

Establishing Links Between Water and Infectious Disease

Felipe J. Colón-González



The Abdus Salam
International Centre
for Theoretical Physics

2nd Workshop on Water Resources in Developing Countries:
Planning and Management in a Climate Change Scenario

Introduction

- The quality and quantity of water may affect human health.
- Flooding, for example, constitute a major threat to both human and animal health:
 - Drowning
 - Faecal/urine contamination
 - Cadaver decomposition
- Water is an excellent vehicle for pathogens.



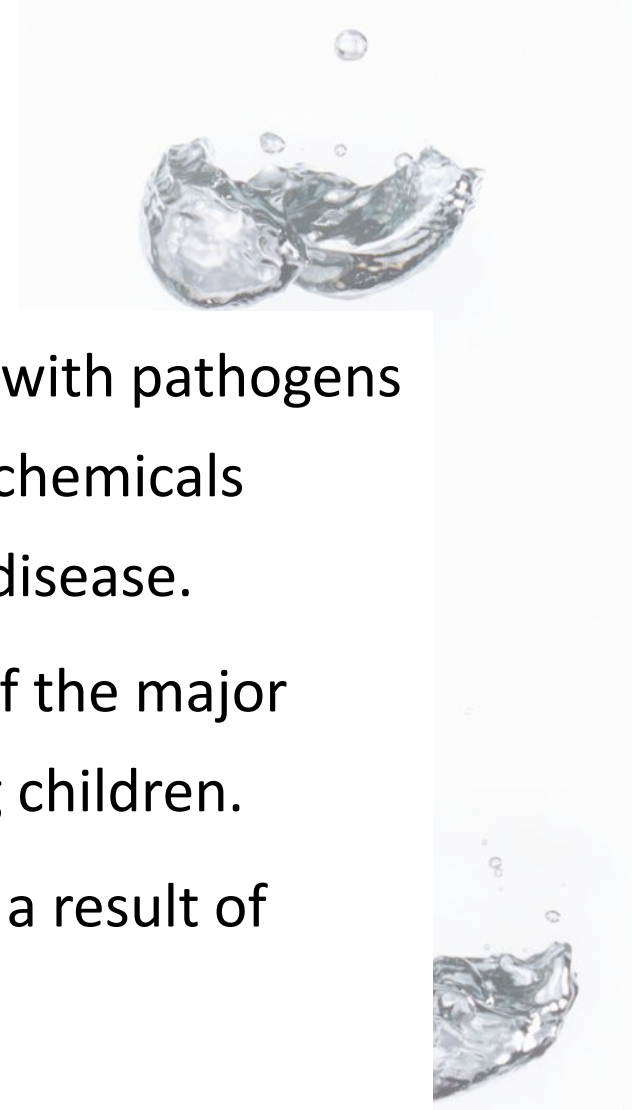
Source: coolgeography.co.uk



Source: southernwater.co.uk

WHO 2011 *Technical guidance on water-related disease surveillance*. Copenhagen: WHO.

Water quality



- Many water resources are contaminated with pathogens (viruses, bacteria, and parasites) or with chemicals (arsenic, fluoride and cadmium) causing disease.
- Gastro-intestinal infections are still one of the major causes of morbidity and mortality among children.
- 5 children/1000 people die every year as a result of diarrhoeal disease in the first year of life.

WHO 2004 *Guidelines for drinking-water quality. Third edition, Volume 1: Recommendations*. Geneva: WHO.

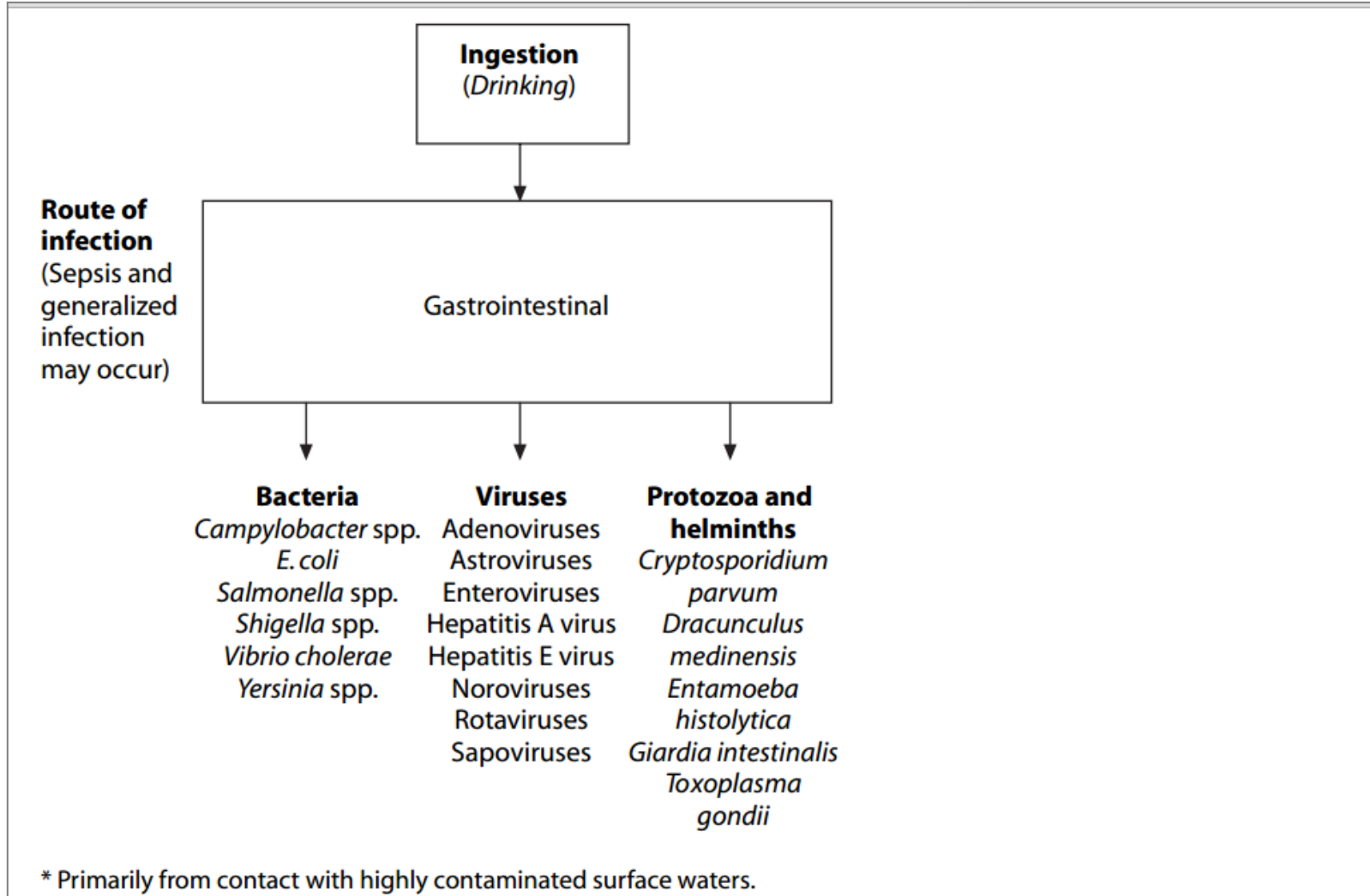
WHO 2011 *Technical guidance on water-related disease surveillance*. Copenhagen: WHO.

Feachem et al. 1981. Enteroviruses in the environment. *Tropical disease bulletin*, 78: 185–230.

Mara, and Feachem 1999. Water- and excreta-related diseases: unitary environmental classification. *Journal of environmental engineering*, 125: 334–339.
doi:10.1061/(ASCE)0733-9372(1999)125:4(334)

Bitton et al. 1986. Viruses in drinking water. *Environmental science and technology*, 20: 216–222. doi:10.1021/es00145a605

Transmission pathways



Source: WHO, 2004 *Guidelines for drinking-water quality. Third edition, Volume 1: Recommendations*. Geneva: WHO.

