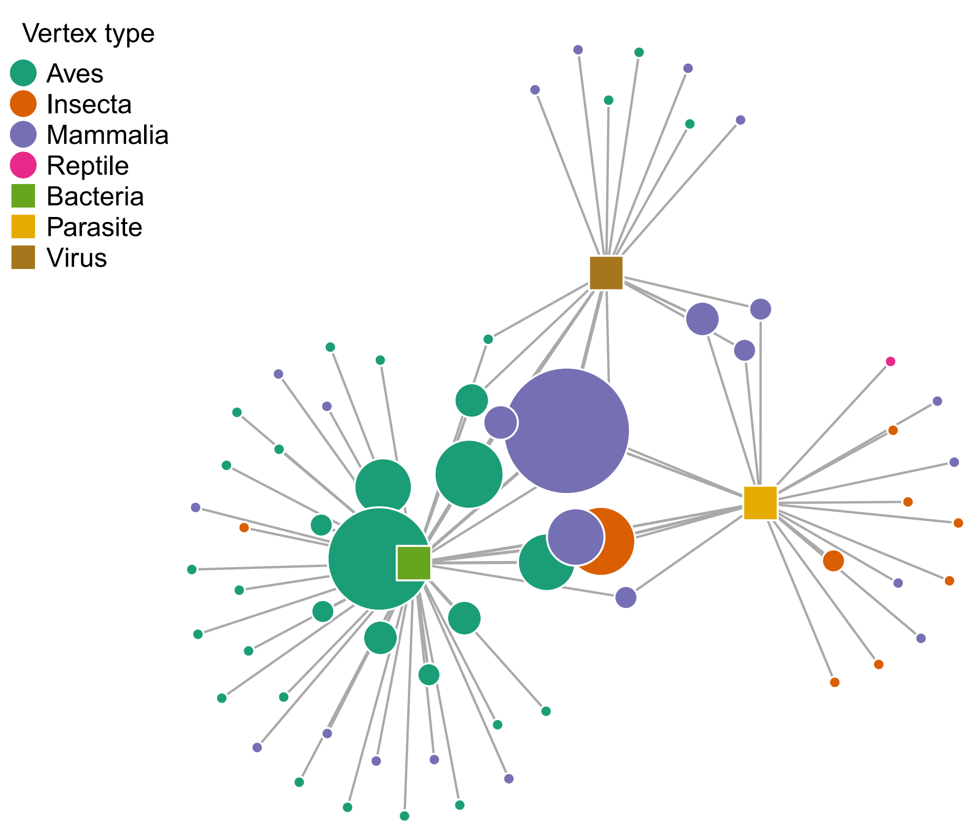


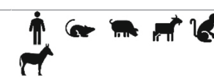
Fig. 4. The host-pathogen network based on the literature review (humans were excluded); a round vertex represents a species, a square one indicates the pathogen type, and an edge between the vertices points out that the species and the pathogen are identified in the same article. The host's vertex size is proportional to the number of articles identifying the species.

Mycobacterium tuberculosis. In animals, tuberculosis cases were found in wild olive baboon (*Papio cynocephalus anubis*) troops feeding at garbage dumps [270]. Leptospirosis was an important rodent-borne disease reported in these workers. Infections were often related to work activities such as working with garbage removal, which is a higher risk [26]. Disease transmission of *Leptospira* spp. was reportedly rodent density-dependent and the pathogen was also detected in other species foraging in garbage dumps, such as pigs, donkeys, and goats [24,38,43,97,263,306,307]. Flies and cockroaches from garbage dumps can also play a role in the transmission of enteric bacterial pathogens such as *Staphylococcus* spp., *Enterobacter* spp., *Escherichia* spp., *Klebsiella* spp., and *Salmonella* spp. [308–310].

Other articles reviewed reported parasitic diseases, including protozoa, helminths, and ectoparasites. Among garbage dump workers, cases of pathogenic protozoans and intestinal parasites were reported [16,19,21,23,24,30–32,36,39,46]. These included *Giardia lamblia*, *Entamoeba histolytica*, and *Entamoeba dispar*.

