Zoonotic Enteric Parasites

A One Health Guide for Preventing Infection

Nomadic Gadrias, originally from Rajasthan, travel with their livestock to sources of water and fodder in Dhar, India, where they also sell milk and wool. © 2008 chetan soni, Courtesy of Photoshare

Duke One Health

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Foreward

Throughout the world, humans and animals share the same environments. For many people, contact with domesticated animals occurs daily through animal husbandry or cohabitation with a pet. Humans are also connected to wildlife through shared natural habitats such as forests and rivers and due to encroachment into previously undisturbed ecosystems. Human movement and changing landscapes and climates have also lead to increased contact between wildlife, domesticated animals and disease vectors.

Typically, our human-animal interactions are positive. Animals and animal-based products provide us with a multitude of benefits, including income generation and protein-based nutrition. Aside from their practical uses, humans also enjoy animal companionship and appreciate wildlife as evidenced by the pet industry, wildlife conservation efforts, animal welfare laws and regulations, zoo visitations, and the creation of animal sanctuaries and rescue organizations.

While the human-animal bond is quite profound, within this relationship lurks the potential for disease exposure- particularly in the form of zoonotic enteric parasites (ZEPs). However, by heeding One Health guidelines for safe human and animal contact, we can reduce the opportunity for zoonoses in our communities and protect our shared environments from harboring these dangerous parasites. The goal of this guide and its accompanying material is to provide human, animal, environmental, and public health care providers with information on how to prevent zoonotic enteric parasites. Practicing the positive public health measures presented in this guide will protect our families, our animals, and our communal ecosystems from the spread of zoonotic pathogens and will ensure a healthier world for us all.

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A livestock health worker holds a baby goat in Bangladesh.
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List of Abbreviations

ZEP	Zoonotic Enteric Parasite
WHO	World Health Organization
EE	Environmental Enteropathy
EED	Environmental Enteric Dysfunction
FBD	Foodborne Disease
MDG	Millennium Development Goal
SDG	Sustainable Development Goal

Smiling children with their goats in Nilphamari, Bangladesh. © 2015 Asad Rassel, Courtesy of Photoshare

Introduction

Zoonotic Enteric Parasites (ZEPs)

Zoonotic enteric parasites, or ZEPs, are transmitted by the ingestion of a parasite that was passed through an animal or completed a stage of its life cycle in an animal host. Parasites are organisms that benefit from a bond with a host while the host is harmed by the relationship Humans can also pass ZEPs to other animals, including other humans. There are many different categories of zoonotic enteric parasites that pose a health threat to humans and animals, as shown below (Table 1).

Although many parasitic-host interactions are asymptomatic in the host, some infections lead to short-term illness or even chronic disease.[1] The common symptom of infection with these pathogens is diarrheal disease in an animal or person, which can be fatal in an immunocompromised host or if left untreated. Chronic diarrheal illness from continued exposure to enteric pathogens can also lead to nutritional disorders and stunting, cognitive and developmental delays, and poor oral vaccine efficacy due to a condition known as Environmental Enteropathy (EE) or Environmental Enteric Dysfunction (EED).[2] Some chronic infections with ZEPs have even been shown to cause cancer and epilepsy if initial treatment is not administered.[3-4]

A man and his water buffalo bathe at a pond in India. © 2012 Dipayan Bhar, Courtesy of Photoshare

An 18-year-old woman cares for a yak in Pamirs, Tajikistan, one of the highest, most remote places in the world.© 2013 Alovaddin K., Courtesy of Photoshare

Table 1. Examples of diseases caused by Zoonotic Enteric Parasites (ZEPs)

Parasitic zoonosis	Synonyms and Related Terms	Pathogen Names
Cestodes		
Alveolar echinococcosis	Alveolar hydatidosis	*Echinococcus multilocularis*
Cystic echinococcosis	Hydatid disease	*Echinococcus granulosus*
	Hydatidosis	Hydatid cyst
Cysticercosis	Neurocysticercosis	*Taenia solium*
Diphyllobothriosis	Diphyllobothriasis	*Diphyllobothrium*
	Bothriocephalosis	*Bothriocephalus*
	Bothriocephaliasis	Broad tapeworm
		Fish tapeworm
Sparganosis	Spirometrosis	*Spirometra*
		Sparganum
Taeniosis	Taeniasis	*Taenia*
	Tapeworm	
Fungi		
Zoonotic microspora	Microsporidia	*Enterocytozooan bieneusi*
		Encephalitozoon cuniculi
		Encephalitozoon intestinalis
		Encephalitozoon hellem
		\`Pleistophora-like organisms'
Nematodes		
Angiostrongylosis	Angiostrongyliasis	*Angiostrongylus cantonensis*
Anisakidae infections		*Anisakis*
		Pseudoterranova
Capillariosis	Capillariasis	*Capillaria*
Gnathostomosis	Gnathostomiasis	*Gnathostoma*

Table 1. Continued

Toxocarosis	Toxocariasis	*Toxocara*
	Toxocariosis	
	Larva migrans	
Trichinellosis	Trichinosis	*Trichinella*
Zoonotic intestinal helminth infection	Helminthosis	Helminth
	Helminthiasis	*Ascaris*
	Ascarosis	*Ancylostoma*
	Ascariasis	Hookworm
	Ancylostomosis	*Trichuris*
	Ancylostomiasis	*Strongyloides*
	Trichuriosis	*Alaria*
	Trichuriasis	rat lungworm
	Strongyloidosis	*Echinostoma spp.*
	Strongyloidiasis	*Lagochilascaris minor*
Toxoplasmosis	TORCH	*Toxoplasma*
Zoonotic intestinal protozoal infection	Protozoosis	Protozoa
	Protozoasis	*Giardia*
	Giardiosis	*Cryptosporidium*
	Giardiasis.	*Blastocystis*
	Cryptosporidiosis	*Sarcocystis*
	Blastocystosis	*Cyclospora cayetanensis*
	Sarcocystosis	*Entamoeba histolytica*
	Cyclosporiasis	*Balantidium coli*
	Cyclospora	
	Amoebiasis	
	Amoebic dysentery	
	Entamoeba	
	Balantidosis	

Table 1. Continued

Zoonotic trypanosomosis	Trypanosomiasis	*Trypanosoma cruzi*
	Chagas	
Trematodes		
Foodborne trematodosis	Trematodiasis Fasciolosis	Fluke Trematode
	Fascioliosis	*Fasciola spp.*
	Fasciolasis	*Fasciolopsis*
	Fascioliasis	*Opisthorchis*
	Distomatosis	*Clonorchis*
	Fasciolopsosis	*Paragonimus*
	Fasciolopsiosis	Minute intestinal fluke
	Opisthorchosis	*Haplorchis pumilio*
	Opisthorchiasis	*Metagonimus yokogawai*
	Clonorchiosis	*Heterophyes spp.*
	Clonorchiasis	
	Paragonimosis	
	Paragonimiasis	
	Metagonimus	
	Heterophyiasis	
	Heterophyiasis	
Pentastomes		
Zoonotic pentastomes	Pentastomiasis	*Armillifer armillatus*
	Linguatulosis	*Armillifer moniliformis*
		Linguatula serrate Tongue worms

Table adapted from Barnes, A. N., Davaasuren, A., Baasandagva, U., & Gray, G. C. (2017). A systematic review of zoonotic enteric parasitic diseases among nomadic and pastoral people. *PloS one*, *12*(11), e0188809.

In the World Health Organization's report "Estimates of the Global Burden of Foodborne Diseases", 17 zoonotic enteric parasites were selected as high priority for their foodborne transmission potential, severity and frequency of illness, global significance, and outbreak potential based on existing data.[5] These ZEPs included the cestode species *Echinococcus multilocularis* and *Taenia solium*, the nematode *Ascaris* spp. and *Trichinella* spp., protozoan species of *Toxoplasma gondii, Cryptosporidium* spp., *Giardia* spp, and *Entamoeba histolytica*, and the trematode species of *Clonorchis sinensis, Fasciola* spp., *Echinostoma* spp., *Fasciolopsis buski, Heterophyes* spp., *Metagonimus* spp., *Opisthorchis* spp., and *Paragonimus* spp.[5]

Understanding how to prevent ZEP exposure and infection among humans, animals, and their shared environment should be a priority for health care providers and public health professionals of all disciplines. This toolkit will provide the reader with a One Health approach for preventing infection, identifying cases and controlling the spread of zoonotic enteric parasites.