Classification of water-related infectious diseases



Category	Description	Main pathway	Examples
Water-borne	Related to the ingestion of pathogens present in water; mostly due to human or animal faecal or urine contamination	Ingestion	Cholera, giardiasis, hepatitis-A
Water-based	Caused by skin contact with pathogen-infested water. Includes diseases transmitted by organisms that develop in water	Contact	Schistosomiasis swimmers itch; fasciolasis
Aerosol-related	Diseases related to aerosols containing suspended pathogens which may enter the respiratory tract	Inhalation	Legionellosis, hepatitis-A
Water-washed	Diseases whose incidence, prevalence and severity can be reduced by using safe water resources for hygienic purposes	Lack of water for personal hygiene	Trachoma
Vector-borne diseases	Diseases transmitted by arthropods that have aquatic stages	Insects	Malaria, dengue, chikungunya

Water-borne diseases

(Related to the ingestion of contaminated water)



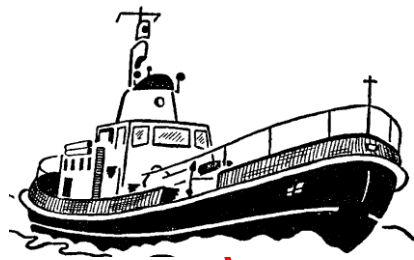
Water-borne diseases

- Faeces and urine can transport a wide range of pathogens (e.g. cholera, giardiasis, cryptosporidium, leptospirosis, schistosomiasis) into water resources.

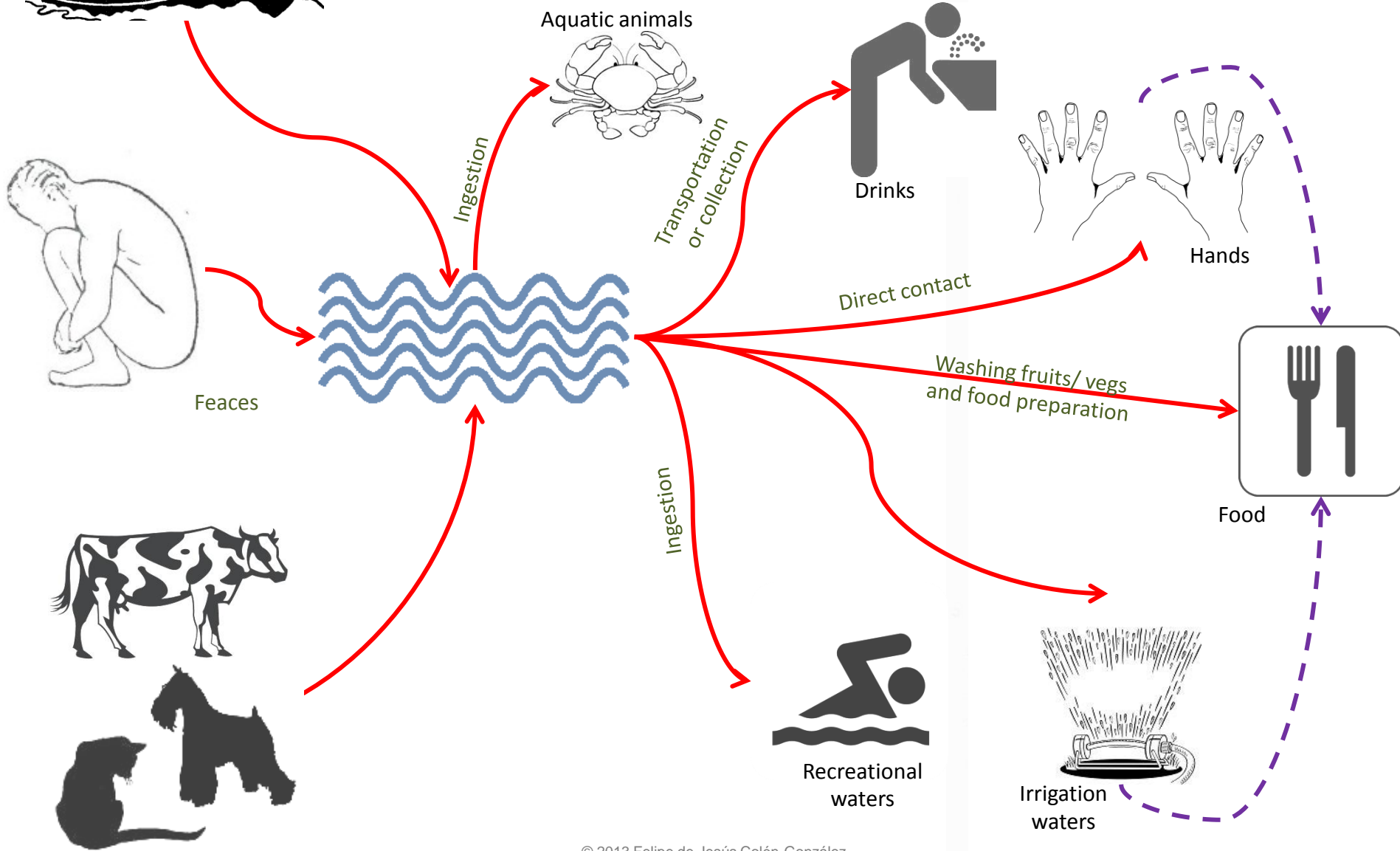


Slifko et al. 2000 Emerging parasite zoonoses associated with water and food. *Int J Parasitol* 30(12-13)





ral transmission



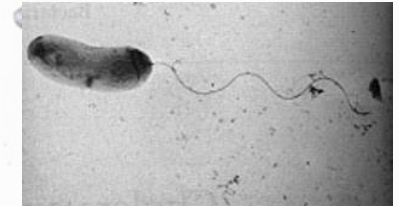
Water-borne diseases

(Some examples)



Cholera

- One of the most emblematic water-borne diseases.
- Cause by a bacterium called *Vibrio cholerae* which has several sero-groups. The most important: O1 and O139.
- In severe cases, mortality rates can exceed 50% if untreated.
- Death caused by dehydration due to profuse diarrhoea and vomiting.
- The first link between cholera and water was established by John Snow in 1850s.



Vibrio cholerae micrograph
Source: Microbe Wiki



PAHO 2001 *El control de las enfermedades transmisibles*. Geneva: PAHO

Righetto et al. 2012 The role of aquatic reservoir fluctuations in long-term cholera patterns. *Epidemics*. 4(2012)



John Snow (1813—1858)



- Discovered that cases of cholera in central London were clustered around a water pump supplied by a particular company.
- He developed a theory about the communication of infectious diseases and suggested a link between cholera spread and water.
- He persuaded the authorities to get the handle of the pump removed.



Source: The Guardian (UK)

Table 1.1. Deaths from cholera in districts of London supplied by two water companies,³ 8 July to 26 August 1854

Water supply company	Population 1851	Cholera deaths (n)	Cholera death rate (per 1000 population)
Southwark	167 654	844	5.0
Lambeth	19 133	18	0.9

Source: Bonita et al., 2006



Figure 4.1. Deaths from cholera in central London, September 1854^{6,7}



Source: Bonita, et al., 2006 Basic Epidemiology, 2nd Edition. WHO, Geneva

The handle-less pump



© Felipe J. Colón González



Cholera transmission

- The main origin of epidemics is related to contamination of drinking water followed by contaminated food, especially seafood products (e.g. oysters, crabs, and shellfish).
- Slime and biofilms produced by some algae create micro-environments that enhance bacterial growth.
- Zooplankton eat the algae (phytoplankton), and then, they're eaten by fish and shellfish or ingested by people passing on the bacteria.

Righetto et al. 2012 The role of aquatic reservoir fluctuations in long-term cholera patterns. *Epidemics*. 4(2012)

Akanda et al 2009 Dual peak cholera transmission in Bengal delta: a hydroclimatological explanation. *Geop Res Lett* 36(L19401)

Epstein 1993 Algal blooms in the spread and persistence of cholera *BioSystems* 31(1993)

Reidl & Kloze 2002 *Vibrio cholerae* and cholera: out of the water and into the host. *FEMS Micr Rev* 26(2002)

Environmental resistance



- Some cholera strains (e.g. O1) can survive both refrigeration and freezing in the food supply chain.
- Dormant forms of the bacterium (to withstand environmental shifts in temperature, nutrient availability or pH) have been observed in a range of environmental niches.
- The viability of the bacterium in rivers and seas depends on water temperature, sunlight, pH, and nutrient availability.