A high prevalence of *Toxoplasma gondii* infection was reported in waste pickers. The pathogen was also found in other mammal species such as the house mouse (*Mus musculus*) and goat [21,70,311]. Intestinal parasites, such as roundworms, threadworms, hookworms, whipworms, and tapeworms were found in humans and other mammals [14,16,19,22,30,44,71,73,245,255,312]. Moreover, intestinal parasitic cysts and eggs were found in flies and cockroaches [313–316]. A

Table 2
Hosts and pathogens found at garbage dumps.

Type of pathogen	Pathogens	Host at garbage dumps
Bacteria	Antimicrobial-resistant bacteria (*Escherichia coli*, *Salmonella* spp., *Campylobacter* spp., and *Listeria* spp. etc.)	
	Mycobacterium tuberculosis (Tuberculosis)	
	Leptospira spp.	
Parasite	*Plasmodium* spp. (Malaria)	
	Leishmania major (Leishmaniasis)	
	Pathogenic protozoans (*Giardia lamblia, Entamoeba histolytica*, and *Entamoeba dispar* etc.)	
	Toxoplasma gondii (Toxoplasmosis)	
	Intestinal parasites (roundworms, threadworms, hookworms, whipworms, and tapeworms)	
	Scabies	
	Haemogregarina varanicola	
Virus	Arboviruses (Dengue, Zika, Chikungunya)	
	SAR-CoV-2 (COVID-19)	
	Hepatitis A, Hepatitis B, Hepatitis C	
	Hepatitis E	
	West Nile virus	
	Avian influenza virus	
	Newcastle disease virus	
	Rabies virus	
	Human noroviruses	
	Hantavirus	
	Junin virus	
	Lymphocytic choriomeningitis virus	

common ectoparasite reported in waste pickers was scabies which can cause intense itching, rash, and skin infection [31,39]. The infection is generally caused by direct contact with contaminated waste and the environment. Faecal matter, blood, bodily fluids, and animal flesh were reported to be present at the garbage dump sites. Consuming poor food and drinking polluted water were reported as factors that contributed to serious illness at dump sites [31,34,39,317].

The majority of articles related to viruses reviewed in waste pickers were concerned with viral hepatitis, including Hepatitis A [24], Hepatitis B [28,29,32,35,40,42,45], Hepatitis C [32,35,40,45], and Hepatitis E [20,37]. In Table 2, many viruses found in animal populations around garbage dumps are with a public health concern, including avian influenza virus, West Nile virus, Newcastle disease virus, Human noroviruses, Hantavirus, Junin virus, lymphocytic choriomeningitis virus and rabies virus [80,135,241,305,318–324].

4. Discussion

Various factors drive the emergence of diseases. Increasing urban populations around the world are resulting in increasing waste production, which leads to waste accumulation in residential areas and open dumping areas. Garbage dumps are used by many species, including humans, domestic animals, wildlife, and vectors. Garbage dumps can influence the likelihood of the emergence of diseases by concentrating animal populations and vector populations and increasing interaction between humans, domestic animals, wildlife, and vectors under socio-economic condition.

4.1. Concentration of animal population

Garbage dumps are important foraging areas for many species. Compared to the natural environments, garbage dumps provide food for animals all year round. Food availability, therefore, drives the population density of various terrestrial animals, including birds, mammals, and reptiles [54,55,75,83,87,95,102,105,107,120,126,127,131,137,151,152,186,189,191,193–195,201,229,231,236,244,247,251,267,270,272,325–332]. It also enables improved reproductive performance in animals associated with garbage dumps.

An increasing number of birds have been found in flocks that rely on anthropogenic waste food sources. Various studies reported effects on the clutch size, egg volume, fledging success, and hatching success associated with food accessibility at garbage dumps in gulls [126,171,201,203,218]. For example, white stork (*Ciconia Ciconia*) foraging at the garbage dumps had better reproductive success [149,182,222,333] and a higher survival rate in juveniles [208]. Furthermore, food resource availability also influences breeding site selection. Many birds nest close to garbage dumps [62,128,151,162,177,192,204,334,335]. The number of colonies increases as the distance to garbage dumps decreases, leading to high population density around garbage dumps.