A grandmother in Kenya with her orphaned grandson and the high-yield dairy goat supplied to them by Project Harambee in Naivasha, Kenya.© 2003 Keen Harrison/Project Harambee, Courtesy of Photoshare

A fisherman's children study their lessons in Chittagong, Bangladesh. © 2014 Faisal Azim, Courtesy of Photoshare

ZEPs and One Health


A man in Sunamganj, Bangladesh, feeds the ducks he keeps to earn his livelihood.© 2013 Prashanta Hridoy, Courtesy of Photoshare

One Health is a holistic approach to fight complex global health issues. One Health simultaneously focuses on improving human, animal and environmental health, sustainable development and practices, protecting our shared natural resources, the production of safe and accessible food, and securing the livelihoods of our most vulnerable communities.[6] Since humans and animals share the same space on this planet, we must create environments that are healthy and free from pollution, including that of zoonotic pathogens.[7] To do this, One Health relies on experts and research from multiple disciplines such as medicine and public health, veterinary science, anthropology, biology, ecology and conservation, zoology, climatology, mathematical modeling and spatial analysis, urban planning, epidemiology, demographics, and many more. By utilizing information from all of these fields, One Health practitioners and researchers work together to come up with solutions to pressing problems like zoonotic enteric parasites and their transmission between people, animals, and our ecosystems.

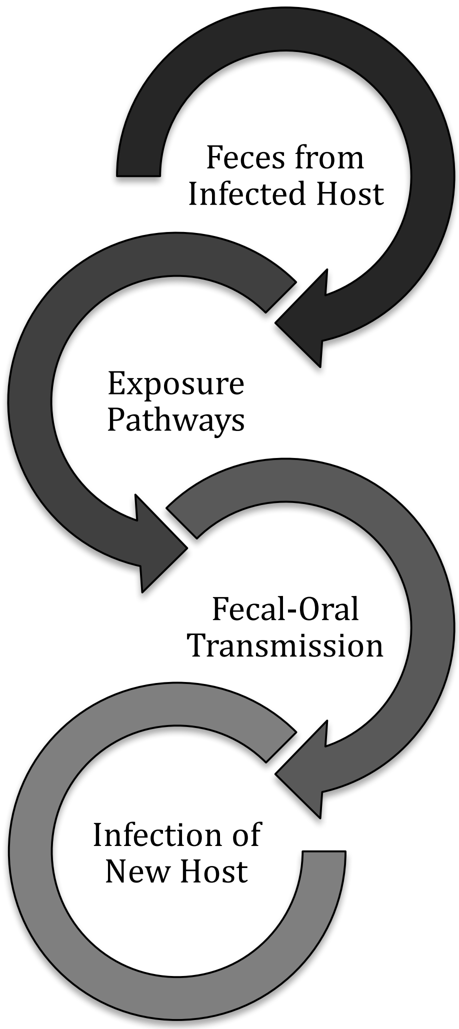
There are many exposure pathways for acquiring a zoonotic enteric parasite from an animal, another human, or the environment. As the name suggests, this type of parasite must be ingested in order to infect the host, which most frequently occurs via the fecal-oral route. While transmission is often through the consumption of food or water that has been contaminated with the infected feces of a person or animal, there are other routes in which we can accidentally ingest these parasites.

Traditionally, a conceptual framework known as the F-diagram has been used to demonstrate how diarrheal pathogens can be transmitted from the feces of an infected host through contaminated fingers, flies, fomites, fluids and fields/floors to food or drinking water that is ingested by a susceptible host.[8] This allows the parasite to continue its life cycle until it is released back into the environment to start the process again.

While the original model takes into consideration the human fecal contribution to diarrheal disease risk, it does not examine the role of animals in the spread of these enteric pathogens. A more complete fecal-oral transmission model using a One Health approach is needed to explore the contribution of zoonotic enteric parasites to diarrheal disease (Figure 1). When considering the risk of ZEP infection in humans and animals, it is important to assess the different routes of exposure for each potential host. Once these zoonotic risk factors have been identified, One Health interventions can be applied to prevent the further spread of disease.

A girl living in a shanty drinks water from a hydrant beside a canal carrying pollutants discharged by hundreds of toxic tanneries in the Hazaribagh neighborhood of Dhaka, Bangladesh. © 2014 Farid Ahmed, Courtesy of Photoshare

Children play near a stream of raw sewage flowing through the Kibera slum of Nairobi, Kenya. © 2014 Greg Allgood,, Courtesy of Photoshare



- Companion animals
- Livestock
- Wildlife
- Synanthropic rodents
- Humans

- Food
- Fluids
- Floors/Fields
- Fur/Feathers
- Fingers
- Fomites
- Flies

- Consumption of contaminated food or water
- Accidental ingestion through contact with contaminated soil or items (e.g. child putting toy in mouth)

- Diarrheal illness and/or other symptoms of enteric disease
- Asymptomatic infection

Figure 1. A modified fecal-oral transmission model including zoonotic contributions. Adapted from Wagner, E.; Lanoix, J., Excreta disposal for rural areas and small communities. Monograph Series World Health Organization. 1958, 39, 182. Copyright 1958, World Health

Risk Factors for ZEP Exposure

ZEP Risk Factors for Humans

Cases of enteric parasites, particularly zoonotic parasites, are increasing due to multiple One Health drivers. These include, but are not limited to:

1. Dietary changes, such as trends to eat more raw or lightly cooked foods and the demand for bush meat or exotic culinary items;
2. Urban population growth;
3. Growing global food markets where the sale of vegetables, fruits, ethnic food items, meat and livestock across country borders means different food safety procedures and oversight;
4. Faster transport times that enable parasites to live on food items for longer and to remain infectious upon arrival;
5. More movement of people across national boundaries, potentially carrying parasites with them;
6. Increased demand for meat and milk-based products and a more meat-based diet expanding into populations that previously relied on a plant-based diet;
7. A higher percentage of immunocompromised individuals in an increasingly aging population with longer life expectancy due to advanced health care and treatment options;
8. Farming practices have changed from small backyard farms to large, industrialized operations;
9. Geopolitics and conflict force the movement of people and animals and prohibit structured veterinary services or supervised production;
10. Human movement into previously wild habitat for development, pasture, logging, etc.;
11. Climate change and temperature-associated expansion of disease vectors and novel zoonotic disease spillover events.[9-10]

ZEPs are regarded as foodborne diseases (FBDs) since they are commonly transmitted through ingested food.[11] Humans are exposed to ZEPs by accidentally eating or drinking the parasite during its infectious life cycle stage (ex. cysts, oocysts, ova, larva, spore, or encysted stage) or through consuming raw or undercooked animal meat/tissue that contains the parasite.[12] Cysts and oocysts are some of the terms to describe the developmental stages of certain parasites' life cycles in which they are too tiny to see with the naked eye but can be transmitted to animals, people, and the environment. For many parasitic zoonoses, it only takes an exposure to a small number of cysts or oocysts for infection to occur.[13] Humans and animals infected with a zoonotic enteric parasite can shed billions of the cysts and oocysts every day in their stool.[13] In fact, a single adult sheep or goat can produce 1-kg of feces each day.[14] Domestic animals such as livestock and poultry contribute to 85% of the world's animal fecal waste, a much larger proportion than the contribution of human waste.[15] Once in the environment, cysts and oocysts can remain infectious for long periods of time with many species resistant to standard water treatment systems and disinfectants, and do not dry out.[1,13] Parasites, unlike bacteria, do not multiply outside of a human or animal host and are not susceptible to antibiotics that are used to kill foodborne bacterial infections.[1] Using antibiotics to try to combat ZEPs can increase the risk for antibiotic resistance among human and animal populations.

A little boy stands with a goat on top of a hill in the Muramvya province of Burundi.© 2003 Isabelle Walhin, Courtesy of Photoshare

The presence of fecal matter in a household, living area, or community space can be due to a lack of safe sanitation measures to dispose of human waste, poor usage of the available sanitation measures, and indiscriminate animal waste demonstrating the One Health challenge to preventing diarrheal disease and zoonotic enteric parasite transmission. [16] Animal waste exposure may occur more commonly in developing countries where animals are allowed to roam freely, defecate arbitrarily, and are not separated from the domestic environment, as compared to higher income countries.[17] These regions typically also have more smallholder farms across urban, peri-urban, and rural communities.[17-18] Although higher income countries may not experience as much close contact with livestock or free-roaming domestic animals, pet ownership within these regions present alternative exposure pathways. In addition, the increasing trade of animal products and ongoing human movement mean ZEPs are being introduced or reintroduced into new regions.[19] Knowing the exposure risks for acquiring a ZEP infection can lead to better health promotion strategies to avoid transmission among humans and animals. The primary pathways for ZEP transmission are described below.