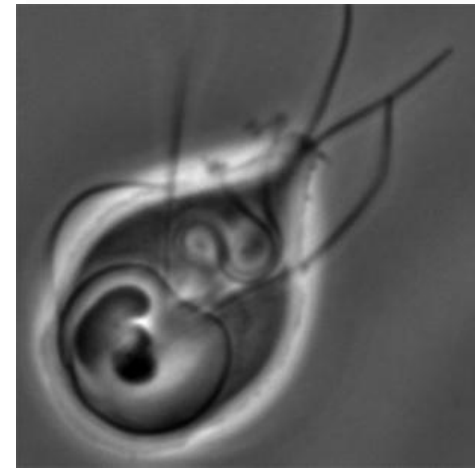
Epstein 1993 Algal blooms in the spread and persistence of cholera *BioSystems* 31(1993)

Reidl & Klose 2002 *Vibrio cholerae* and cholera: out of the water and into the host. *FEMS Microbiol Rev* 26(2002)



Giardia & Cryptosporidium

- *Giardia* and *Cryptosporidium* are the most common parasites of humans and domestic animals (cattle, dogs).
- *Giardia* is a common cause of diarrhoea, particularly among disadvantaged groups.
- *Cryptosporidium* is an opportunistic parasite that causes diarrhoea in AIDS patients.
- Both parasites are insensitive to the disinfectants commonly used in water treatment. Filtration, boiling, UV radiation reduce the risk.



Giardia intestinalis micrograph
Source: Stanford University

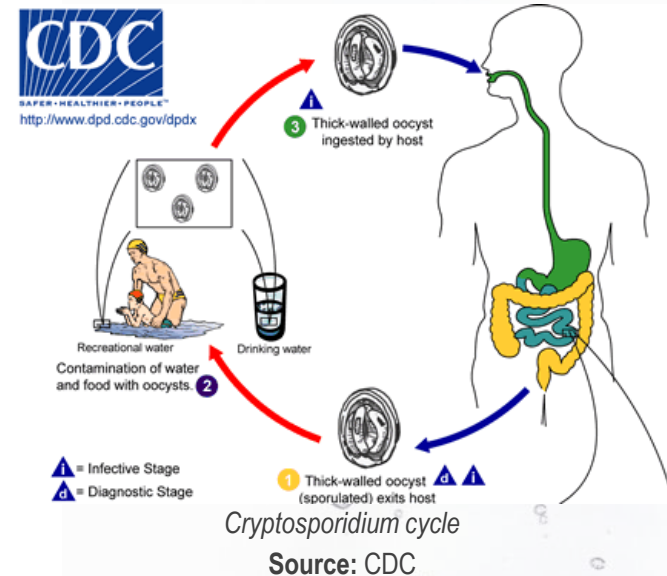


Slifko et al. 2000 Emerging parasite zoonoses associated with water and food. *Int J Parasitol* 30(12-13)
Hunter & Thompson 2005 The zoonotic transmission of *Giardia* and *Cryptosporidium*. *Int J Parasitol*. 35(2005)

© 2013 Felipe de Jesús Colón-González

Giardia & Cryptosporidium

- The infective stages of both parasites are released in the faeces.
- These infective stages are capable of prolonged survival in the environment.
- Infection is achieved when the infective stages are ingested through direct contact or via contaminated materials (e.g. water or food).



Hunter & Thompson 2005 The zoonotic transmission of *Giardia* and *Cryptosporidium*. *Int J Parasitol.* 35(2005)
Budu-Amoako et al. 2012 Occurrence of *Cryptosporidium* and *Giardia* on beef farms and water sources within the vicinity of the farms on Prince Edward Island, Canada. *Vet Parasitol* 184(2012)

Transmission by irrigation



- In many developing countries, use of insufficiently treated wastewater to irrigate vegetables has been reported to be responsible for the high rates of contamination with parasites.
- Study performed on 300 samples of vegetables purchased on a local small retailer.

Table 1 The number and percentage of contaminated samples and the mean of parasite score density in some raw green vegetables.

	Rocket		Lettuce		Parsley		Leek		Green onion		Total No. (%) n2 = 300
	No. (%) n1 = 60	D	No. (%) n1 = 60	D	No. (%) n1 = 60	D	No. (%) n1 = 60	D	No. (%) n1 = 60	D	
<i>Cryptosporidia</i> spp. oocysts	27(45)	2.22	26 (43.3)	2.10	20 (33.3)	1.90	8 (13.3)	1.10	7 (11.7)	1.30	88 (29.3)
<i>Microsporidia</i> spp. spores	22 (36.7)	1.80	25 (41.7)	2.00	10 (16.7)	1.80	8 (13.3)	1.42	11(18.3)	1.34	76 (25.3)
<i>Cyclospora</i> spp. oocysts	19 (31.7)	1.88	23 (38.3)	1.95	15 (25)	1.74	5 (8.3)	1.60	2 (3.3)	1.50	64 (21.3)
<i>Ascaris</i> eggs	21(35%)	1.30	23 (38.3)	1.75	10 (16.7)	1.42	4 (6.7)	1.25	3(5)	1.33	61 (20.3)
<i>Toxocara</i> eggs	15 (25)	1.86	19(31.7)	1.81	12 (20)	1.54	5 (8.3)	1.02	6(10)	1.00	57 (19)
<i>Giardia</i> spp. cysts	6 (10)	1.00	9 (15)	0.88	3 (5)	0.66	1(1.7)	1.00	0 (0)	0	19 (6.7)
<i>Hymenolepis nana</i> eggs	2(3.3)	0.33	4 (6.7)	0.50	2 (3.3)	0.03	0 (0)	0	0 (0)	0	8 (2.6)

No.: Number of contaminated sample by each parasite.

n1 = Number of examined samples for each type of green vegetable = 60.

D: mean score density for each parasite in green vegetables.

Total No.: Total number of contaminated samples by each parasite.

n2: Total number of examined samples = 300.



Recreational water



- *Giardia* and *Cryptosporidium* are also the most commonly recognised cause of recreational waterborne disease.
- *Cryptosporidium* was responsible for 51% of 325 water-related outbreaks of protozoan disease documented worldwide.
- Both diseases are important contributors to traveller's diarrhea and are more common in developing countries.
- Outbreaks are more common during the summer which may be due either to increased contamination of water supplies or greater numbers of susceptible people swimming.

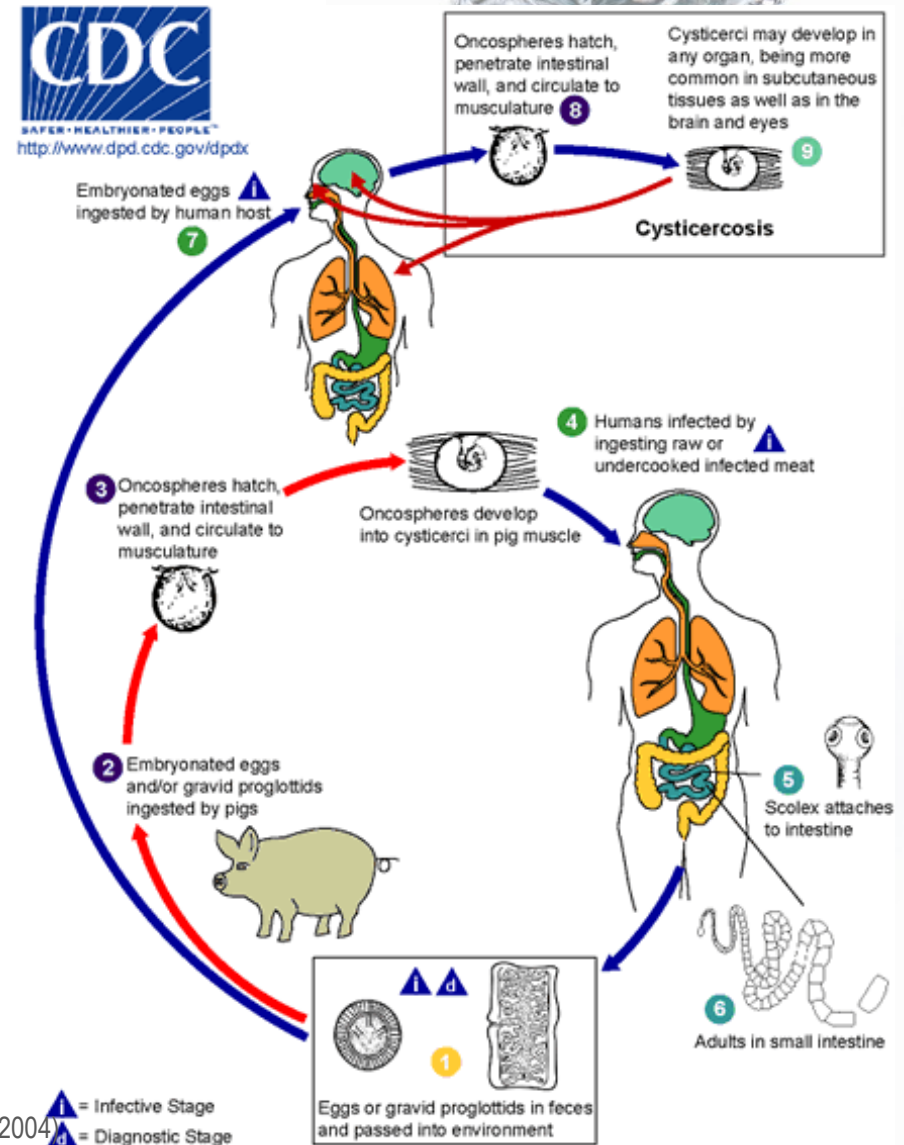
Slifko et al. 2000 Emerging parasite zoonoses associated with water and food. *Int J Parasitol* 30(12-13)

