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ecosan - closing the loop in wastewater management and sanitation

Health Aspects of ecosan

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Abstract

- ecosan systems are prone to expose the public to potential health risks, because they deal with recycling excreta and wastewater.
- In developing countries, excreta-related diseases are common, because excreta and wastewater contain correspondingly high concentrations of excreted pathogens. It is important to understand the transmission routes of these diseases, and health-risk factors involved, in order to design and implement (or modify) ecosan systems.
- Health risks are examined from two perspectives: actual versus potential risk, supported by epidemiological evidence from agricultural and aquacultural use of excreta.
- Transmission routes and survival of pathogens are outlined, along with ecosan options to control them.
- Issues associated with standards for indicator bacteria are examined.
Pathogens

Excreta, primarily feces, can contain pathogens. Pathogens, or pathogenic organisms, are responsible for the transmission of communicable diseases. They are generally bacteria, viruses, and parasites (e.g., worms, amoebae or protozoa) that invade the body and cause illness.

Each pathogen has its own life cycle. For many, that cycle includes a saprophytic period when the organism is out of the human host and viable to be transmitted to another human. This is the stage in which these pathogens can be killed (or at least immobilized).

Generally speaking, pathogens survive best in an aqueous environment, and are vulnerable to hostile environments, such as high temperatures or high pH.

### Number of excreted pathogens

<table>
<thead>
<tr>
<th>Pathogens</th>
<th>Incidence (per 100,000)</th>
<th>Excretion (per g wet weight)</th>
<th>Duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacteria</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salmonella</td>
<td>500</td>
<td>$10^6$ - $10^8$</td>
<td>37</td>
</tr>
<tr>
<td>EHEC</td>
<td>30</td>
<td>$10^2$ - $10^3$</td>
<td>8</td>
</tr>
<tr>
<td><strong>Viruses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotavi</td>
<td>20</td>
<td>$10^7$ - $10^8$</td>
<td>7</td>
</tr>
<tr>
<td>Hepatitis A</td>
<td>6</td>
<td>$10^5$</td>
<td>20</td>
</tr>
<tr>
<td><strong>Parasites</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giardia</td>
<td>1100</td>
<td>$10^5$ - $10^6$</td>
<td>90</td>
</tr>
<tr>
<td>Cryptosporidium</td>
<td>200</td>
<td>$10^5$ - $10^6$</td>
<td>7</td>
</tr>
<tr>
<td>Ascaris</td>
<td>20</td>
<td>$10^4$ - $10^5$</td>
<td>245</td>
</tr>
</tbody>
</table>
Pathogen Survival

- There are wide variations in reported survival times of pathogens, which reflect strain variation, differing climatic factors, and different analytical techniques. Nevertheless, it is possible to summarize current knowledge, as illustrated to the right and noted as follows:
  - In ponds, bacterial and viral numbers may be expected to decrease by only 1-3 orders of magnitude, depending on
    - Dilution
    - Hydraulic retention time
    - Climatic factors
  - Almost all excreted pathogens can survive in soil and ponds for a sufficient length of time to pose potential risks to farm and pond workers.
  - Pathogen survival on crop surfaces is much shorter than in the soil due to sunlight and desiccation.
  - In some cases, survival times can be long enough to pose potential risks to crop handlers and consumers, especially when they exceed the length of crop growing cycles (mainly vegetables). The situation is similar for those who handle and consume fish and aquatic macrophytes.