Food

Geography, ethnicity, religion, and culture can all impact the foods we eat and how we prepare them.[13] Zoonotic enteric parasites can be transferred to food and drinking water through poor sanitation and hygiene measures.[20-21] Livestock waste can contaminate food crops in the field by run off from fecally-polluted water used for irrigation or watering of animals.[21-22] Parasites can also be deposited on salad crops through contaminated water used in the packing houses or at the market displays and can taint meat products during the slaughtering process.[17,20,22] Filth flies or other vectors can spread zoonotic enteric parasites by carrying them from both on and inside their bodies.[22]

In fact, ZEP contamination of food products can be caused by a number of different sources such as:

1. Poor personal hygiene practices among food handlers
2. Use of contaminated animal or human waste as crop fertilizer
3. Infected livestock grazing near food crops
4. The defecation of infected wildlife in or near crops
5. Food items contaminated with feces from infected synanthropic rodents, birds, or insect vectors (e.g. flies)
6. Aerosolized contaminants from slurry spraying and manure spreading
7. Contaminated water used for irrigating crops
8. Use of contaminated water to "wash" vegetables eaten raw or uncooked
9. Use of contaminated water for making ice, frozen foods or products that do not receive sufficient heat treatment prior to consumption[22]

A farmer waters his vegetable crops in the Philippines. © Rodolfo Vincente, Courtesy of Photoshare.

A migrant street vendor prepared "litti," a baked snack, at the wholesale market in Sheoraphuli, India © Rajib Singha, Courtesy of Photoshare.

Vegetables, Herbs, and Fruits

Though varied in nature, the diets of different populations around the globe often include raw or lightly cooked fruits and vegetables, which have been demonstrated to reduce the risk of hypertension, coronary heart disease, stroke, dementia, cancer, and diabetes and provide a source of energy and critical nutrients and minerals.[13,23-39] However, consuming unwashed or unclean raw and undercooked vegetables can put you at risk for ZEP exposure.[20-21,23,26,]

Zoonotic enteric parasites have been found on vegetables, herbs, and fruits and fruit juices.[20-21,26,40] The shape and surface of a fruit or vegetable may determine how contaminated the food item can become with parasite oocysts and cysts.[21] For example, some studies have shown that large, leafy vegetables have more surface area for parasites to stick while items with rough surfaces have the ability for parasites to adhere through a light washing.[20.26] In research done on the parasitic contamination of salad vegetables, smooth surface items such as leeks and green onion had lower parasite burdens than their leafy counterparts of lettuce, watercress or parsley.[21] The difference in vegetable parasite contamination may also be due to the way the vegetable or fruit grows and whether it has more contact with soil (ex. lettuce and parsley) as opposed to plants that grow off the ground (ex. tomatoes and cucumbers).[41]

ZEP contamination of vegetables, herbs, and fruits may also be seasonal. Research has shown higher parasite loads on raw vegetables during the warmer months.[21,42-44] There is some work to suggest this is because there are more parasite eggs or oocysts shed in the feces of humans and animals during warmer seasons than in colder ones [21,43,45]

The agricultural process of growing crops for human consumption allows for many opportunities for parasite contamination. For example, at the growing stage, vegetables, herbs, and fruits are grown in soil that can be polluted by poorly managed human or animal waste.[20,26] ZEPs from infected people, domestic animals, wildlife, and synanthropic rodents can accumulate on the ground near crops and attach to the food items. In addition, irrigation water used for vegetables and fruits can be contaminated with parasites from the runoff of domestic animal and human waste that pollute watersheds and bodies of water used for agriculture.[20-21,26,46] In certain instances, untreated sewage water is purposely used for irrigation.[21] It is also a common practice in many countries to use animal manure or even human feces (known as 'night soil') to fertilize fields of growing crops, which can introduce parasites and other infectious disease to the food items.[11,21,41]

Women sell mangoes and a fruit called "maad" (wild fruit) at a roadside market at the border town of Bambatenda, The Gambia, along the Trans-Gambia Highway.© 2006 Sara A. Holtz, Courtesy of Photoshare

After the vegetable, herb, or fruit is grown and is ready for sale, there are still many occasions for ZEP contamination prior to food consumption. Food handlers in developing nations typically have little education or instruction on safe practices for food preservation or personal hygiene measures.[21,26,47-48] This leads to the spread of parasites to food products during the course of harvesting, transport, processing, storage, and distribution.[20,23,49] Food products may be stored or transported without temperature control and in dirty bags or boxes.[47-48] Vegetables in open-air markets may be displayed on the floor and if unsold, they may be left at the market or taken to a shop owner's backyard.[20,47] This can expose the items to flies and other parasite vectors such as synanthropic rodents.[20]

In order to keep vegetables, herbs, and fruits fresh during their display, water is often sprinkled onto the produce. However, studies have found the water used to splash onto vegetables to keep them from wilting and to appear fresh is often dirty and tainted with zoonotic enteric parasites.[23,48] When vegetables and fruits are washed, the cleanliness of the food product is dependent upon the safety of the water used. Researchers have found that washing produce with dirty, contaminated water can actually put ZEPs onto the surface of a previously clean food item.[11,47-48] And due to the fragile nature of some vegetables, such as lettuce leaves, some vendors choose not to wash these items at all before sale.[48] However, when fresh vegetables and fruits are washed with clean water either prior to sale or consumption, the risk for parasite exposure from eating that food item is reduced.[20,48-50] Differences between the sale of vegetables and fruits in open-air markets versus supermarkets can also impact contamination risk. In open-air markets and with street vendors, food items are exposed to flies and may be displayed on the ground, in pans or other containers, or on top of unwashed fabric or blankets.[48] However, the cost of these vegetables and fruits tends to be lower than that of a supermarket and appeal to many consumers who prefer this type of grocer. Yet, in the supermarket these food items are typically washed, packaged, and refrigerated.[48]

Once the produce is purchased by an open-air market, street vendor or supermarket, safe food handling is up to the consumer or person in charge of preparing meals in the household. The consumption of contaminated food items in the household can be due to negligence in washing or cooking the produce with clean water or insufficient heat to cook the food. Many households across the globe use animal dung as a heating or cooking source. Although typically dried by the sun prior to use, the dung is often formed with bare hands when still fresh which can facilitate the spread of ZEPs to food in the home through unwashed hands.[16]

Meat and Milk

The consumption of animal products such as meat and milk is on the rise, especially among developing nations.[51] This dietary change is leading to more exposure with zoonotic disease, especially parasitic zoonoses. The role of animals as a source of food is unique to each society and religion and varies across animal species.[9,13] ZEP exposure from meat, blood and milk products is often overlooked and should be considered when examining risk factors for transmission.

Several ZEPs are found in animal tissue or meat such as *Toxoplasma gondii, Taenia solium*, and *Trichinella spp*..[13] ZEP infection of animal tissue or products can occur from the animals grazing on contaminated pasture where human and animal waste is present or from being fed infected material, such as the meat of another animal.[13,54-55]Domestic animals such as pigs and cattle can harbor zoonotic enteric parasites in their flesh.[13,52] Wild game such as bear, crocodiles, and seals have also been shown to have ZEP cysts in their tissue.[13] Humans are infected with the parasite by eating the

Villagers render fresh meat in Mankhan Soum, Hovd Aimag, Mongolia.© 2004 Mark Rosenwald, Courtesy of Photoshare

Villagers render fresh meat in Mankhan Soum, Hovd Aimag, Mongolia.© 2004 Mark Rosenwald, Courtesy of Photoshare raw or undercooked animal tissue that contains cysts.[11,40,53] Meat from carnivorous or scavenging animals has been demonstrated as an exposure risk if the food is not properly prepared.[13] ZEPs can also be present on the udders of an infected animal and lead to the transmission of the parasite to milk products, which remain an exposure risk to humans if consumed raw or unpasteurized.[57] And because of contact with animal tissue and blood, workers in slaughterhouses or abattoirs, butchers, and meat inspectors have demonstrated higher infection with these ZEPs.[13,58] Backyard animal slaughters are carried out in developing countries with little oversight into hygiene measures or the quality of the meat produced.[52]

Vendors sell seafood at a market in Kampot, Cambodia. © Esther Braud, Courtesy of Photoshare.