Macpherson 2005 Human behaviour and the epidemiology of parasitic zoonoses. *Int J Parasitol* 35(2005)

Smith & Nichols 2010 *Cryptosporidium*: Detection in water and food. *Exp Parasitol* 124(2010)

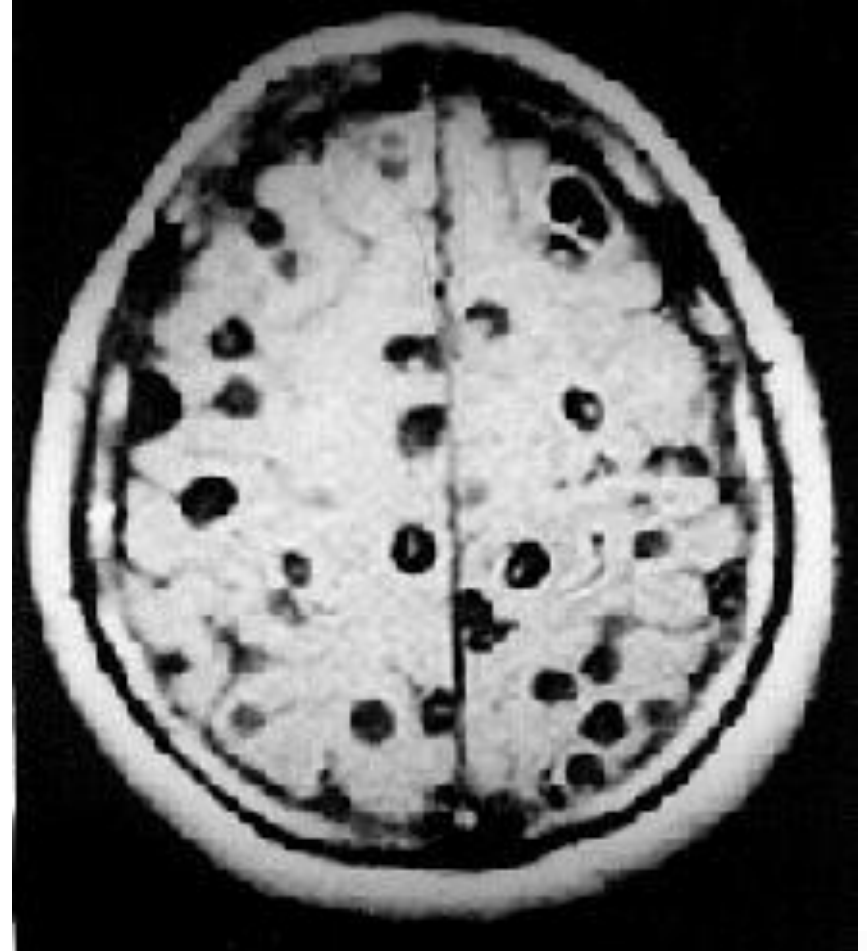
Cysticercosis

- Acquired after the ingestion of food or water contaminated with *Taenia solium* (tapeworm) eggs.
- Eggs are commonly released by human feces. Eggs then develop into a cysticercus.
- May end up in the muscles, the eye, or the brain.



Nithiuthaia et al. 2004 Waterborne zoonotic helminthiases. *Vet Parasitol.* 126(2004)

