Vector-borne diseases associated with water
Vector-borne diseases

Vector

- **General definition:** vectors are living agents that transfer a pathogen from one host to another.
- Many vectors are invertebrate animals, frequently arthropods (e.g. insects, ticks, mites).
- Intermediary animals often serve as a **host** or a **reservoir** for the pathogens, until susceptible humans are exposed, and then transmission can occur through these animals in their function as a **vector**.
Vector-borne infectious diseases associated with water

- Water acts as a breeding-site for many disease vectors (mainly insects, sometimes copepods, snails) that play a key role in the spread of pathogens (viruses, protozoa, parasitic worms).

- Water resources development projects (dams, irrigation schemes) in rural areas or open water collections in urban areas promote spread of vectors.

- Vector-borne diseases are prevalent in tropical and subtropical countries.

- There has been a worldwide (re)emergence of vector-borne diseases since the 1970s.
## Vector-borne diseases associated with water

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Dengue

The disease
Mosquito-borne infectious disease occurring in two forms:
- Dengue fever: a severe flu-like illness, seldom causes death.
- Dengue haemorrhagic fever: potentially deadly complication, high fever, haemorrhages (bleeding of skin, nose or gums, internal bleeding from blood vessels), enlargement of the liver, circulatory failure; the leading cause of childhood death in several Asian countries (case-fatality rate: 5 %, but can exceed 20 %).

Causal agents
- Pathogens: four distinct, closely related arboviruses (genus *Flavivirus*),
- Vectors: female *Aedes* mosquitoes (*Aedes aegypti, Aedes albopictus*).
Replication and Transmission of Dengue virus (Part 1)

1. Virus transmitted to human in mosquito saliva.
2. Virus replicates in target organs.
3. Virus infects white blood cells and lymphatic tissues.
4. Virus is released and circulates in blood.
Replication and Transmission of Dengue virus (Part 2)

5. Second mosquito ingests virus with blood.

6. Virus replicates in mosquito midgut and other organs, infects salivary glands.

7. Virus replicates in salivary glands; once infected, a mosquito is capable of transmitting the virus to susceptible people for the rest of its life and to the next generation of mosquitoes.

*Note: Aedes aegypti mosquito*
The first reported epidemics of dengue occurred in 1779-1780 in Asia, Africa, and North America.

Dengue viruses and their mosquito vectors have had a worldwide distribution in the tropics for more than 200 years.

A pandemic of dengue began in Southeast Asia after World War II and has been spread around the globe since then.

DEN: dengue
DHF: dengue haemorrhagic fever
History of dengue

- The global incidence of dengue has grown dramatically in recent decades!
- Not only is the number of cases increasing as the disease spreads to new areas, but explosive outbreaks are occurring.
- Recent epidemics in 2008/09: Australia, Brazil, Bolivia, Argentina.
Present situation

- Dengue fever is regarded as an emerging infectious disease.
- The spread of dengue is attributed to expanding geographic distribution of the four dengue viruses and their mosquito vectors (predominantly the urban species *Aedes aegypti*).

World distribution of dengue viruses and their mosquito vector (*Aedes aegypti*) in 2008. Dengue is now endemic in more than 100 countries.
Global distribution of dengue

- Dengue is found in most tropical and subtropical regions.
- Typically in urbanized areas, where the mosquitoes find breeding opportunities in water collections in and around houses (drinking water containers, discarded car tires, flower vases, cisterns, etc.).