Die-off rate of selected pathogens over time in relation to temperature

(Feachem, 1983)
Estimated survival times (in days if not otherwise stated) for microorganisms in faeces, sludge, soil and on crop (according to Faechem\textsuperscript{a} 1983 and Kowan\textsuperscript{b} 1985, in EPA 1999)

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>Faeces and sludge\textsuperscript{a} 20-30°C</th>
<th>Soil\textsuperscript{a} 20-30°C</th>
<th>Soil\textsuperscript{b} absolute max/normal max</th>
<th>Crop\textsuperscript{b} 20-30°C</th>
<th>Crop\textsuperscript{c} absolute max/normal max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faecal coliforms</td>
<td>&lt;90 normally &lt;50</td>
<td>&lt;70 normally &lt;20</td>
<td>&lt;30 normally &lt;15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salmonella</td>
<td>&lt;60 normally &lt;30</td>
<td>&lt;70 normally &lt;20</td>
<td>&lt;30 normally &lt;15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virus</td>
<td>&lt;100 normally &lt;20</td>
<td>&lt;100 normally &lt;20</td>
<td>1 year/3 months</td>
<td>&lt;60 normally &lt;15</td>
<td>2 months /1 month</td>
</tr>
<tr>
<td>Protozoa\textsuperscript{d} (Amoeba)</td>
<td>&lt;30 normally &lt;15</td>
<td>&lt;20 normally &lt;10</td>
<td>10/2</td>
<td>&lt;10 normally &lt;2</td>
<td>5/2</td>
</tr>
<tr>
<td>Helminths (egg)</td>
<td>several months</td>
<td>several months</td>
<td>7 year/2 yr</td>
<td>&lt;60 normally &lt;30</td>
<td>5 months /1 month</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Absolute maximum times for survival are possible during unusual conditions, such as at constant low temperature or at extremely protected conditions.

\textsuperscript{b} Data is missing for Giardia and Cryptosporidium. Their cysts and oocysts, respectively, probably survive longer than what is stated here for protozoa.
How disease is transmitted from excreta

- Humans themselves are the main reservoir of most diseases that affect them. Transmission of excreta-related diseases from one host to another normally follows the routes shown in the diagram to the right.
- Poor personal hygiene often diminishes (or negates) the benefit of improved excreta disposal and treatment.
- Most routes for fecal-related diseases are similar to those for water-related diseases:
  - Direct contact with excreta
    - Wound infection
    - Oral transmission
  - Vectors (birds, insects, rats, etc.)
  - Water
    - Indirect contact with drains and pipes
    - Ingesting contaminated food and water
    - Bathing in contaminated water
- Diarrheal diseases and helminthes infections account for the greatest number of cases, although there is considerable difference in the levels of debility they produce.

Mara & Cross (1989)
Epidemiological Evidence

The actual public health importance of excreta or wastewater use can be assessed only by determining whether it results in an incidence, prevalence or intensity of disease measurably in excess of that which occurs in absence.

- **Agricultural use of wastewater:**
  - When untreated wastewater is used for crop irrigation, intestinal nematodes and bacteria present high actual risk.
  - Sprinkler irrigation of treated wastewater may promote the aerosol transmission of excreted viruses, but disease transmission is likely to be rare because most people have high levels of immunity to the viral disease endemic in their community.
  - Treatment of wastewater is a very effective method of safeguarding public health.

Relative health risks from use of untreated excreta and wastewater in agriculture and aquaculture (Marra & Cross, 1989)
Epidemiological Evidence

• **Agricultural use of excreta**
  – Crops fertilized with raw excreta causes excess infection with intestinal nematodes to both consumers and field workers, but excreta treatment reduces the transmission of infection.
  – Fertilization of rice paddies with excreta may lead to excess schistosomiasis infection among rice farmers.
  – Cattle may be infected with *Cysticerus bovis* but are unlikely to contract salmonellosis.

• **Aquacultural use**
  – Potential health risks include passive transference of excreted pathogens by fish and culture aquatic macrophyte, and the transmission of trematodes and schistosomiasis.
  – However, few studies have shown actual health risks associated with the above.
Killing pathogens

Whereas many conventional wastewater treatment systems depend on chemical or thermal disinfections, ecologically engineered systems kill or immobilize pathogens in a variety of ways:

- **Containment**: Human pathogens have specific lifetimes, and many cannot survive long once they have left the human host. Containing excreta for an extended period, say, two years, is one method.

- **Competition**: When carbon and nutrients are consumed, the microorganisms begin to consume their own protoplasm for cell maintenance. When these die, their cellular matter is digested by other organism.