Neurocysticercosis

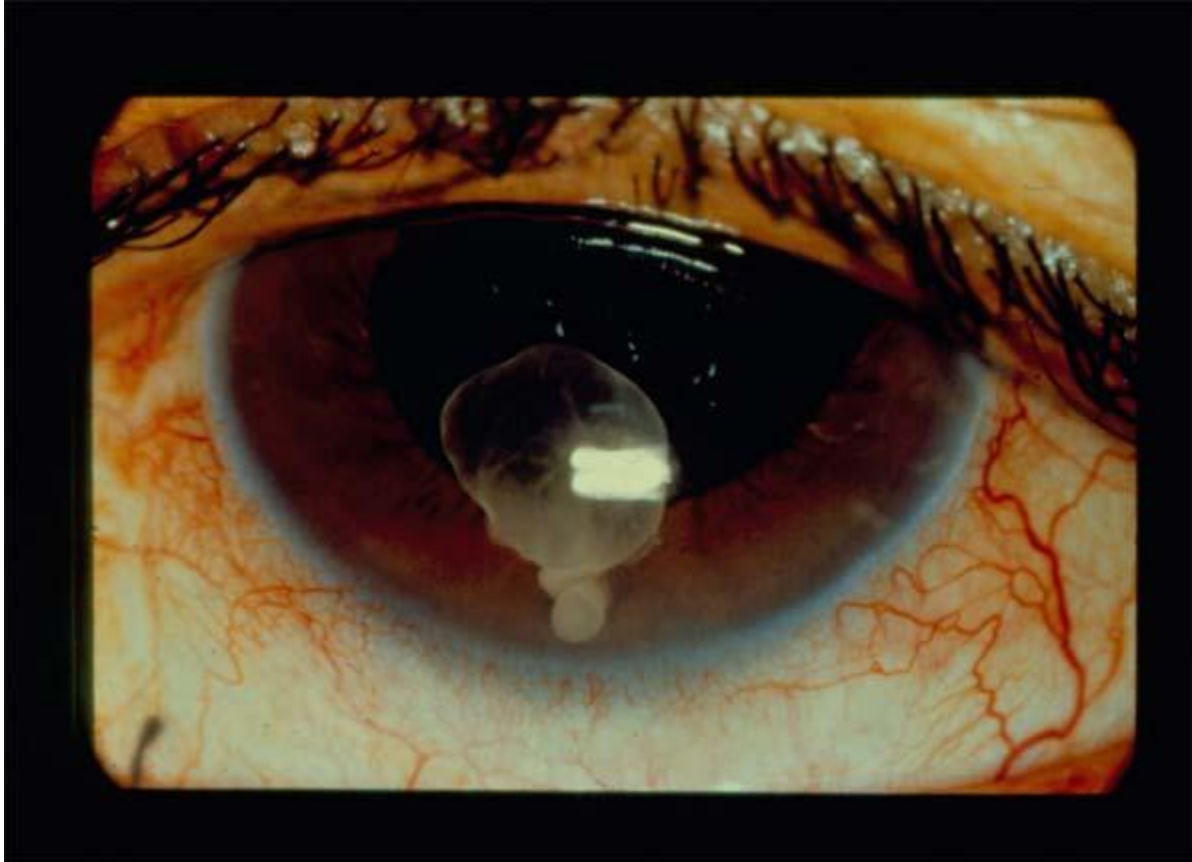


Source: neurology.org

© 2013 Felipe de Jesús Colón-González



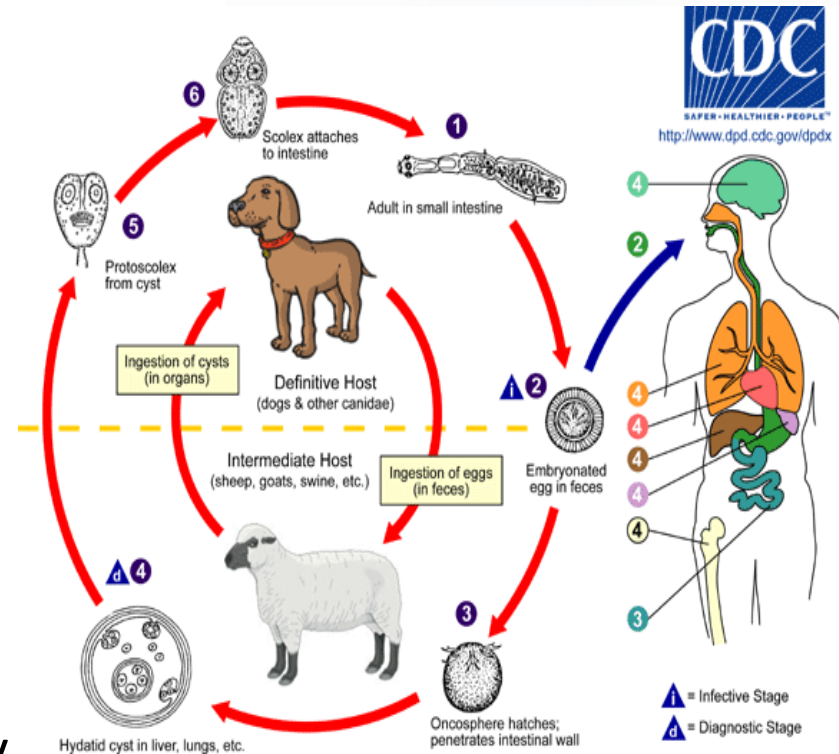
Cysticercus in the eye



Source: www.shopeastwest.com

Echinococcosis

- Caused by a tapeworm called *Echinococcus granulosum*.
- Develop in dogs and other canids.
- Infection occurs with ingestion of contaminated water with dog feces.
- Eggs develop into cysts usually in the liver, although they may infect other organs (e.g. lungs, spleen, kidneys).
- Cysts can cause life-threatening problems (e.g. liver failure, pulmonary edema and anaphylactic shock).



Hepatitis A & Human astrovirus



- ~30-40% of infectious diarrhoea in developed countries may be attributable to viruses of human faecal origin.
- Hepatitis A (HA) causes moderate hepatitis and astrovirus (HAstV) causes gastroenteritis in all age groups.
- Like protozoans, they are resistant to disinfectants, therefore their presence in water for domestic and recreational purposes pose health threats.
- Transmission may occur through ingestion of contaminated water and food (salads, seafood, souces).

De Paula et al. 2007 Hepatitis A virus in environmental water samples from the Amazon Basin. *Wat Res* 41(2007)

Taylor et al. 2000 The occurrence of hepatitis A and astroviruses in selected river and dam waters in South Africa. *Wat Res* 35(11)

Gammie & Wyn-Jones 1997 Does hepatitis a pose a significant health risk to recreational water users? *Wat Sci and Tech* 35(11-12)



Risk groups

- Travellers from low endemic areas going to high endemic areas... including people staying in luxurious hotels.
- Non-immunized surfers have a 3-fold greater risk of infection with HA in compared to immunized ones.
- Military when performing activities in water bodies.
- Sewage workers have due to aerosols and direct contact with contaminated water.



Source: layoutsparks.com



Source: invisio.com

Aerosol-related diseases

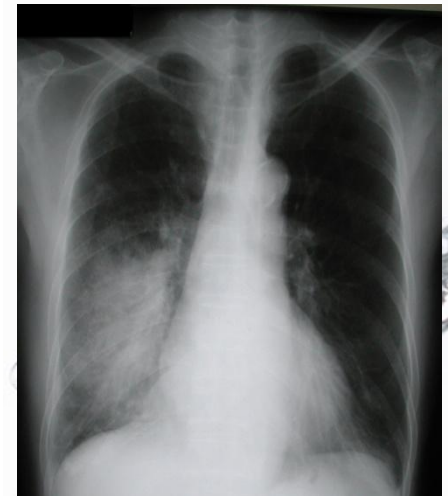


Legionella pneumophila

- Bacterium that causes the Legionnaires' disease.
- The disease is characterized by head-ache, coughing, fever, myalgia, abdominal pain and diarrhoea.
- Legionnaires' disease may cause bilateral pneumonia and respiratory distress.
- Mortality may be ~39% in hospitalized patients, and higher among immunocompromised people.



Source: lifeinthefastlane.com



Source: lifeinthefastlane.com

Ishimatsu et al. 2001 Sampling and Detection of Legionella pneumophila Aerosols Generated from an Industrial Cooling Tower. *Ann Occup Hyg* 45(6).

Legionella pneumophila

- Transmission to humans occurs through droplets generated from environmental sources such as cooling towers, humidifiers, showerheads, and other human-made devices that generate aerosols.
- High temperatures in the hot water systems ($> 50^{\circ}\text{C}$) seem to reduce the risk of infection.



Source: Wikipedia



Source: <http://atbloomlife.blogspot.it>

Ishimatsu et al. 2001 Sampling and Detection of Legionella pneumophila Aerosols Generated from an Industrial Cooling Tower. *Ann Occup Hyg* 45(6).

PAHO 2001 *El control de las enfermedades transmisibles*. Geneva: PAHO

Water-washed diseases

(Preventable using safe water)



Trachoma

- Cause by the *Chlamydia trachomatis* bacterium.
- Trachoma is an infection of the eyes that may result in blindness after repeated re-infections.
- It is the world's leading cause of preventable blindness.
- Occurs where people live in overcrowded conditions with limited access to water for personal hygiene and health care.
- Trachoma spreads easily from person to person and can also be transmitted by flies.

WHO 2001 *Trachoma* Geneva: WHO. Available at:
http://www.who.int/water_sanitation_health/diseases/trachoma/en/index.html



Source: webpages.scu.edu



Source: pilarhernandezpastor.wordpress.com

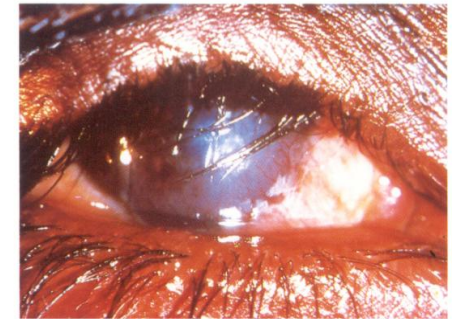


Trachoma

- Infection usually first occurs in childhood but people do not become blind until adulthood.
- The disease progresses over years as repeated infections cause scarring on the inside of the eyelid, earning it the name of the “quiet disease”
- The cornea becomes scarred leading to severe vision loss and eventually blindness.
- Trachoma can be prevented with personal hygiene.