- An estimated 2.5 billion people live in areas at risk for epidemic transmission.
- An estimated 50 million cases of dengue fever and around 500,000 cases of dengue haemorrhagic fever occur each year.
- In 2007 alone, there were 890,000 reported cases of dengue in the Americas, of which 26,000 cases were dengue haemorrhagic fever.
Global distribution of dengue

- **Reasons for global emergence of dengue**
  - Major global demographic changes, especially uncontrolled urbanization and concurrent population growth. These demographic changes have resulted in substandard housing and inadequate water, sewer, and waste management systems.
  - Deterioration of public health infrastructure.
  - Increased travel by airplane providing the ideal mechanism for infected human transport of dengue viruses between populations.
  - Nonexistence of effective mosquito control in most dengue endemic countries.
  - Possibly climate change

- **Interventions:**
  - Most effective method of prevention is removal of mosquito breeding-sites (vector control).
  - Other control measures: preventing mosquito bites with screens, protective clothing and use of insect repellents.
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Chikungunya fever

The disease
- Fever, headache, nausea, vomiting, muscle pain, rash, significant pain in the joints (ankles, wrists); the disease is rarely fatal.
- Incubation period: usually 3-7 days; the disease lasts a few days to a couple of weeks.

Causal agents
- Pathogen: Chikungunya virus (genus Alphavirus, family Togaviridae).
- Vectors: Aedes mosquitoes (most commonly A. aegypti and A. albopictus) which transmit the viruses to humans through bites during the day.
- Mosquitoes acquire the virus while feeding on blood of infected people.

Aedes albopictus (Asian tiger mosquito): viruses are transmitted during the feeding process.
Chikungunya fever

- **Distribution**
  - In Africa and Asia (Southeast Asia, Indian subcontinent).
  - Typically in urbanized areas, where the mosquitoes find breeding opportunities in water collections in and around houses (drinking water containers, discarded car tires, flower vases, etc.).

- **Outbreak on the Island of Réunion 2005/2006**
  (French overseas department in the Indian Ocean)
  In 2005 and 2006: 266,000 cases, more than 40,000 cases alone in week 5 of 2006; over 250 deaths.
Distribution of chikungunya fever

- The disease was first described during an outbreak in Tanzania in 1952, and has since appeared in west, central and southern Africa and many areas of Asia.

- In 2007, transmission was reported for the first time in Europe (localized outbreak in north-eastern Italy).

- *Aedes aegypti* mosquitoes are common vectors for dengue virus and Chikungunya virus; in areas where both viruses circulate, they can be transmitted together.

Cases of chikungunya fever (between 1953-2008) have been reported in the countries depicted in red on this map.
**Chikungunya fever**

- **Factors relevant for risk assessment concerning Europe**
  - Importation of the virus into Europe by people travelling from high incidence areas in the Indian Ocean to Europe (imported cases have occurred in some European countries).
  - Importation of the mosquito (as the epidemic vector) through the trade of used tires (mosquito lays eggs in pools of water in the tires), and ornamental plants which are transported in water ⇒ establishment of mosquito in Albania and Northern/ Central Italy.

- **Interventions**
  - Most effective method of prevention is removal of mosquito breeding-sites:
    prevention/elimination of any stagnant water, covering water tanks and other water containers.
  - Other control measures:
    preventing mosquito bites with screens, protective clothing and use of insect repellents.
Dissemination of *Aedes albopictus* in Europe

Two independent cases of autochthonous transmission of dengue fever and two cases of chikungunya fever were recorded in south-eastern France during September 2010.

(Gould et al., Clinical Microbiology and Infection, 2010)
Japanese encephalitis

The disease
- Acute encephalitis; can progress to paralysis, seizures, coma and death; case-fatality rates: 0.3 % to 60 %.
- The majority of infections are subclinical.

Causal agents
- **Pathogen:** Japanese encephalitis virus (genus *Flavivirus*).
- **Vectors:** *Culex* mosquitoes which transmit the viruses to humans through bites.

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**Japanese encephalitis virus**

**Culex mosquito laying eggs**
(photograph by R. Weber)
Transmission of Japanese encephalitis

- Mosquitoes become infected by feeding on domestic pigs and wild birds infected with the Japanese encephalitis virus.
- The virus is amplified in the blood systems of pigs and wild birds.
- Infected mosquitoes transmit the virus to humans and animals during the feeding process.
Japanese encephalitis is restricted to the Asian region.