In the case of mammals, the availability and accessibility of anthropogenic food sources at garbage dumps could affect animals. Yellow baboon (*Papio cynocephalus*) feed at the garbage dumps because of easy accessibility and spending less time foraging [236,242]. Moreover, garbage dumps also play an important role as breeding grounds and shelters for animals [78,253]. An abundance of rodents was found at garbage dumps where food was easily accessible [272,332]. A study of the White-footed mouse (*Peromyscus leucopus*) living in rural garbage dumps found that the number of pregnant females increased and the garbage dump was a suitable place for birth and rearing young [87]. Bears were also found at the garbage dumps because of more food [244,246,251]. Greater reproductive success was observed in populations of American black bears (*Ursus americanus*) that feed on garbage dumps, with more cubs per litter [250]. Female garbage-feeding Banded mongoose (*Mungos mungo*) carried more foetuses which made their group larger and denser [260].

A high population density of multiple species at a dump site increases the rate of contact within and between species, allowing for the rapid transfer of pathogens and an increased chance of new pathogen strains emergence [336–338]. Animals from garbage dumps were reported to have a high prevalence of infectious diseases [97,311,318,339–341]. Therefore, the aggregation of different species of animals in large numbers around garbage dumps provides an environment that can enhance the emergence of infectious diseases.

4.2. Concentration of vector populations

The environmental conditions and related factors at the garbage dumps were suitable for increasing the population of insects and sustaining their population in urban areas. Mosquitoes, flies, and cockroaches were commonly found foraging and breeding in garbage dumps [231,308,314,328,342–346]. In addition to the variation of climatic factors, the availability of breeding sites is also an important factor affecting the number of mosquitoes. There was a positive correlation between the amount of household waste and Yellow Fever mosquito (*Aedes aegypti*) and Asian Tiger mosquito (*Aedes albopictus*) populations [346]. The areas around garbage dumps can therefore act as artificial breeding sites for mosquitoes. Moreover, there was a change in oviposition behaviour observed from *Culex usquatus*, *Lutzia bigoti*, *Anopheles argyritarsis* and *Limatus durhamii*. Immature forms of those species found at eutrophic landfills were different from those found in natural conditions [344]. Additionally, garbage management also influenced the number of *Aedes aegypti*. For example, increasing the frequency of garbage collection reduced the mosquito population [347].

A large number of flies were generally found around garbage dumps [348–352]. However, their population depended on many factors, such as environmental conditions, food availability, and suitable habitats for breeding sites [330]. The composition of garbage is one of the factors that affect fly populations. For example, animal waste or animal carcasses would attract more flesh flies (*Sarcophaga* spp.) and blowflies (*Lucilia* spp.) [231,345]. Filth flies, such as the house fly (*Musca domestica*), Lesser house fly (*Fannia canicularis*), and Bazaar fly (*Musca sorbens*) were delivered daily to garbage dumps at early stages as eggs, larvae or pupae, and some of them were able to emerge from buried refuse [328,329]. In addition, cockroaches were well adapted to human habitation associated with human waste. As they consume organic matter, increased waste accumulation leads to increased infestation. Cockroaches in households with poor waste disposal practices were found to harbor intestinal parasites, particularly *Entamoeba histolytica* and *Hymenolepis nana* which are significant concerns for public health [314,343].

Increasing vector populations may result in an increase in the risk of the spread of zoonotic and EIDs. These insects have the potential to be biological and mechanical vectors for transmission of pathogens of public health concern, including viruses, bacteria, and parasites. Therefore, waste pickers are at high risk of vector-borne disease infection that could include zoonotic diseases. They work outside with insufficient access or use of personal protective equipment. Daytime workers were more affected by vector-borne diseases than night time or mixed shift workers, and proximity to the garbage dump site was also a risk factor [25].