Trachomatous scarring (TS)



Trachomatous trichiasis (TT)



Corneal opacity (CO)

Source: WHO 2001

WHO 2001 *Trachoma* Geneva: WHO. Available at:
http://www.who.int/water_sanitation_health/diseases/trachoma/en/index.html

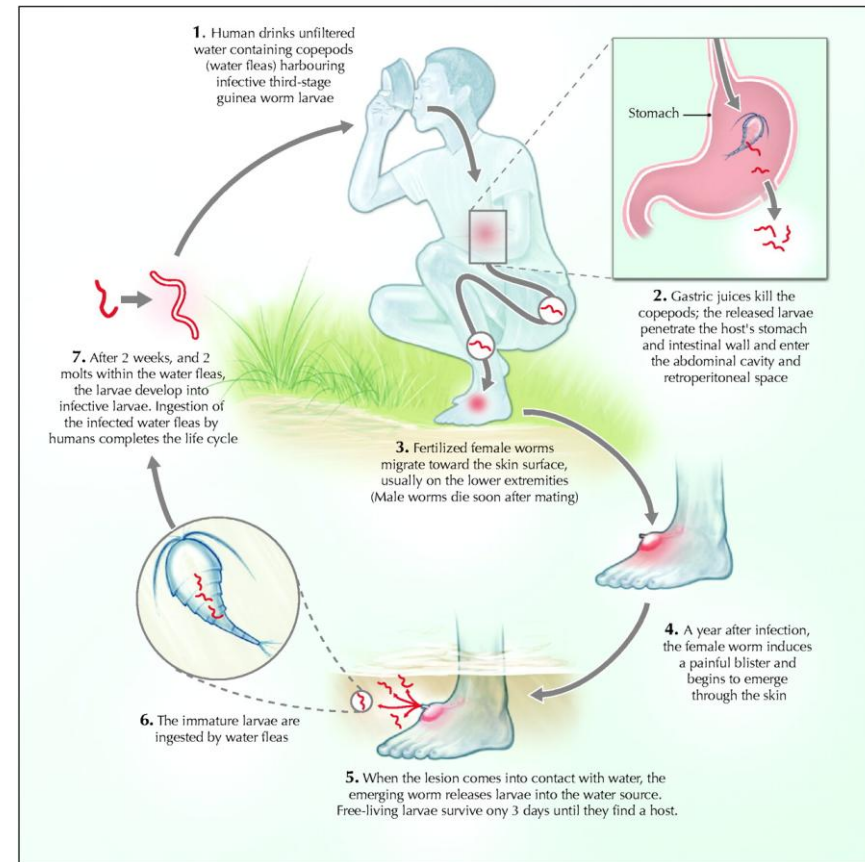
Water-based diseases

(Transmitted by organisms that develop in water)



Dracunculiasis

- Caused by a nematode called *Dracunculus medinensis* with copepods (water fleas) are intermediate hosts.
- Transmission occurs with the ingestion of stagnant water contaminated with copepods, then worms then develop into the human host (up to 1 metre long!).



Source: www.ecmaj.ca



Dracunculiasis

- Thousands of larvae are released into water by the bust of a blister (90% of the time from the feet).
- Blisters appear about a year after infection.
- Does not produce mortality but affects quality of life and productivity.



Source: flickr.com



Source: CDC

Swimmer's itch

- Caused by the larval stages of birds' schistosomes (e.g. *Schistosoma spp.*, *Gigantobilharzia*, *Trichobilharzia* and *Austrobilharzia*).
- Their life cycle includes snails and waterfowl. Humans are accidental hosts and the larvae cannot complete their cycle within them.
- Most larvae die soon after penetration.
- Repeated exposure leads to unpleasant, non-harmful dermatitis.



Figure 3. Swimmer's itch developed after sampling snails in shallow water for 2 h by one of the authors.

Source: Soldánová et al. 2013 p. 68



- Larvae are released by faeces or through the nasal mucosa.
- The larval host-finding behaviours (swimming) are stimulated by shadow, water turbulence, and tactile stimuli.

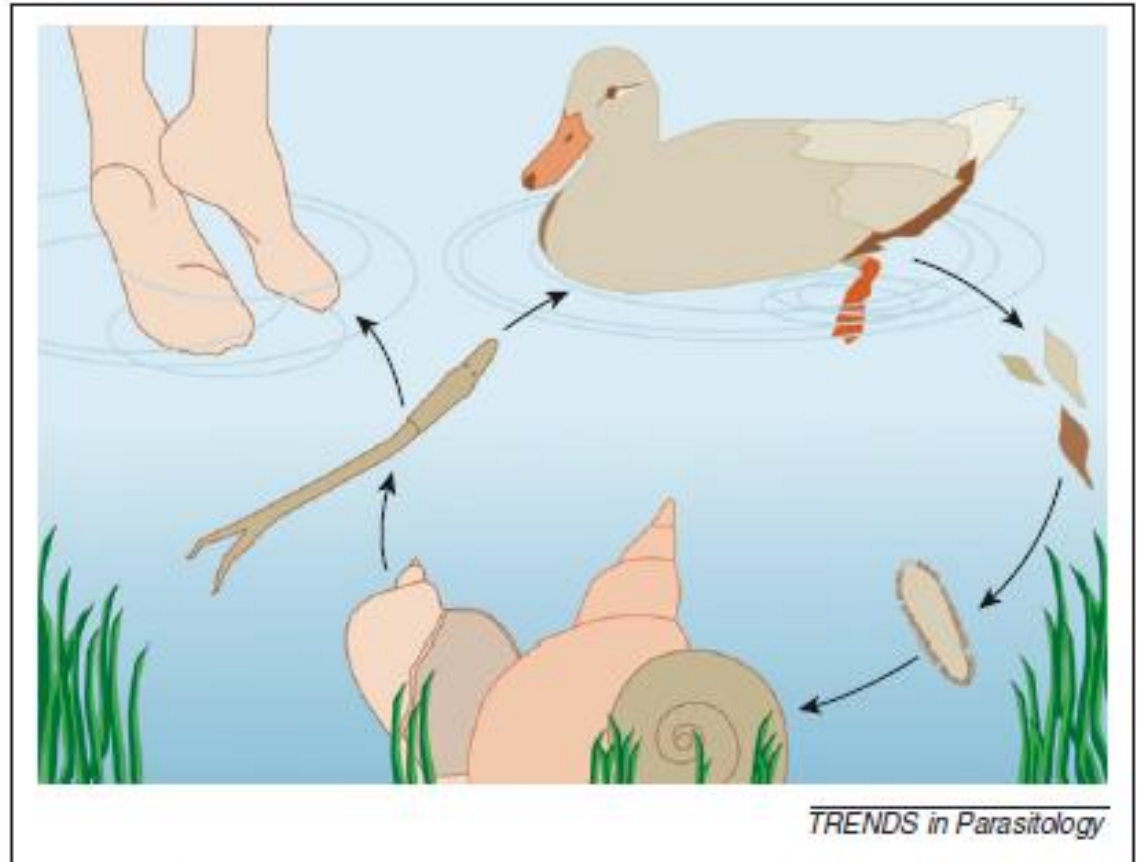


Figure 1. Generalized life-cycle of a bird schistosome. Adult trematodes reproduce in waterfowl, and eggs are released into the water. From eggs the first dispersive larval stages (miracidia) hatch and infect suitable snail intermediate hosts in which asexual reproduction occurs, resulting in the production of the second dispersive larval stages (ocellate furcocercariae). Cercariae emerge from infected snails and infect appropriate final hosts (birds) thus completing the life cycle. Swimmer's itch occurs when cercariae accidentally penetrate human skin.