Japanese encephalitis is the leading cause of viral encephalitis in Asia with 30,000 to 50,000 clinical cases reported annually.

Japanese encephalitis is closely associated with irrigated rice areas, where the *Culex* mosquitos prefer to breed.

Transmission risks are greatly enhanced where pig rearing is practised.
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Malaria

- Malaria is the world's most important parasitic infectious disease, transmitted by mosquitoes which breed in fresh or occasionally brackish water, ponds etc.
- Symptoms include fever, headache, muscle aches, tiredness, nausea, vomiting, diarrhea, anaemia, and jaundice.

A child with severe malaria; malaria kills an African child every 30 seconds.

Open water sources are breeding sites for larvae of *Anopheles* mosquitoes.
Malaria

- **Pathogens**: malaria is caused by 4 protozoan species of the Sporozoa group: *Plasmodium falciparum* (Malaria tropica), *P. vivax* (Malaria tertiana), *P. ovale* (Malaria tertiana) and *P. malariae* (Malaria quartana); *P. falciparum* causes the most deadly type of malaria infection.

- **Vectors**: female mosquitoes of the genus *Anopheles* (important species: *A. gambiae*, *A. arabiensis*, *A. funestes*), which transmit *Plasmodium* spp. through bites.

*Plasmodium* (arrow) among red blood cells

*Anopheles* mosquito
Life cycle of the malaria parasite *P. vivax*

**Erythrocytic stage**: Merozoites infect and reproduce in red blood cells.

**Liver phase**: 8 days to several months.

Clinical symptoms occur when red blood cells break up.

*Source: Madigan and Martinko, 2006*
Disease burden of malaria

- Malaria occurs mainly in tropical and subtropical regions; most of the disease burden is in Africa south of the Sahara. Malaria was eliminated from many countries with temperate climates during the mid 20th century.
- Some regions are malaria endemic (constant number of cases throughout the year), whereas in other regions there are malaria seasons, usually coinciding with the rainy season.
- Approximately half the world's population, mostly those living in the poorest countries, are at risk of malaria.
- World Malaria Report 2011 (WHO): in 2010, 216 million cases of malaria and approximately 655,000 deaths (86 % of whom were children under 5).
- Climate change may contribute to an increase in malaria risk.
Global distribution of malaria

Most cases and deaths occur in sub-Saharan countries; Asia, Latin America, the Middle East and parts of Europe are also affected.
Malaria and HIV/AIDS

- Malaria and HIV/AIDS are the most devastating global health problems today, causing more than 4 million deaths a year together.
- To a large extent, both diseases are concentrated in the same geographical regions, resulting in co-infection and interaction between the two diseases.
- HIV-infected people are considered as particularly vulnerable to malaria.

Areas with significant overlap of malaria and HIV prevalence
Relationship between malaria and different types of water projects

Source: Keiser et al., 2005
Malaria – a major public health challenge

- Problems:
  - increasing resistance of mosquitoes to insecticides
  - increasing resistance of the malaria parasite to many drugs.

- There are indications of the spread of *P. falciparum* malaria into new regions of the world and its reappearance in areas where it had been eliminated.

- Intensified irrigation, dams and other water related projects contribute importantly to the disease burden.

- Better management of water resources, vector-control (control of the malaria-bearing mosquitos) and artemisinin-based combination therapies are among the measures which are supposed to prevent or reduce transmission of malaria.
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Nemtode-mediated diseases

- **The pathogens:**
  - Nematodes (roundworms).

- **Nematodes causing vector-borne diseases associated with water:**
  - *Onchocerca volvulus*, inhabits subcutaneous tissues,
  - *Wuchereria bancrofti*, *Brugia malayi* and *Brugia timori*, inhabit the lymphatic system.