4.3. The role of garbage dumps in antimicrobial resistance

Many antimicrobial-resistant strains of bacteria isolated from domestic animals and wildlife were reported at garbage dumps. These bacteria had been isolated from healthy wild birds foraging in garbage dumps [106,108–114,116–118,134,168,176,200,205,339,341,353–357]. Garbage dumps are an abundant source of food that many animals can access. However, the very large population of birds at the garbage dumps also access urban, agricultural, and coastal areas. Thus, there were some antimicrobial-resistant bacteria found in gulls similar to those found in human and domestic animals. In addition, crows were found scavenging at poorly managed hospital waste dumps in Bangladesh. This increased the risk of exposure to antibiotic-resistant bacteria [118]. Furthermore, there was evidence in the United State that landfill-foraging migratory gulls were important reservoirs for antimicrobial-resistant bacteria that could disperse the pathogens across and between continents via migratory movements [108,111]. Therefore, wild birds play an important role as reservoirs and disseminators of antimicrobial resistance. However, carrier rates could vary among species with different feeding habits. For example, in Norway, high rates of campylobacter infection was found in omnivores such as crows and gulls compared to herbivores such as pigeons [115]. In South Africa, the pigs scavenging on garbage dumps contained a high diversity of bacteria and there was a potential for nosocomial infection and multidrug resistance arising from these animals. Additionally, flies could be mechanical carriers of enteric bacterial pathogens. Various bacterial genera can develop resistance through an exchange of genetic material from other resistant organisms. Garbage dumps may facilitate the exchange of genetic material among bacteria, leading to the emergence of new, drug-resistant strains. This poses a significant public health risk due to the potential for EID outbreaks.

4.4. The human, animal, and wildlife interface of garbage dumps

Garbage dumps are an important food source for many animals, and some species have adapted to rely more on them. Overlapping foraging areas increases opportunities for intraspecies and interspecies interactions. Increasing population affect interactions with humans and other species [107,126,163,201,370]. There is a high chance of wildlife moving to urban areas and interacting as the population increases in the garbage dumps. For example, troops of wild baboons in Saudi Arabia roam around garbage dumps and village areas [236,270]. American black bear (*Ursus americanus*) was also found foraging in garbage dumps and residential areas in the United States [269]. Many garbage-feeding animals have been found with behavioural changes, such as Hamadryas baboon (*Papio hamadryas*) at garbage dumps with lower flight distances [236]. In Brazil, coatis and the mongoose that fed at garbage dumps were found to develop beg-for-food behaviour [271]. Wolves also adapted behaviour to exploit food resources [76,232]. Their home range and movement overlap with those of humans and other animals, including wildlife and domestic animals, potentially causing human-wildlife conflicts [240,242,254,358]. In addition, many domestic animals, such as cats, dogs, and pigs, roamed around the garbage dumps [73,74,76,78,86,88,89]. Domestic animals found using garbage dumps could be considered a key source of zoonotic diseases because they interacted with wildlife and other animals at garbage dumps and could have close contact with humans in the households. Moreover, there were commensal and wild rodent species abundant in the garbage dumps, and their populations were associated with human activity [241,272,294,295,298–300,359,360]. The presence of rodent infestation can significantly heighten human health risks, as these populations have been found to harbor numerous zoonotic pathogens [7,97,263,266,305–307,311,312,321,323,324]. For example, Brown rats (*Rattus norvegicus*) in garbage dumps in Japan were naturally infected by *Echinococcus multilocularis*. The parasites can infect carnivores such as foxes, dogs, or cats which may be the source of human infection [312].

Furthermore, many people are also involved in solid waste management systems. Humans can take part in various processes, such as before collection, during collection, and at disposal sites where waste pickers play an important role in human–animal ecologies at the point of garbage disposal. Especially waste-pickers in low and middle-income countries, who spend the most time in garbage dumps and live in slums around those areas [11,12]. They are at high risk and more likely to be exposed to different zoonotic pathogens. Animal bite accidents were also recorded in waste pickers [15,18,32,33]. Stray dogs and other animals feeding at garbage dumps can create obstacles collecting the waste [11,20]. Additionally, human activities also influence contact with animals [78,133,235,278,283,335]. For example, during the tourist season there was an increase in the amount of waste generated and more direct contact with hand-feeding wildlife [239,250].

4.5. The relationship between socioeconomic conditions and waste

Socio-economic conditions are considered one of the drivers of EIDs events [1,361,362]. High rates of urbanisation in low- and middle-income countries were associated with increased consumption, land-use changes, and high population density that can affect disease risk to people [363,364]. The fast-growing population in the cities also increases waste production, resulting in sanitation issues. About 32, 53, and 57 % of the total food and green waste were in high, medium, and low-income countries, respectively [365]. The composition of municipal solid waste differed, depending on various factors such as economic development, culture, and climate. Disparities in waste management practices observed between developing and developed countries. The percentage of organic matter in waste composition was high in low-income countries. Uncontrolled disposal, such as open dumps with open burning, was normally found in these countries, and institutional and financial resources in low-income countries were limited. Garbage collection coverage was generally low in low-income countries and the informal sectors played an important role in many activities associated with waste disposal [8,12,366]. Improper waste management could attract different species of animals and insects to garbage dumps. Additionally, there was evidence that houseflies caught in low-income residential areas have more parasitic eggs and cysts compared to high-income residential areas [315].