ZEP exposure from the consumption of meat, blood, or milk products occurs when food preparation methods fail to inactivate or remove infectious parasites. Smoking, curing, fermenting, air-drying, and raw preparation of fish, meat, and crustaceans can put a person at risk for the transmission of several ZEPs.[13] Understanding the specialized diets and food preparation techniques and customs of a population at risk will mean more tailored and effective prevention strategies and education efforts.

Fish, Crustaceans, Snails, Reptiles, Amphibians, etc.

Undercooked and raw fish, crustaceans, snail, reptiles, and amphibians can spread the ZEPs of *Opisthorchis spp., Conorchis sinensis, Gnathostoma spp., Anisakidae*, and other intestinal flukes or pentastomids.[40] The life cycles of these parasites are perpetuated by the domestic and wild animals who eat them or have contact with them.[13] For many cultures, seafood items are eaten raw such as sushi, sashimi, koi-pla, kinilaw, or ceviche.[13] These once unique food items are becoming increasingly common internationally due to travel, immigration, and media trends.[13] As is the case with the meat-borne ZEPs previously discussed, the parasite is encapsulated in the tissue of the animal tissue and is accidentally eaten by a human or other animal.[13] If proper food preparation methods are not used, the parasite remains infectious and can then transmit disease to the person or animal that consumes it. Traditional treatments such as freezing, heating, or salting can prevent the spread of the ZEP if they are done correctly.[40] However, smoking, picking, and brining of fish, crabs, mollusks, snails, and other animals may not be enough to kill the parasite living in the animal's tissue.[13,40,59] Understanding the zoonotic enteric parasite risks associated with the animal species meant for consumption, along with the ZEPs endemic to the geographical area, should assist with safe food preparation methods to avoid transmission.

Children play in water from a drainage runoff near Agra Fort, Uttar Pradesh, India. © 2013 vijeesh/igsss, Courtesy of Photoshare.

Water

For many zoonotic enteric parasites, water is critical for their development stages and their spread throughout the environment.[12,40] Water moves the parasites into water bodies used for recreation, washing, fishing and aquaculture, irrigation of crops, water for livestock operations, and as the drinking water source for humans, domestic animals, and wildlife.[12,41,46] Water is also used to wash food items prior to consumption and cooking, which can also expose a person to a ZEP.[12] In many studies that look at the causes of enteric disease, most of the illness triggered by parasites is credited to a water exposure.[60]

As mentioned before, unmanaged waste from humans and animals can pollute water environments.[12,22] Open ponds and surface water is more susceptible to animal fecal waste but it can also taint public and private tube wells with ZEPs.[17,61-63] Despite this, some people have reported a preference for defecation near streams, thus contributing to the fecal contamination of the water source.[50,64]

Water that contains ZEPs can be consumed directly by drinking unboiled or untreated water but also by having contact with a polluted water source.[50] Bathing in contaminated water sources, playing in water (ex. swimming), fishing or collecting food items grown in water, and simply having water contact for domestic chores have all been shown to increase the exposure risk for zoonotic enteric parasites.[13,50,65] Table 2 outlines food and water sources that have been associated with ZEP transmission.

Table 2. Zoonotic Enteric Parasites Found in Food Products

Foods	Protozoa	Nematodes	Cestodes	Trematodes
Beef	Toxoplasma gondii Cryptosporidium parvum		Taenia saginata	Fasciola hepatica
Pork	Toxoplasma gondii	Trichinella spp.	Taenia solium/asiatica	
Other Meat	Toxoplasma Cryptosporidium (sheep/goat)	Trichinella spp. (horse, wild boar bear, walrus, crocodile, Gnathostoma (frogs)	Alaria alata (wild boar)	Paragonimus (wild boar)
Milk	Toxoplasma Cryptosporidium			
Fish/squid		Anisakis spp. Gnathostoma	Diphyllobothrium	Clonorchis Opisthorchis
Crabs, shrimps		Gnathostoma		Paragonimus
Shell fish	Cryptosporidium spp. Giardia lamblia Toxoplasma gondii	Gnathostoma		Echinostomes
Snails/slugs		Angiostrongylus		Echinostomes
Fruit/ vegetables (raw)	Cyclospora Cryptosporidium spp. Giardia lamblia Toxoplasma gondii Entamoeba histolytica Balantidium coli Trypanosoma cruzi	Angiostrongylus Ascaris Toxocara Baylisascaris spp Trichuris trichiura	Echinococcus Taenia solium	Fasciola hepatica Fasciolopsis
Water	Cyclospora Cryptosporidium Giardia lamblia Toxoplasma gondii Balantidium coli	Ascaris	Echinococcus	Fasciola Fasciolopsis

Table courtesy of Newell DG, Koopmans M, Verhoef L, Duizer E, Aidara-Kane A, Sprong H, Opsteegh M, Langelaar M, Threfall J, Scheutz F, van der Giessen J. Food-borne diseases—the challenges of 20 years ago still persist while new ones continue to emerge. International journal of food microbiology. 2010 May 30;139:S3-15.

Fur and Feathers

The relationship between humans and animals is at once both close and complex. It is estimated that people domesticated dogs close to 13,000 years ago and cats 5,000.[13,66] Pets provide many health benefits to humans, especially children, the elderly, those who are lonely or isolated, and those with disabilities.[13,19,67-77] Households with livestock and poultry are more likely to consume a protein-rich diet and may demonstrate more financial freedom.[6] However, contact with animals can present an exposure risk to the acquisition of ZEPs.

A boy living in an urban slum on the porder of Brazil and Bolivia holds up a young capybara- a wild species found only in this area of the world. © 2004 Carol Boender, Courtesy of Photoshare.

ZEPs can be shed in the feces of domestic animals, wildlife, and synanthropic rodents that can contaminate our hands, living environment or food. Across many cultures, animals are frequently cohabitating with household members in the same home. But allowing an animal to live or roam inside a house can lead to the contamination of the shared space and exposure humans and other animals to ZEPs.[50,78] Parasitic oocysts can remain infectious in the environment for an extended period of time and can be picked up on the fur, skin, or feathers of animals.[50] Exotic or nonconventional pets may also share our homes. These animals come from areas of the world were zoonoses are endemic.[79] Major zoonotic diseases have been associated with pet rabbits, rodents, reptiles, aquarium fish, wild carnivores/ferrets, nonhuman primates as well as the more common dogs and cats.[19,65,79] Handling these animals or playing with them can facilitate the spread of the parasite, especially when hands are not watched afterwards.[50] Cleaning the litter box of cats has also been shown to increase the risk for the ZEP *T. gondii*, although the greater risk is probably associated with eating infected meat.[19] Infections with ZEPs from pets may also occur from the contamination of food products, water, and hands.[79]

Domestic animals can also contaminate sleeping and food preparation areas, sometimes entering the house due to poor housing construction. Often this is the case with synanthropic rodents who may be active in the home near food and water storage areas, potentially contaminating these areas with infected droppings. Several studies have demonstrated that sharing a home with poultry and other livestock leads to more diarrheal disease and a longer duration of illness.[17, 80-85]

Animals are also a risk for ZEP transmission outside of the home. Livestock and poultry that are kept near the home may expose soil, shoes, hands, and water to their concentrated waste.[79] Their manure may also be used as fertilizer and a fuel source.[17,78] Stray and free roaming dogs present a municipal challenge since they may defecate in public areas such as beaches, parks, and playgrounds.[13,65] And as human development continues to expand into previously uninhabited areas, contact between humans, wildlife, and domestic animals will continue to escalate.[6] Public recreation areas have been known to draw wildlife and synanthropic rodents who scavenge the leftover food and rummage through the garbage.[13,86] Not only are humans coming into contact with wildlife, but domestic animals such as dogs and cats are having more interactions with wildlife and synanthropic rodents which can lead to transmission from wildlife to pets.[86]

Flies cover watermelon for sale from a street vendor in Rawalpindi, Pakistan. © 2006 Khalid Mahmood Raja, Courtesy of Photoshare.