- **General life cycle:**
  - Infective larvae are transmitted by infected and biting insects during a blood meal,
  - Larvae migrate to appropriate site of the host's body, where they develop into adult worms producing young worms (microfilariae),
  - Microfilariae infect biting insects,
  - Inside the insects, the microfilariae develop into infective larvae within 1 to 2 weeks,
  - During blood meal by the insect, the larvae infect the human host.
Onchocerciasis (river blindness)

- **The disease and the pathogen**
  - Skin and eye disease caused by *Onchocerca volvulus*, a thin parasitic worm that can live up to 15 years in the human body.
  - Symptoms: young worms (microfilariae) migrate through the skin, live in tissue nodules, and cause intense itching, depigmentation of skin, serious visual impairment, blindness.

- **The vectors**
  - Infected blackflies (*Simulium* species) which transmit the pathogen from one person infected with worm larvae to another person through bites.

Cutaneous nodules (left) and blindness (right) caused by *Onchocerca volvulus* (Kayser et al., 2005).
Life cycle of *Onchocerca volvulus*

Adult blackfly *Simulium damnosum*; lays its eggs in river water.

Adult worms of *O. volvulus*

Microfilariae of *O. volvulus* in skin

(Hof and Dörries, 2005)
Distribution

- In tropical and subtropical countries.
- Onchocerciasis is the world's second leading infectious cause of blindness; an estimated 18 million people are affected worldwide, of whom about 270,000 are blind and another 500,000 have visual impairment.
- About 99% of infected persons are in Africa; the remainder is in Yemen and in the Americas.
Onchocerciasis (river blindness)

- **Epidemiology**
  - Humans are the sole reservoir of *Onchocerca volvulus*.
  - Onchocerciasis is endemic in areas along rivers in which the larvae of blackflies develop.
  - Risk of blindness is increased in individuals living near rivers (⇒ "river blindness").

- **Interventions**
  - Spraying of blackfly breeding sites in water with larvicides.
  - Treatment of patients with a drug (ivermectin) that kills young worms.

- **Control programs**
  Several international onchocerciasis control programs are ongoing in order to eradicate the disease; examples:
    - African Programme for Onchocerciasis Control
    - Onchocerciasis Elimination Program for the Americas
Lymphatic filariasis

The disease
Chronic lymphoedema and elephantiasis, which can be accompanied by acute episodes of local inflammation involving skin, lymph nodes and lymph vessels.

Elephantiasis (swelling) of the legs.

Lymphoedema of the arm.
Lymphatic filariasis

The pathogens
The parasitic worms *Wuchereria bancrofti*, *Brugia malayi* and *Brugia timori*, that live almost exclusively in humans; > 90 % of cases are attributable to *W. bancrofti*.

The vectors:
Diverse species of several genera of mosquitoes.

Distribution:
More than a billion people in more than 80 countries are at risk; *Wuchereria bancrofti* occurs in tropical areas worldwide, *Brugia malayi* is limited to Asia.
Different species of the following genera of mosquitos are vectors of *W. bancrofti* depending on geographical distribution: *Culex*, *Anopheles*, *Aedes*, *Mansonidae* and *Coquillettidia*.
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**Schistosomiasis (bilharziasis)**

- The pathogens and the disease
  Tropical disease caused by trematode worms (blood flukes) of the genus *Schistosoma* with 5 important species:
    - **intestinal** schistosomes (four species; *S. mansoni*, *S. japonicum*, *S. mekongi*, *S. intercalatum*)
    - **urinary** schistosomes (one species; *S. haematobium*)

Symptoms
- **acute phase**: fever, headache, limb pains, swelling of liver, spleen and lymph nodes
- **chronic phase** (eggs laid in tissue): affection of the urinary tract or the large intestine.

- The vectors
  Freshwater snails.
Schistosomiasis (bilharziasis)

Transmission

- Infected person excretes eggs,
- Eggs hatch in water and release larvae called **miracidia**, 
- Miracidia infect freshwater snails and multiply, producing thousands of larval stages called **cercariae**, 
- Snail releases cercariae into surrounding water, 
- Humans become infected by **skin contact** with contaminated water.