In developing countries, poor waste pickers depend on waste picking as their source of income, and many local waste pickers' houses are located in slum-like areas [367]. Most waste pickers in developing countries were informal workers who were unable to access proper healthcare and, as a result, could potentially carry diseases without being able to do something about it or without being aware of disease transmission [368]. Informal waste pickers often did not have access to proper protective equipment or received proper training before entry to dumpsites. In addition, some workers refused to use personal protective equipment because of their religious faith. Some believed personal protective equipment would never protect them from sustaining injuries or contracting diseases [18]. In contrast, waste workers in developed countries often had training and guidelines for handling infectious waste [369]. Therefore, people living in low-income areas probably have a higher risk of infection.

Waste pickers were highly susceptible to infectious diseases due to occupational activities. Their activities increase the risk of infection due to exposure to waste that may contain harmful chemical and biological substances. Infection in waste pickers can arise from cuts, needle pricks, drinking unfiltered water, consumption of contaminated food, and animal or insect bites. During the COVID-19 pandemic, the increasing number of COVID-19 infections in waste pickers was linked to work routes associated with higher rates of residents' infection with COVID-19. Lack of training, protective equipment, and awareness of working with infectious waste increases the chance of infection [27]. In addition, the prevalence of *Toxoplasma gondii* infection was higher among workers at the waste transfer station than in drivers or helpers of waste vehicles [21].

In high-income countries, policies to increase public participation in recycling and use incinerators were implemented to sustain waste management services. These can decrease the number of garbage dumps, animals, and waste pickers. Closing the garbage dumps had a huge impact on scavenging animals around the sites. This leads to a reduction in the number of vectors as the availability of the habitats decreases. Therefore, better waste management will reduce interaction between humans, animals, vectors, and pathogens in the garbage dumps. Sustainable waste management will also reduce the impact on health and the environment. Starting with reducing waste generation at the household level by educating and encouraging people to make zero-waste living. The safety guidelines should be developed. Waste workers should receive regular training and have protective equipment to ensure safety in waste collection and disposal. Besides that, appropriate disposal methods and locations are also important to reduce the health and environmental impacts.

Our review study may have encountered reporting bias, as a significant portion of the literature we examined was conducted in high-income countries, which have the resources for research and disease surveillance. Low-income countries, on the other hand, may not be capable of reflecting their current situation due to the scarcity of finances and manpower. Moreover, most waste pickers in developing countries are unregistered, resulting in a lack of medical records in the official system.

5. Conclusion

The human-animal-environmental interaction found around garbage dumps may profoundly increase the risk of infectious disease emergence. The availability of food in garbage dumps was a key factor affecting reproductive performance, physical condition, and behaviour of wildlife, domestic animals, and insects. Garbage dumps increase animal density and insect population, which may raise the risk of EIDs because it increases the intersection between wildlife, domestic animals, vectors, and humans, which enhances the likelihood of pathogen evolution and transmission. Thus, emphasising the need for a holistic approach for effective disease prevention and control. It is apparent, therefore that future studies should apply a One Health approach to comprehensively examine the disease ecology within garbage dumps and that better waste management will reduce interaction between humans, animals, vectors, and pathogens in the garbage dumps, which are key factors in reducing the impact on health and environment.

CRediT authorship contribution statement

Nareerat Sangkachai: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Bruce Gummow:** Writing – review & editing, Validation, Supervision, Project administration, Conceptualization. **Orachun Hayakijkosol:** Writing – review & editing, Validation, Supervision, Conceptualization. **Sarin Suwanpakdee:** Writing – review & editing, Validation, Supervision, Conceptualization. **Anuwat Wiratsudakul:** Writing – review & editing, Validation, Supervision, Project administration, Formal analysis, Conceptualization.

Declaration of competing interest

The authors have no competing interests to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.onehlt.2024.100915.

Data availability

Non-confidential data can be shared upon request.

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