Flies

Another exposure pathway for acquiring zoonotic enteric parasites is through filth flies that land on infected fecal matter and then carry the oocyst either on their exoskeleton or inside their digestive tract.[87,88,89] Flies are vectors for viruses, bacteria, fungi, and parasites.[90] Flies then deposit the parasites once they land on food or raw/unprocessed food products through defecation, regurgitation, or dislodgement.[88,89, 91-92] Research has demonstrated that flies can carry from 4-131 parasitic oocysts at one time and they can remain infectious on or inside the fly for up to three weeks.[89] A single female fly can live up to a month and produce 9-12 generations of up to six egg batches at a time.[88, 92-93] Filth flies can fly up to a distance of 20 miles (approximately 32 kilometers) and usually in the direction of an unhygienic source.[88, 92-93]

Flies become infected with ZEPs from unsanitary sites such as toilets, manure/feces, slaughterhouses/abattoirs, garbage, animal carcasses, sewage, and livestock rearing areas.[88-89] High fly densities have been found where garbage is disposed close to homes, animals are present in the household or the living area, a lack of indoor latrines, and nearby defecation sites.[17,82,94] Research has demonstrated that larger fly densities coincide with more diarrheal disease.[82] Flies contaminated with ZEPs have been found in areas associated with livestock husbandry practices but also where wildlife are known to reside.[87] Flies have also been able to transmit zoonotic enteric parasites after contact with wild dog and fox feces.[86] ZEP contaminated flies have been studied in both rural and urban areas and have even been found in remote locations such as bush retreats, national parks, and forests.[86,90]

The percentage of ZEP infection due to the transmission of parasite by filth flies is difficult to estimate. Since a fly can contaminate a food item upon landing, subsequent enteric illness is most often contributed to food contamination and not to the fly itself.[88] However, additional research on the influence vectors for the spread of enteric disease is demonstrating that other insects and arthropods are capable of transmission. Enteric diseases and parasites have been found in dung beetles and even cockroaches.[89, 95-97]

Fields and Floors

Animal and human waste on the ground can be a major exposure pathway to diarrheal disease, especially due to zoonotic enteric parasites.[11,13,16] In fact, some ZEPs actually need soil to complete their life cycle (ex. *Ascaris lumbricoides*).[11] Parasitic oocysts can be dispersed by wind, water, by automobiles, by shoes/feet of humans and animals, and several other routes.[13] ZEPs in the soil come from infected animal waste dropped and left on the ground, spread out for fertilizer, or water contaminated with infected fecal material.[6,12,98] Research shows that when infected animal waste is collected from the environment, soil at the same site if often contaminated as well.[99] The waste of chickens and other poultry are frequently left undisturbed since they are small deposits and tend to smell less.[16] As previously mentioned, waste from animals, and even humans, may be collected and spread in gardens or agricultural fields, used as fish feed, dried for cooking fuel, and even used as housing material/flooring.[16,78,100-101]

A Bangladeshi homeless man plays with a street dog inside a public park in Dhaka, Bangladesh. © 2014 A.M. Ahad, Courtesy of Photoshare.

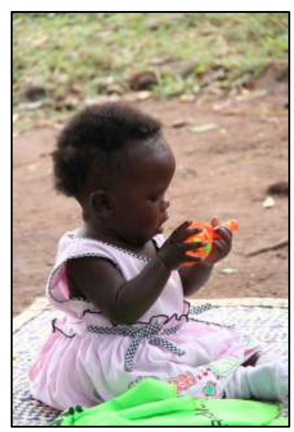
A woman in Alirajpur, India, builds a wall using cow dung solution instead of cement. © 2010 chetan soni, Courtesy of Photoshare.

Areas with animal pens or places where animals graze and scavenge can create hotspots for ZEPs. Domestic animals defecate in gardens, in yards and housing compounds, in pastures, in playgrounds, on beaches, and in homes.[13,99] Humans can become exposed to these fields and floors by not wearing shoes, gardening, harvesting crops, and other outdoor activities.[50,78,86,99] Children in particular are at risk for contracting a ZEP through soil exposure since they play with soil, have poor hygiene awareness and often engage in exploratory mouthing behaviors.[99,102] Young children who are not potty-trained and do not have access to a latrine may defecate directly onto the ground, infecting the living space. Due to their size, these children are also closer to the ground with a higher risk of soil exposure.[103]

Fomites

Inanimate objects and items, fomites, can become contaminated with ZEPs. Parasitic oocysts may attach to the surface of toys, cooking utensils, electronic devices, shoes and clothing, and other objects. Research has shown that in areas where human and animal waste is not managed safely, household toys demonstrated high levels of fecal contamination.[17,104] Dirty toys are often put directly inside the mouth of young children, thus exposing them to possible ZEPs.[102] Cooking and eating utensils such as infant bottle nipples, spoons, can openers, and cups have shown to carry fecal contamination.[17,80,105] Parasites can also be transmitted on clothing that has had contact with the infected waste of a person or animal and can cause disease for the person who washes those items.[106] Aside from household objects and toys, zoonotic enteric parasites have also been found on currency, representing a risk to every hand that touches that money.[107] Personal mobile devices, such as cell phones, have also been shown to harbor pathogens.[108]

A woman in Madhya Pradesh, India, dries her clothes on top of the drying cow dung that will be used as fuel. © 2006 Nicoletta Di Tanno, Courtesy of Photoshare.



Left: A young schoolgirl holds a toy cell phone at a local market in Cajamarca, Peru © 2007 Alfredo L. Fort. Right:A young girl in Iganga, Uganda, plays with a toy. © Basil Safi. Courtesy of Photoshare.

Fingers


A young child eats on the ground surrounded by flies and dust in Devisthaan village at Gorkha district, Nepal. © 2006 Rakesh Yogal Shrestha, Courtesy of Photoshare.

Hands are critical for the oral transmission of ZEPs from environmental sources.[109] Poor hand hygiene provides a pathway from touching contaminated soil, objects, animal fur or feathers, human or animal feces, a food product, or a water source and then having oral contact with that dirty hand. Accidental contact with any of these contaminated items and then touching your mouth or eating with your hands can lead to ZEP exposure.[109] Food handlers and household members in charge of food preparation who do not wash their hands well may risk spreading ZEPs.[47] Research has proven that not having access to an improved hand washing area or not properly washing hands with soap before eating or after playing with animals can expose a person to diarrheal illness and zoonotic enteric disease.[50,110] Handling animal waste for cooking fuel or the spread of manure is also an exposure risk for ZEPs transmission from fingers.[16-17]

ZEP Risk Factors for Animals

Companion animals

Domestic animals such as cats, dogs, and other pets like rodents, reptiles, and birds have an intimate relationship with household members and may live inside the home or in close proximity.[111] People often touch these animals, kiss and hug them, let them sleep in their beds, feed them from their hands or communal pots, travel with them, and take responsibility for their care and well-being.[112]

However, companion animals and pets can be at risk for ZEP exposure through these close interactions with humans. Reverse zoonoses is the transmission of a zoonotic disease from a human to an animal. Several studies have shown pet owners and those closely associated with companion animals can spread zoonotic enteric parasites to the animal.[113] In the same ways that humans can be exposed to ZEPs through animal waste, animals can be exposed through human waste. In developing countries where improved sanitation access may be limited, open defecation by humans can spread disease to their neighbors and to domestic animals that roam and scavenge the shared environment.


A dog and two pigs feast on trash along a road in India. © 2007 Srikrishna Sulgodu Ramachandra, Courtesy of Photoshare.

Companion animals that are free-range may also be exposed to the fecal waste of other animals such as synanthropic rodents, livestock, or wildlife.[111] The presence of companion animals may also draw in wildlife to human habitats. Hunting or take dogs out into recreational areas can mean interactions between companion animals and wildlife.[111] Carcasses from animals shot or hit by cars can also bring wildlife closer to human and domestic animal environments.[111]

Still, one of the largest risks to companion animal exposure to ZEPs is through feeding dogs raw offal or viscera from slaughtered livestock.[19,114-115] When infected livestock are slaughtered and butchered in regions endemic for the ZEP *Echinococcosis spp.*, their encysted organ tissue is frequently fed to nearby dogs.[19,114-115] This can lead to ZEP infection in the dogs and an exposure risk to household members. Dogs may also become infected when they are allowed to feed on the dead carcasses of animals.[19]

Livestock

Livestock, including poultry, are at risk for ZEP exposure from the infected waste of both humans and other animals. When livestock graze on unrestricted pastures, animals such as wildlife predators and companion animals like dogs may also access those areas and contaminate the shared environment with infected waste.[19,86] For example, sheep and goats have a ZEP exposure risk due to their grazing habits.[14]

For livestock and poultry, their housing environments can play a role in their ZEP infection risk. When barns, pens, or other structures meant to shelter livestock are not properly cleaned, they can expose the animal to disease through bird, rodent, fly and other insect vector droppings.[57] The fecal waste of other livestock in the shared environment can also infect or reinfect the rest of the herd. The floors of livestock pens, milking areas, animal drinking water, manure storage areas, and animal bedding material have all demonstrated ZEP contamination potential.[57]

Wildlife

Two foxes in an urban setting in London, United Kingdom. © 2012 Paul Sanders/Photopaul, Courtesy of Photoshare.