200-2000 eggs are produced per day over an average of 5 years.
Schistosomiasis (bilharziasis)

- About half of the eggs are excreted in the faeces and urine, and the rest become trapped in the body tissues and cause the major damage.
- It is the eggs, not the worms, which cause the damage to the intestine, the bladder and other organs.
- Because schistosomes do not multiply in the human host (unlike viruses, bacteria, fungi and protozoa), reinfection is always the result of new contact with an infected environment.
- The disease is strongly related to unsanitary excreta disposal and absence of nearby sources of safe water.
- People are at risk of infection due to agricultural, domestic and recreational activities which expose them to infested water.
- Control of schistosomiasis is based on drug treatment (praziquantel), snail control, improved sanitation and health education.
At least 230 million people require treatment for schistosomiasis yearly; more than 650 million people live in endemic areas.

The disease causes tens of thousands of deaths every year, mainly in sub-Saharan Africa.

Man-made reservoirs and poorly designed irrigation schemes are main causes of schistosomiasis expansion and intensification (e.g., construction of Aswan Dam in Egypt, Diama Dam in Senegal).
Cercarial dermatitis

- Cutaneous lesions in humans caused by skin penetration of cercariae normally parasitizing birds and mammals.
- Infection occurs worldwide in freshwater and brackish water during swimming or bathing ("swimmer's itch").

- Humans are inadvertent and inappropriate hosts.
- Disease is mild; symptoms abate after a few days.
Relationship between vector-borne diseases and different types of water projects

- Water resource development projects are among the most important human-made ecological transformations over the past 50 years.
- At least 40,000 large dams (impoundments more than 15 m high or storing more than 3 million m³ water) and 800,000 small dams have been built worldwide.
- The majority of the large dams serve irrigation purposes.
- More than 400,000 km² have been inundated by reservoirs worldwide,
- Consequences:
  - creation of new environments for vectors (e.g. mosquito breeding sites)
  - demographic changes, altering human-vector-pathogen (parasite) contact patterns.
Global estimates of people at risk of four vector-borne diseases

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<td>213</td>
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<td>People at risk near dams, globally</td>
<td>18.3</td>
<td>n.a.</td>
<td>n.a.</td>
<td>42</td>
</tr>
<tr>
<td>People at risk in urban settings (no access</td>
<td>395</td>
<td>n.a.</td>
<td>n.a.</td>
<td></td>
</tr>
<tr>
<td>to improved sanitation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>People at risk near dams and irrigation schemes,</td>
<td>9.4</td>
<td>n.a.</td>
<td>n.a.</td>
<td>39</td>
</tr>
<tr>
<td>sub-Saharan Africa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>People at risk near dams and irrigation schemes,</td>
<td>860.3</td>
<td>n.a.</td>
<td>n.a.</td>
<td>66</td>
</tr>
<tr>
<td>excluding sub-Saharan Africa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>People at risk near dams and irrigation schemes,</td>
<td>n.a.*</td>
<td>n.a.</td>
<td>n.a.</td>
<td>40</td>
</tr>
<tr>
<td>Western Pacific</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>People at risk near irrigation schemes, South East Asia</td>
<td>n.a.*</td>
<td>n.a.</td>
<td>132 (in irrigated areas)</td>
<td></td>
</tr>
<tr>
<td>and Western Pacific</td>
<td></td>
<td></td>
<td>167 (in rice irrigated areas)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>921 (in irrigated areas)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36 (in rice irrigated areas)</td>
<td></td>
</tr>
</tbody>
</table>

*Not segregated to this level.