Swimmer's itch



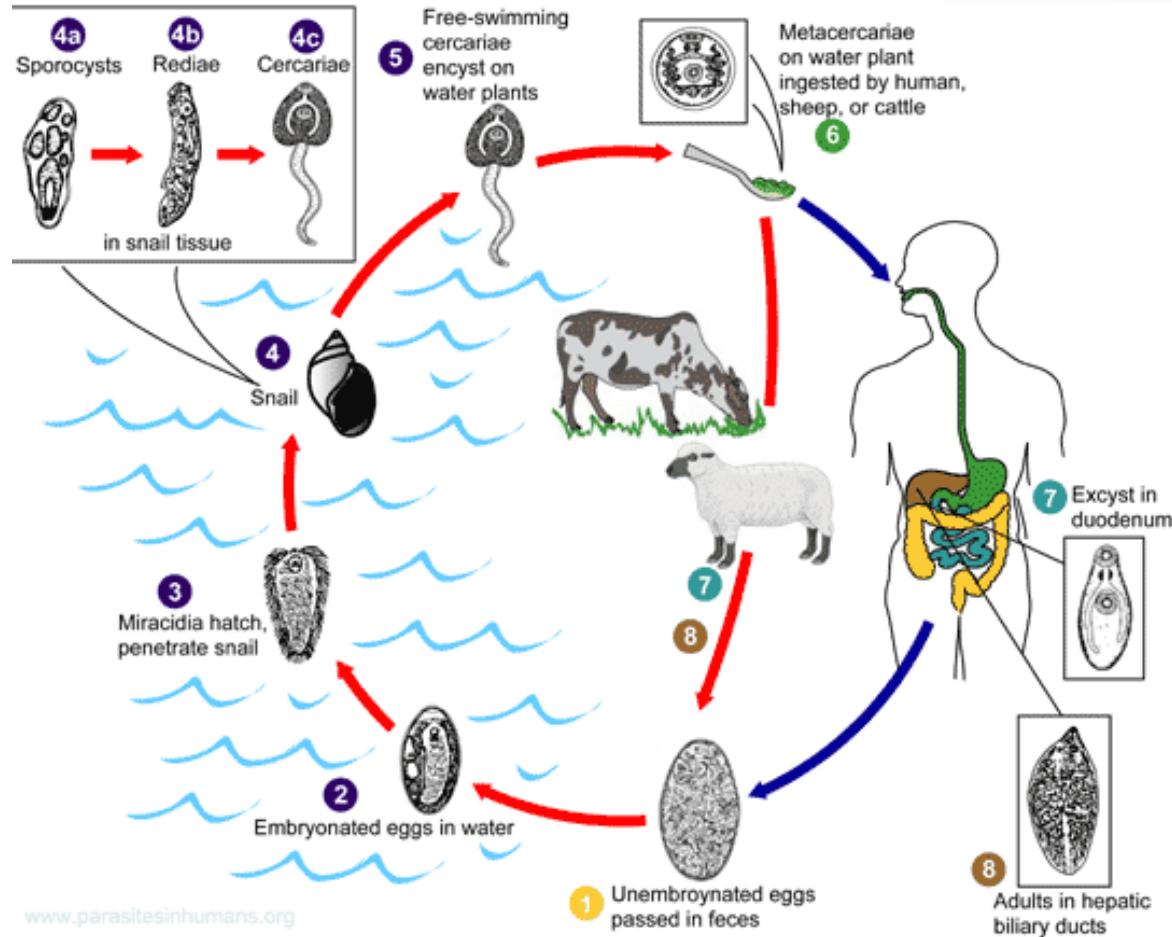
- Cases may occur in brackish and fresh water environments.
- Anthropogenic eutrophication is a major contributor to the disease.
- A recent study found a greater risk to swimmer's itch in eutrophic lakes (> 55%) in Europe.
- Increased nitrogen and phosphorus concentrations stimulate biomass growth which provides ideal conditions for snail abundance.



Soldánová et al. 2013 Swimmer's itch: etiology, impact and risk factors in Europe. *Trends in Parasitol* 29(2))



Other water-based diseases



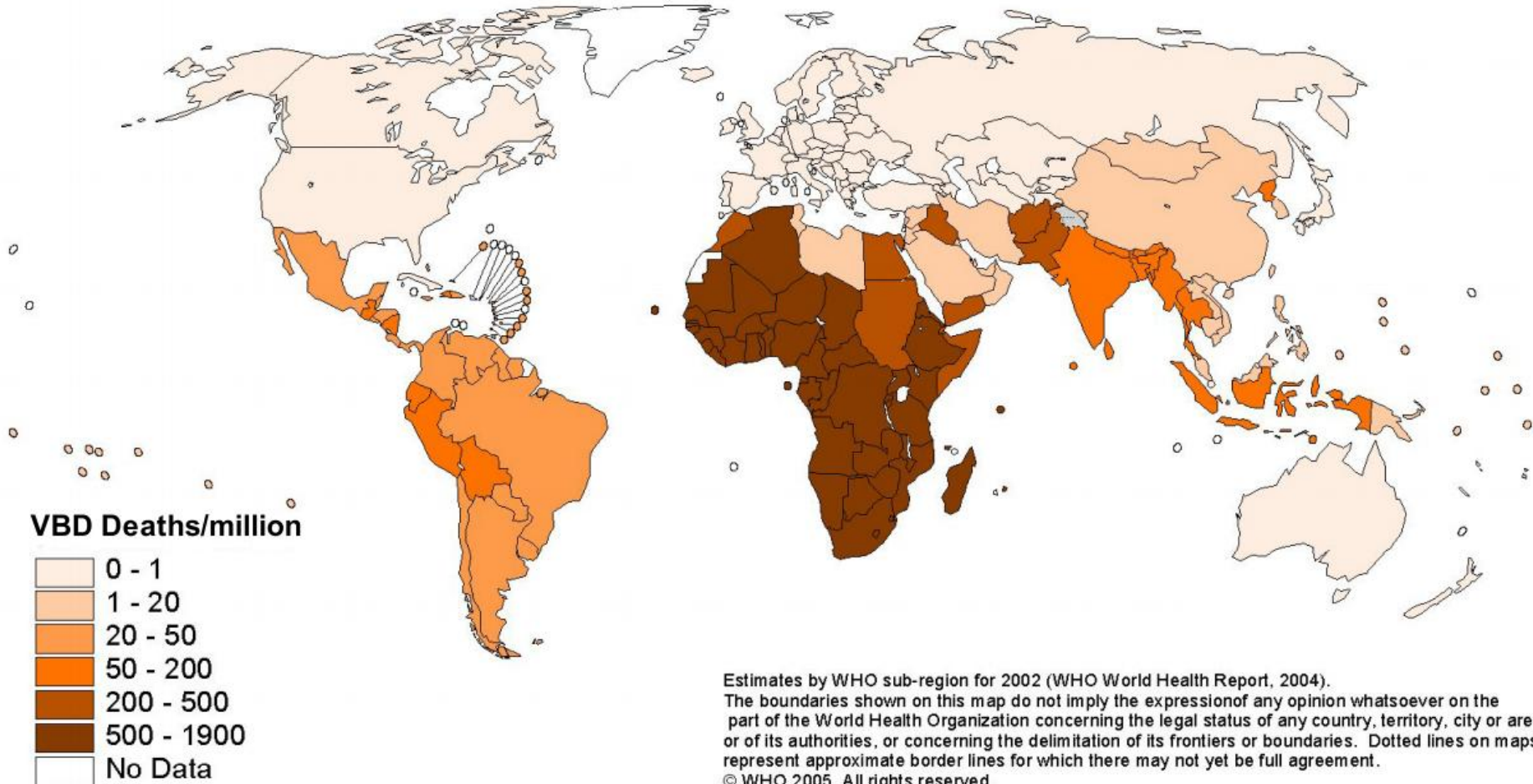
Fasciola hepatica

Vector-borne diseases

(Transmitted by arthropods)



Deaths caused by VBIDs



Source: WHO 2005



Some VBIDs

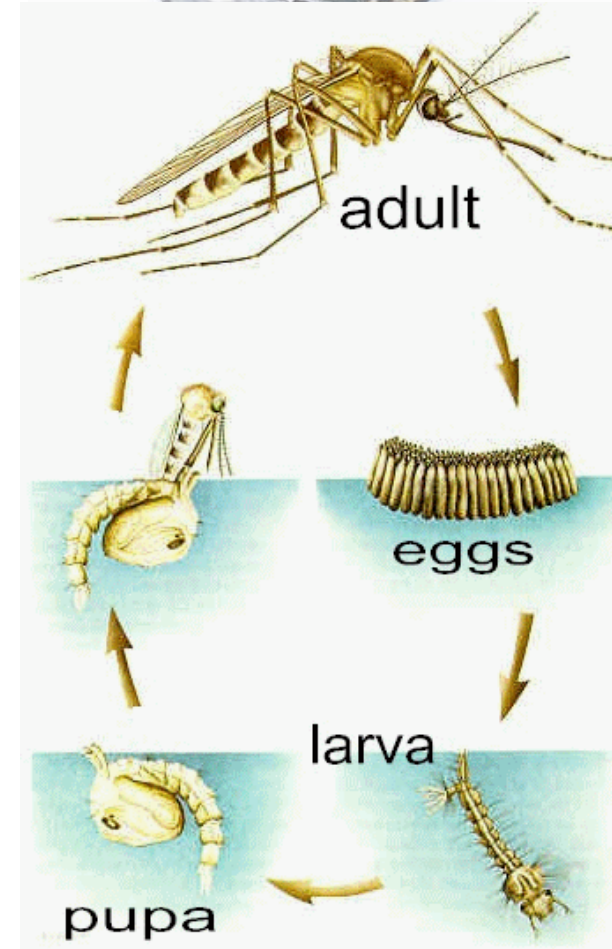
- Arboviral encephalites:
 - Eastern equine encephalitis
 - Japanese encephalitis
 - West Nile virus encephalitis
 - Western equine encephalitis
 - St Louis encephalitis
- Dengue / Severe Dengue
- Malaria
- Rift Valley fever
- Yellow fever
- Chikungunya

- Chagas disease (triatomines)
- Leishmaniasis (sand flies)
- Lyme disease (ticks)
- Crimean-Congo hemorrhagic fever (ticks)
- Human Granulocytic Anaplasmosis (ticks)
- Tick-borne encephalitis (ticks)



Life cycle of a mosquito

- Potential larval sites
 - Brackish or fresh water
 - Stagnant or flowing
 - Natural or artificial
 - Lagoons, lakes, marshes, slow flowing rivers, small streams, pools, wells, puddles, tree holes, leaves...
 - Borrow pits, rice fields, fish ponds, irrigation channels and ditches, wheel ruts, hoof prints, empty cans, bottles, water tanks, tyres...