Many wildlife species are suitable hosts for zoonotic enteric parasites. Undomesticated animals such as wolves, semi-aquatic rodents, deer, boar, lions, wild birds, wild forest reindeer, foxes, elk, coyotes, wild dogs, cougars, jaguars and other species have been found to be infected with ZEPs.[86,111] Wildlife may acquire the zoonotic enteric parasites from contact with infectious animal waste and also through predator-prey cycles.[86] Wild animals, especially carnivores, which have access to livestock pastures and to carcasses can also facilitate the spread of ZEPs.[86] The growing number of wildlife-domestic animal-human interactions due to habitat encroachment and development could lead to future emerging and reemerging ZEPs spillover events.

Synanthropic rodents

Rodents that live in close proximity to human households and settlements are known to be infected with ZEPs and transmit zoonotic enteric parasites to other animals and to humans, just like forest rodents.[111] Like companion animals, synanthropic rodents may share our homes, although typically uninvited. These rodents become infected from contact with human and animal waste or ingesting contaminated food or water. Other domestic animals, such as cats and dogs, can be exposed to infected rodents through predation.[19] Some rodents are considered pets and serve the same function as a companion animal. Just like cats or dogs, pet rodents are allowed to live in our homes and have intimate contact with their owners.[19]

ZEP Risk Factors for the Environment

The rate of infectious ZEPs in the environment depends upon many unique variables. For instance, some research has demonstrated that zoonotic enteric parasites burdens vary according to differences in soil type, elevation, rainfall levels, temperature, and humidity level.[19,116-117] The burden of ZEPs present in environmental soil, water, or air can also be influenced by landscape patterns and the way in which the land is utilized (ex. for agriculture or livestock pasture).[86] Grazing animals drawn to grasslands can bring predators. Similarly, water-based ecosystems home to aquatic animals are also used by other wildlife, domestic animals, and humans as a source of drinking water and food and for crop irrigation, bathing and swimming, and transportation. Pollution of the environment through garbage and human and animal waste can lead to highly-contaminated areas.[99]

During morning activity at a landfill in Surakarta, Central Java, Indonesia, humans and animals compete to scavenge the rubbish. © 2011 Harjono Djoyobisono, Courtesy of Photoshare.

Animals migrate through habitats, both seasonally and in search of food or water, potentially spreading disease in their wake.[6, 118-119] Humans may also introduce ZEPs to new environmental zones through migration from travel or due to conflict and displacement.[6, 118-119] Within the home environment, ZEPs tend to proliferate when the space has poor water, sanitation, or hygiene measures in place, there is overcrowding and unmanaged trash, and the living area is shared with domestic animals.[99] How humans and animals use an environmental space will create multiple opportunities for ZEP contamination.

Prevention and Control

Case and Outbreak Response

When a human or animal is suspected of infection with a ZEP, the case should be confirmed with the appropriate diagnostic tool and followed up with clinical care and treatment, if necessary. Single infections with a zoonotic enteric parasite can quickly turn into an outbreak if the transmission cycle is not broken through One Health intervention strategies. Suspected cases of ZEPs in animals may be discovered by the animal’s owner or veterinarian by the symptoms displayed by the animal (e.g. diarrhea, anorexia, vomiting, etc.) or by a known exposure risk (e.g. infected animals at the same household or in the same herd). Suspected cases of ZEPs in humans may also appear following similar symptoms as seen in animals or through contact tracing done on contaminated water/food items, environmental exposure risks, or ill household members or close contacts.

Because health care access for humans and animals in developing countries can be cost, time, and distance-prohibitive, most outbreaks related to enteric pathogens go undetected, unreported, and uninvestigated.[21] Because of the close relationship between humans and animals, suspected cases of ZEPs should be fully inspected right away to thwart the risk of an outbreak and the further spread of disease. When a case and/or outbreak has been identified through proper diagnostic methods, treatment measures, if necessary, should be administered to all humans and animals affected. When clinical treatment is not warranted, supportive care through oral rehydration therapies and WASH education should be provided to assist the impacted human and animal communities.

When following up on a suspected ZEP infection, several topic areas should be investigated to determine the potential source of infection and determine areas to incorporate interventions. Case investigations and report forms should reflect the unique risk factors for the ZEP pathogen(s) in question (Table 3). Creating a uniform case report form will allow epidemiologists, health professionals, and veterinarians to determine if multiple cases are similar or potential part of the same exposure risk, thus forming an outbreak. It will also allow professionals to share data and time-sensitive information to multiple sectors at once for a coordinated response.

Table 3: Exposure Categories to Consider for ZEP Case and Outbreak Investigations

Patient Characteristics
• Home and work address • Contact information • Demographics (e.g. sex, age, religion/ethnicity) • Occupation • Type of residence (e.g. apartment v. grass hut) • Household members (e.g. number and ages)
Description of Illness
• Symptom onset and duration • Symptom description since illness onset • Health care consultation and diagnoses • Current treatment plan • Lab work completed and results • Hospitalization history for current illness • Health and medication history • Household members with symptoms (e.g. number of members and their demographics)

Table 3 Continued

Water Exposure Risks in Two Weeks Prior to Illness
• Source of drinking water at home, work, and/or school • Type and frequency of water treatment (if applicable) • Source of consumed ice (if applicable) • Type and location of consumed beverages made water (e.g. lemonade) • Name of water body where any swimming occurred (e.g. lake, pool, or river) • If applicable, whether face was submerged in water or water was swallowed • Location of any hot tub of Jacuzzi used • Water body where domestic chores occurred (e.g. bathing, washing, fishing, watering animals)
Food Exposure Risks in Two Weeks Prior to Illness
• Number and location of any meals eaten outside of the home (e.g. restaurant) • If applicable, description of how food is served at these locations (e.g. buffet, take away, eaten on site) • Number of times the following foods were eaten and type: o Lettuce/salad vegetables o Raw vegetables such as carrots, tomatoes, or cucumbers o Other cold salads or deli meats/cold cuts o Raw fruits • Number of times unpasteurized foods were eaten and type: o Raw, unpasteurized or untreated milk o Other raw, unpasteurized or untreated dairy products (e.g. cheese or yogurt) o Raw, unpasteurized or untreated fruit juices o Raw, unpasteurized or untreated alcoholic drinks • Number of times uncooked, raw, smoked, fermented, pickled, salted or undercooked/rare meat or animal products were eaten and type: o Meat or poultry o Game/bush meat or wildlife o Fish o Shellfish, crustaceans, mollusks, or snails o Frogs/amphibians, crocodiles, or snakes • Location where most household food is purchased or collected
New Product Exposure Risks in Two Weeks Prior to Illness
• Description of any new health foods or dietary supplements consumed • Number and type of alternative or traditional medicinal therapies used
Travel/Social Exposure Risks in Two Weeks Prior to Illness
• Location and duration of travel outside of home community • Purpose of travel • Location and date of social events (e.g. weddings or funeral) or public facilities (e.g. bar, church) attended • Location and date of any visits to a person at a health care facility (e.g. hospital or nursing home)

Table 3 Continued

Person-to-person and Animal Exposure Risks in Two Weeks Prior to Illness

• Involvement in food handling or preparation:
  ○ Hot and cold food preparation
  ○ Food server or waiter
  ○ Bartender
  ○ Salad bar/buffet organizer
  ○ Other (describe)
• Involvement in child care work:
  ○ Child care center outside of the home or in the home
  ○ Babysitter out of the home or in the home
  ○ Other (describe)
• Involvement in animal care:
  ○ Work in a pet store
  ○ Work on a farm or dairy farm
  ○ Dog walker
  ○ Pet groomer
  ○ Veterinarian or veterinary assistant
  ○ Work at a slaughterhouse/abattoir
  ○ Other (describe)
• Involvement in patient care:
  ○ Physician
  ○ Nurse
  ○ Nurse's aid
  ○ Community health care worker
  ○ Home health care worker
  ○ Other (describe)
• Number of children in child care/day care outside of home and location of facility
• Previous contact with ill individual with gastrointestinal illness (e.g. diarrhea, nausea, vomiting):
  ○ Adult or teenager
  ○ Children
  ○ Animals
• If applicable, location where contact occurred
• Type and location of any contact with children not yet potty-trained or animals under the age of six months
• Species of animals for which contact occurred
• Potential sexual exposures (Only if acceptable to situation, patient and appropriate to the specific ZEP of interest)

Table adapted from U.S. Centers for Disease Control and Prevention, *Generic Outbreak Case Control Questionnaire*, available at https://www.cdc.gov/healthywater/pdf/emergency/generic-outbreak-case-control-questionnaire.pdf.