Sources: Erlanger et al., 2005; Keiser et al., 2005a,b; Steinman et al., in press; www.who.int/water_sanitation_health/resources/envmanagement/en/index.html
Dracunculiasis (Guinea-worm disease)

The disease and the pathogen
- The disease has been known for more than 3000 years.
- The disease is caused by the nematode *Dracunculus medinensis* (Guinea worm).
- The worm lives in connective tissue until it migrates down to the legs and feet where, after about 1 year after infection, it eventually emerges, causing severe pain, oedema, blister formation, ulcers, accompanied by fever, nausea and vomiting. Complete emergence of female worms can take 2 to 3 months.

Manual removal of Guinea worm
Life cycle of *Dracunculus medinensis*

Larvae are ingested by microscopic copepods (water fleas, *Cyclops*), where they develop to the infective stage in 14 days at 26 °C.

Transmission

Ingestion of water contaminated with water fleas which contain larvae of *D. medinensis.*
The larva of *Dracunculus medinensis*.

The predatory copepod *Cyclops* (intermediate host of *D. medinensis*).

*Guinea worm emerging from a foot of a person in Sudan.*

*A jar containing a Guinea worm at the Carter Center in Jos, Nigeria.*

*Cyclops* that just ingested a larva.

Guinea worm emerging from a foot of a person in Sudan.
Dracunculiasis

- *Dracunculus medinensis* is the only helminth that spreads exclusively through **ingestion** of unsafe drinking water; especially in rural areas without piped water supplies.

- The transmission to humans is determined largely by the use of open water such as ponds or shallow wells.

- Elementary measures to minimize transmission:
  - **systematic filtering** of drinking water derived from ponds, shallow unprotected wells or surface water with the aim of filtering out the copepods,
  - **construction** of copings around well heads or the installation of boreholes with handpumps, ensuring protection of wells and production of safe groundwater,
  - **health education** of people.
Eradication of dracunculiasis

Guinea worm disease is targeted for global eradication (International Guinea Worm Eradication Program led by the Carter Center); in 1986: 3.5 million cases worldwide - in 2011: 1058 cases; in January - April 2012: 143 cases.

In 2011, the disease was endemic only in 4 countries: Ethiopia, Ghana, Mali and Sudan.
Transmission pathways: water-related pathogens

**Ingestion (drinking)**
- **Gastrointestinal**

**Inhalation/aspiration (aerosols)**
- **Respiratory**

**Contact (bathing, washing)**
- **Skin, mucous membranes, wounds, eyes**

**Bacteria**
- *Campylobacter* spp., *E. coli* O157:H7, *Helicobacter pylori*, *Salmonella* spp., *Shigella* spp., *Vibrio cholerae*, *Yersinia* spp. (obligate pathogens); some non-tuberculous mycobacteria (opportunistic pathogens)
- **Viruses**
  - Adenoviruses, enteroviruses, hepatitis A virus, hepatitis E virus, noroviruses, rotaviruses (obligate pathogens)
- **Parasitic protozoa**
  - *Cryptosporidium* spp., *Entamoeba histolytica*, *Giardia intestinalis*, *Toxoplasma gondii*, *Cyclospora cayetanensis* (obligate pathogens)
- **Helminth**
  - *Dracunculus medinensis* (obligate pathogen)

**Bacteria**
- *Legionella pneumophila* and other legionellae, *Pseudomonas aeruginosa*, non-tuberculous mycobacteria, (opportunistic pathogens)
- **Viruses**
  - Adenoviruses (obligate pathogens)
- **Free-living protozoa**
  - *Naegleria fowleri* (opportunistic pathogen)

**Bacteria**
- *Aeromonas* spp., *Pseudomonas aeruginosa*, non-tuberculous mycobacteria (opportunistic pathogens)
- **Free-living protozoa**
  - *Acanthamoeba* spp. (opportunistic pathogens)
- **Helminths**
  - *Schistosoma* spp. (obligate pathogen)
- **Insect vector-borne diseases**
  - Contact with insect transmitting the pathogen (e.g. dengue virus, *Plasmodium* spp., *Onchocerca volvulus*).