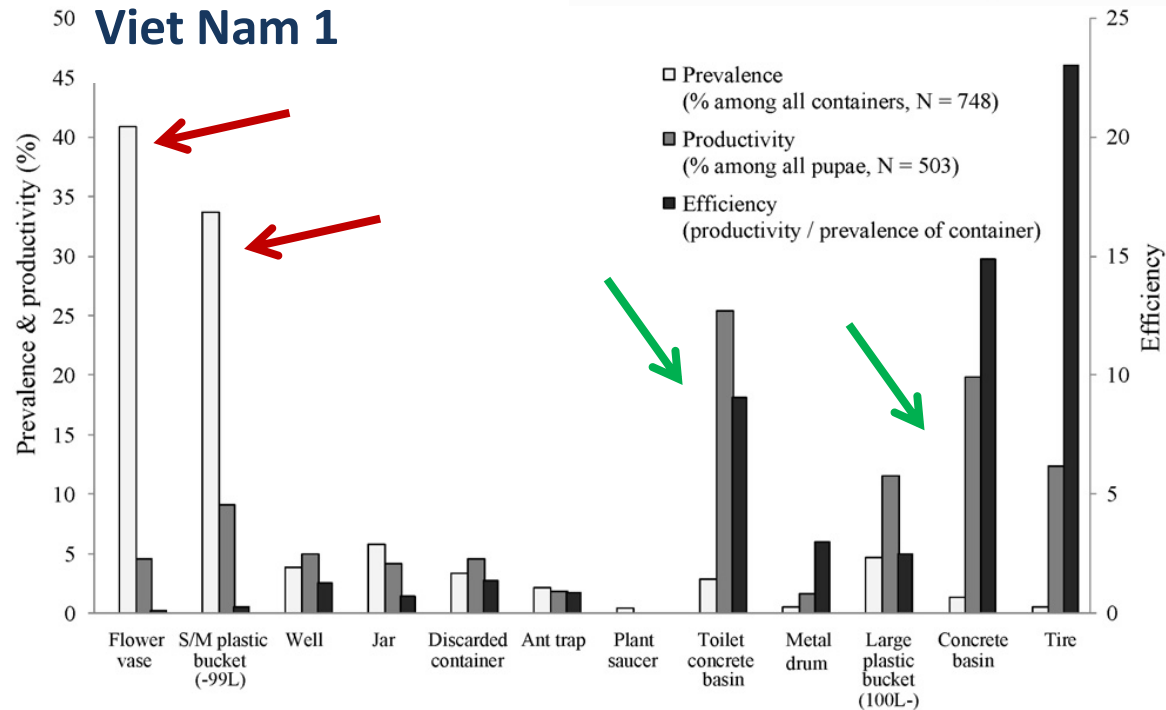


Source: Mosquito Misting News

Mosquito breeding sites

- *Aedes aegypti* seems to prefer small-to-medium sized man-made containers in some settings (above) and larger in others.
- Larger containers likely to contain more predators.
- Large containers more likely to be under control measures (drinking water).

Viet Nam 1



Viet Nam 2

Container type	Binh Hoa Bac				
	No. cont.	III/IV instars		Pupae	
		No. +ve	Total no. larvae	No. +ve	Total no. pupae
Cylindrical tank	132	2	71	0	0
UNICEF style jar	9	0	0	0	0
Box tank >500L	8	0	0	0	0
Other tanks	22	0	0	0	0
Standard jar >100L	839	188	7484	77	992
Small jar <100L	118	12	614	5	66
Bucket	7	0	0	0	0
Drum	2	0	0	0	0
Aquarium	2	0	0	0	0
Discard	6	0	0	0	0
Flower vase	17	1	5	0	0
Other	19	0	0	0	0
Ant trap	35	7	48	5	12
Total	1216	210	8222	87	1070

Tsuzuki et al. 2009 High potential risk of dengue transmission during the hot-dry season in Nha Trang City, Vietnam. *Acta Tropica* 111(2009)

Harrington et al. 2008 Influence of Container Size, Location, and Time of Day on Oviposition Patterns of the Dengue Vector, *Aedes aegypti*, in Thailand. *Vector Borne Zoonotic Dis* 8(3)

The complexity of the dengue-water relationship



- In some settings access to piped water seems to be protective against dengue.
- In others it seems to increase dengue incidence possibly due to increased water storage.

International Health 3 (2011) 115–125

Contents lists available at ScienceDirect

International Health

journal homepage: <http://www.elsevier.com/locate/inhe>



Abundance and prevalence of *Aedes aegypti* immatures and relationships with household water storage in rural areas in southern Viet Nam

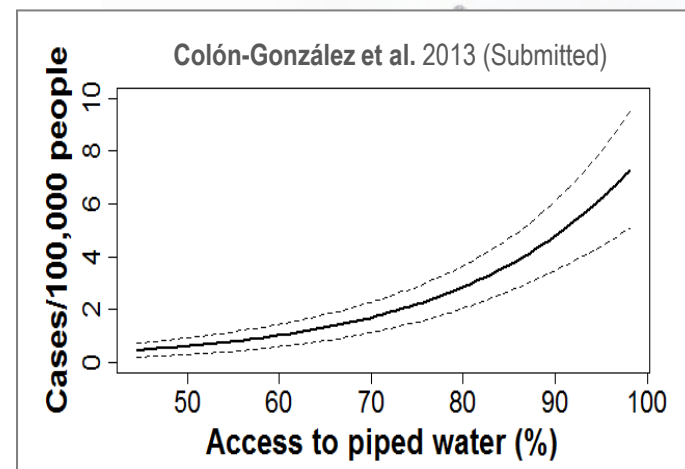
Le Anh P. Nguyen^{a,b,c}, Archie C.A. Clements^{b,c}, Jason A.L. Jeffery^c, Nguyen Thi Yen^a, Vu Sinh Nam^d, Gregory Vaughan^e, Ramon Shinkfield^e, Simon C. Kutcher^e, Michelle L. Gatton^c, Brian H. Kay^c, Peter A. Ryan^{c,*}

OPEN ACCESS Freely available online

PLOS MEDICINE

Population Density, Water Supply, and the Risk of Dengue Fever in Vietnam: Cohort Study and Spatial Analysis

Wolf-Peter Schmidt¹, Motoi Suzuki¹, Vu Dinh Thiem², Richard G. White³, Ataru Tsuzuki⁴, Lay-Myint Yoshida¹, Hideki Yanai¹, Ubydul Haque⁵, Le Huu Tho⁶, Dang Duc Anh², Koya Ariyoshi^{1,7*}



Dengue

- Droughts and unreliable water supply may lead to increased water storage that provides breeding sites.
- Some people store because of cultural reasons ('just in case').



Source: www.poceros.wordpress.com



Source: www.quebarato.com.mx



Source: Novedades de Quintana Roo

Padmanabha et al. 2010 Ecological Links Between Water Storage Behaviors and *Aedes aegypti* Production: Implications for Dengue Vector Control in Variable Climates. *Ecohealth* 7(2010)

Thank you for your attention!

Felipe J. Colón-González
fcolon_g@ictp.it



The Abdus Salam
International Centre
for Theoretical Physics

2nd Workshop on Water Resources in Developing Countries:
Planning and Management in a Climate Change Scenario

Indirect transmission



Figure 1 Boy washing dishes in polluted irrigation canal in the Philippines (Source: M/IMC Photoshare, www.jhuccp.org/immc).