ZEP Surveillance

Piggery run by community health workers in Kigali, Rwanda. The veterinarian employed by the cooperative checks the health of the animals. © 2017 Riccardo Gangale, Courtesy of Photoshare.

Surveillance methods by human, animal, and environmental specialists work to ensure that new ZEP cases are discovered and treated as quickly as possible. This is done through active and passive surveillance techniques. For active surveillance of ZEPs, professionals purposely look for new cases or outbreaks by monitoring potential exposure risks and reaching out to partners and stakeholders. For example, a clinic doctor may speak routinely to the local veterinarian to see what conditions and illnesses are circulating. This feedback is important to ensure a One Health relationship is employed to combat ZEPs in the community. It also leads to earlier diagnosis of problems or potential ZEP transmission. Active surveillance is also administered when a case or outbreak is occurring and the human and/or animal health care practitioner is looking for additional related cases. Researchers and scientists who test for pathogens in the environment are also conducting active surveillance. By reporting their findings to public health and animal health departments, they can help avoid the infection of new cases.

Passive surveillance is also essential for a quick response to ZEP cases and the implementation of a successful outbreak intervention. Passive surveillance relies upon case reporting by doctors, veterinarians, and other clinical care providers when they see a patient or animal with an infection. Because this technique relies upon the timeliness and discretion of local practitioners, it is usually not enough on its own to combat ZEP transmission. It should be implemented in conjunction with active surveillance to produce a successful infectious disease case reporting program.

Active and passive surveillance does not happen just one time or periodically. In order to identify cases and outbreaks of ZEPs as they occur, ongoing surveillance in both human and animal health care sectors as well as the food and agriculture industry is necessary. The increasing global demand for animal-based food has led to intensified production of livestock, poultry, and fish.[40] When safe measures are not administered throughout these industries, the potential for ZEP exposure and contamination increases.[40] Monitoring and inspection of animal husbandry practices, slaughter and processing methods, food packaging and transport, and consumer sales and distribution is critical to ensure that we are not subjected to unsafe food products.[40] This should also be occurring in agricultural systems for vegetable, grain, and fruit production.


Children in a village near Ghazni, Afghanistan, bring their livestock for deworming treatment by a U.S. Army Medical and veterinary team. © 2004 Ben Barber, Courtesy of Photoshare.

More international safety standards should be implemented as humans and animals move across geopolitical boundaries. When a region experiences social or political upheaval, the public health and veterinary health departments serving the population can break down and zoonotic diseases go unreported and untreated.[86] When these events occur, disease surveillance is often halted and outbreaks can be devastating to human and animal health.

When proper surveillance has discovered ZEP infection in a human or animal or contamination in the environment or a food/water source, immediate steps are needed to halt further infection. This is when One Health networks must come together to determine the best course of action.[22] Depending on the ZEP species and the situation, this could entail a large food recall, mass vaccination and/or deworming, the temporary closing of an establishment, environmental cleanup efforts, restriction of animal movement, improvement of water and sanitation infrastructure, or large-scale education and public health messages.

WASH and ZEP Prevention

The best way to prevent the spread of ZEPs in humans, animals, and the environment is through practicing proper water, sanitation, and hygiene (WASH) measures. Utilizing safe WASH methods in the home and the community will help to break the transmission cycle of zoonotic enteric parasites and avoid further infection. The most effective way to do this is to use a One Health approach that implements simultaneous efforts to address contamination for humans, animals, and the environment we share.

Water

Water is necessary to support human, animal, and plant life on earth. But it can also serve as a vehicle for dangerous pathogens, including ZEPs, when not protected against contamination. The new international targets for achieving global health are called Sustainable Development Goals (SDGs) and contain water, sanitation, and hygiene measures. For example, just like the expired 2015 Millennium Development Goals (MDGs), the SDGs call for access to safe drinking water and sanitation.[121]

A woman from Betanyili, Northern Region, Ghana demonstrates how she protects herself and her family by putting a water filter over the water urn. © 2004 Christine Giraud, Courtesy of Photoshare.

However, access to an improved drinking water source alone does not ensure that the water will be safe once your drink or cook with it. This is because there are multiple opportunities for contamination between the source of the water and the consumption of the water.[124] This is why the updated SDG target extends on using an improved water source to include three additional components for the safe management of drinking water: 1) the water should be accessible on the premises; 2) water should be available when needed; and 3) the water should be contamination-free.[121] In order to keep water contamination free, proper water storage at the household should be adhered. Covering storage containers and not using dirty hands or cups to remove water is one way to help prevent the contamination of drinking water in the home. Animals should also be kept away from the water storage area and kitchen. And finally, stored drinking water should be treated regularly to prevent the growth or spread of pathogens, such as ZEPs.

Water treatment can be down by boiling drinking water before use for 1 minute of full boil (three minutes for areas where the altitude is higher than 1,000 meters (5,000 feet).[123] Water should be cooled and then stored in clean containers with covers. If water is cloudy before boiling, consider filtering the water prior to boiling by pouring water through a filter such as a clean cloth or coffee filter.[123] As an alternative, drinking water can be disinfected using chlorine or iodine tablets commercially available by following package instructions.[123] Regular, unscented household bleach can be used to disinfect water by adding either 8 drops of 6% bleach or 6 drops of 8.25% bleach to one gallon of water.[123] The amount of bleach can be doubled if the water is cloudy, cold, or has a color.[123] After bleach is added, stir and wait for 30 minutes. If the water does not have a slight chlorine smell, add more drops and wait 15 minutes before use.[123]

The young boys of the Johnson Nkosi Memorial Primary School in Mpoma, Uganda, line up to learn hygienic hand washing practices. © 2014 Alexaya Learner/GlobeMed at UCLA, Courtesy of Photoshare.

Sanitation

In addition to working towards equal access to safe drinking water, the SDGs aim to improve access to safe sanitation for each household while 1) ending open defecation; and 2) ensuring safe storage of waste and treatment of waste off-site.[125] This means that improved sanitation methods should be used, such as flush and pour toilets that connect to pit latrines, sewers, or septic tanks, pit latrines that are ventilated or have a slab and composting toilets.[122] Ideally, each household would have their own sanitation systems and not share with other families or households.[122] Unimproved sanitation methods that can promote the spread of ZEPs and other disease include open defecation, pit latrines without a slab or platform, hanging latrines, and buckets or containers.[122]

Good sanitation efforts should also be geared towards the management of animal waste from the shared environment. As demonstrated by this guide, animal waste contamination of the living space can lead to multiple exposure paths for ZEPs. Animal waste from companion animals, livestock, and poultry should be removed from shared space to avoid health risks to humans and other animals. In addition, garbage and trash should not be allowed to pile up around a household as it can bring vectors such as flies and synanthropic rodents, domestic animals, and wildlife near the home. This can facilitate the spread of ZEPs within the environment.

Hygiene

Proper hygiene at the community, household, and individual level should be prioritized to prevent ZEP exposure and infection. Hand washing with soap and clean water should be practiced by residents of all ages at many times throughout the day such a prior to cooking, before eating, after using the bathroom or helping a child go to the bathroom, after cleaning or picking up something dirty, before preparing child's food, after animal contact, and any other time hands have had the chance to touch something that is a potential vehicle for disease. Children should be discouraged from playing in the soil or from handling dirty toys or animal waste. In the home, safe food storage means that food is covered and protected from flies, synanthropic rodents, and domestic animals. Food should also be kept at a safe temperature so that pathogens do not multiply. When preparing food, items should be washed thoroughly with clean water prior to cooking or eating. If possible, fruits and vegetables should be peeled to prevent the accidental ingestion of ZEPs. When cooking foods, they should be heated thoroughly to kill potential ZEPs that have remained on or inside the food. Animal products like meat, milk, and other tissues should be examined for evidence of ZEPs and cooked in safe manners that use proper heating techniques to remove infectious parasites. When eating, clean utensils, cups, and storage containers should be used and when dirty, they must be washed with clean water before being stored away from animals or environmental contaminants. And households and living spaces should be kept clean and free of debris and waste, which can invite flies, synanthropic rodents, and other animals.

Children at an NGO in Asuncion, Paraguay, perform a play about parasite prevention after receiving a lesson from an educator at an organization. © 2007 Krista McKean, Courtesy of Photoshare.

Education

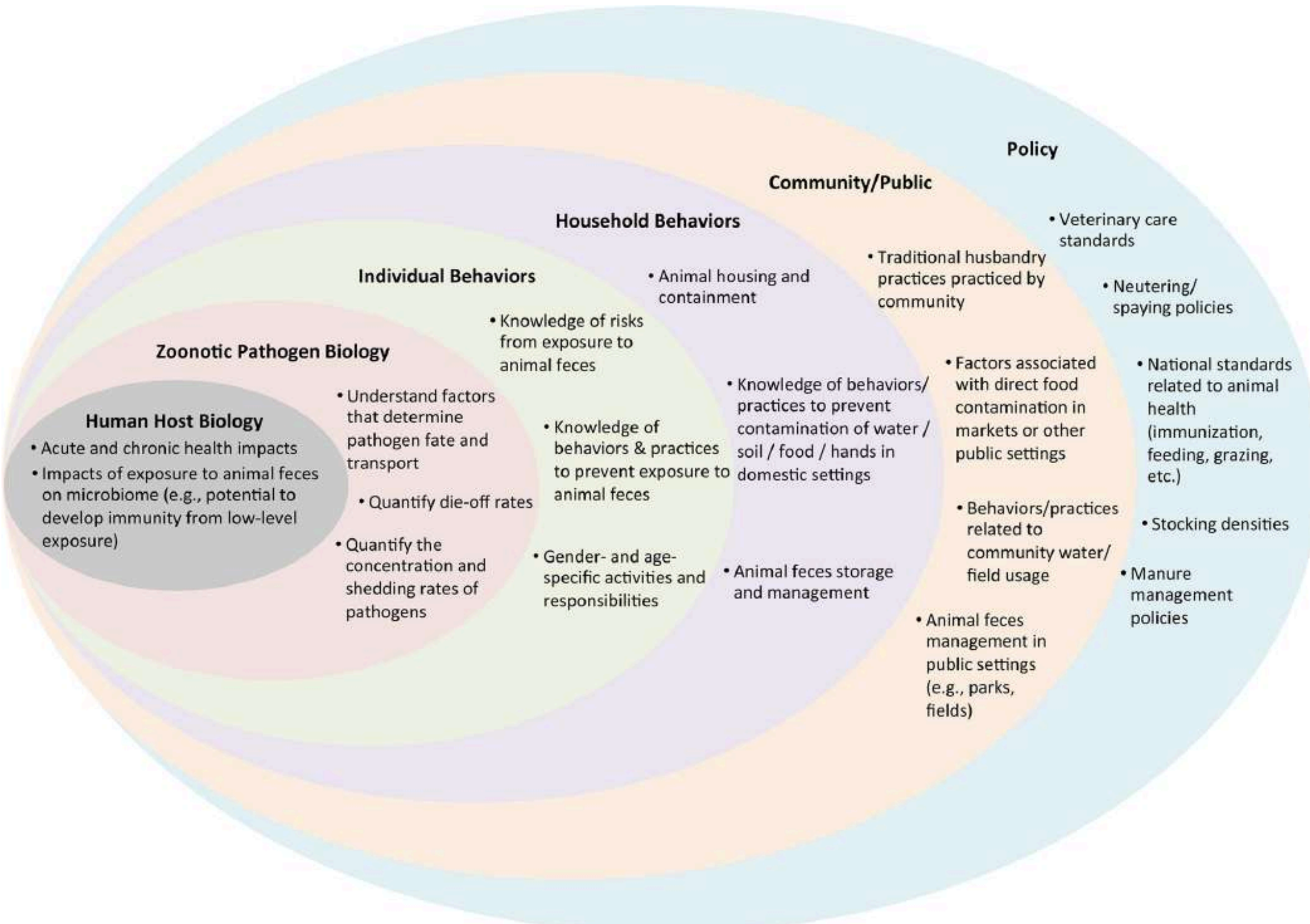
When it comes to education on WASH and the prevention of ZEP exposure, each audience will need tailored messages that are appropriate for their unique risk factors. At the household level, different ages of children can mean different exposure pathways. Young children should be taught not to put dirty things in their mouth, such as chicken feces or soiled toys.[17] Older children should be provided hand washing stations with soap so that they can practice safe hygiene measures. Women and men who have animal contact either through companion animals or husbandry practices such as feeding, milking, collecting eggs, herding, animal births, cleaning out pens, using manure for fuel or fertilizer, butchering, and food preparation should be provided health education messages to prevent ZEP exposure or transmission to other people, animals and the environment.[97] Households that have vegetable or fruit gardens should be educated on how to prevent ZEP contamination of the soil or crops by using clean irrigation water and safe fertilizers.

ZEP education should not be limited to the home. Exposures can also occur at the workplace, in schools and day cares, in clinical care settings, and restaurants and markets. Risk factors due to contaminated water, unimproved sanitation, and poor hygiene can be combatted through interventions developed to the setting. At restaurants and markets, workers should be taught hand hygiene and food storage methods that will prevent ZEP contamination of the products for sale. In schools and day cares, working toilets and hand washing stations should be available and encouraged so that students can begin good hygiene habits but also prevent ZEP outbreaks between school and home.[110]

A woman flash heats milk as a way of providing a safe feeding option for children of HIV-positive mothers in Durban, South Africa. © 2007 Kiersten Israel-Ballard, Courtesy of Photoshare.

And finally, at-risk populations such as the immunocompromised, pregnant women, and the elderly or very young should all be protected against ZEP threats. Additional high-risk groups that deserve extra attention when creating ZEP prevention programs. These individuals have significant contact with companion and domestic animals and may be ZEP exposed to infected animal waste. But both pet owners and livestock keepers should be responsible for the management of their animals' waste. Hunters are another group that should be receiving ZEP public health messages, particularly if they are exposed to wildlife or bush meat. Special precautions should be taken to avoid ZEP exposure in the environment overall or from contact with wild game or birds. Slaughterhouse or abattoir workers should use personal protective equipment to prevent hand or clothing contamination. They should be taught how to identify ZEPs in carcasses and prohibited from feeding viscera and offal to nearby stray dogs.[114] Farm workers who are in agricultural fields harvesting vegetables and fruits must be aware of the ZEP risk associated with water, soil, and human and animal waste used for fertilizer. Produce must be washed with clean water and packaged, transported, and sold using safe food techniques. And veterinarian and human health care workers should be vigilant about their patient exposures. They should be aware of the signs and symptoms of ZEPs endemic in their communities and must communicate between the disciplines to thwart any potential zoonotic outbreaks.

Education on ZEP risk factors and prevention methods must be adapted for each population and each area in order to be effective.[13] Messaging formats may also differ depending upon the needs and interest of the intended audience.[13] Partnerships between agricultural sectors, veterinarians, and public health professionals are necessary to identify ZEP infections and exposure risks in animals, humans, and the environment while working to protect the food chain.[1]



This figure adapts the socio-ecological model to illustrate how different domains can influence zoonotic disease exposure and transmission pathways. Figure courtesy of Penakalapati G, Swarthout J, Delahoy MJ, McAliley L, Wodnik B, Levy K, Freeman MC. Exposure to animal feces and human health: A systematic review and proposed research priorities. Environmental science & technology. 2017 Oct 9;51(20):11537-52. DOI: 10.1021/acs.est.7b02811 Copyright © 2017 American Chemical Society. Priority research gaps in assessing human health impacts from exposure to poorly managed animal feces.

Concluding Remarks

Zoonotic enteric parasites continue to infect humans and animals through complex and effective transmission strategies.[1] While ZEP infection in the past was limited by geographic, political or cultural boundaries, today these pathogens can travel to all corners of the globe in a single day.[40] The threats to human and animal health faced by ZEP infection cannot be addressed by a single discipline. We must confront ZEPs through a One Health approach. We must look for risk factors at household, community, national, and international levels within our food chains, our animal husbandry practices, our individual WASH access and behaviors, and our environment at large so that we can create best practices to prevent exposure to zoonotic enteric parasites and subsequent disease. This guide has touched on many issues concerning the health concerns and transmission pathways for ZEPs infection but it is not an in-depth manual on any one specific parasite. Additional research and background information on the ZEP disease burden for each unique human or animal population is necessary before implementing interventions and One Health messages and education.

A group of boys surround a young girl holding a goat in India. © 2013 Pranab Basak, Courtesy of Photoshare.

A housewife living in Rangpur, Bangladesh, with the goat she purchased using an NGO loan. © 2013 Sumon Yusuf, Courtesy of Photoshare.

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