- **Antagonism**: Some organisms produce toxic substances which harm or kill other microorganisms.

- **Adverse environmental factors**: pH, temperature and ammonia content and retention time also destroy pathogens.
ecosan options for health protection

- Available measures for protecting health can be grouped under four main headings:
  - Waste treatment
  - Crop restriction
  - Waste application methods
  - Control of human exposure
- It is often desirable to apply a combination of several methods to interrupt transmission routes of excreted pathogens.
- The level of risk to human health from different combinations of control measures can help determine the level of contamination and degree of risk.

A conceptual model showing the influence of treatment, application, human-exposure control and crop restriction on health protection. (Mara & Caincross, 1989)
Health Risk

Risk means different things to different people, but we must understand that voluntary risk (e.g. cancer from smoking) is always more acceptable than involuntary risk (diarrhea from rotavirus), even though the former is often a greater health risk than the latter. Thus to evaluate risk, we tend to compare one risk with a host of others. But comparison with other risks cannot itself establish the acceptability of a risk.

Assessing risk is both quantitative and subjective, but there are certain elements that professionals account for to judge the quality of wastewater:

• **Hazard identification**, which defines the nature of the harm, e.g. identifying a microbial pathogen.

• **Exposure assessment**, which determines the concentration of the pathogens in the water and average dose to ingest.

• **Dose-response assessment**, which quantifies the effects arising from exposure.

• **Risk characterization**, which estimates potential impact of microorganisms.

The Minitek® System is one of a number of tests used in identifying members of the family Enterobacteriaceae. It consists of disposable well plates that are used to hold disks impregnated with biochemical substrates.

Measuring Risk

• **Mean severity** - likelihood of infection
  – Infection does not mean illness
  – Illness does not mean death

• Risk greater in warm climates

• Pathogens survive longer in cold climates

• **Infectious dose**
  – number of pathogens required to infect a host
  – Varies considerably
    • One egg or cyst from parasitic worm
    • $10^{10}$ bacteria or viruses

• Indicator organisms
Actual and Potential Risks

- For the agricultural or aquacultural use of excreta and wastewater to pose an **actual** risk to health requires all of the following to occur:
  - *Either* an infective dose of an excreted pathogen reaches the field or pond, or the pathogen multiplies in the field or pond to form an infective dose.
  - The infective dose reaches a human host.
  - The host becomes infected.
  - The infection causes disease or further transmission.

Even if there is an actual risk involved, the recycling of excreta will be of public health importance only if it causes a:
  - measurable excess incidence, or
  - prevalence of disease, or
  - intensity of infection.

Epidemiological studies are needed to determine whether this is the case.

- The sequence of events required for an actual risk to be posed – together with the pathogen-host properties and interactions that influence each step – are outlined in this sequential diagram. If the sequence is broken at any point, the **potential** risks cannot combine to constitute an actual risk.

Pathogen host properties influencing the sequence of events between the presence of a pathogen in excreta or wastewater and measurable human disease attributable to excreta or wastewater use. (Mara & Caincross, 1989)
Risk Factors

• There is ample evidence that excreta and wastewater may, and usually do, contain high concentrations of pathogens, and that many of these pathogens can survive in recycled material for some time, and can also withstand most conventional treatment processes. If sufficient pathogens reach the field or pond, infection occurs only if an infective dose is received by a susceptible host, and this depends on the following:
  – Survival time of the pathogen in the soil, on crops, in fish or in water.
  – Potential routes of transmission of the disease.
  – The mode and frequency of excreta or wastewater application
  – The type of crop to which the excreta or wastewater is applied
  – The nature of exposure of the human host to contaminates soil, water, crop or fish.

• What are pathogens?
  • Responsible for transmission of diseases
  • Agents
    – Bacteria
    – Viruses
    – Worms
    – Parasites
  • Survival best in aqueous environment
    – Enteric (human digestion system)
    – Saprophytic (out of host) life cycle
    – Incubation
Indicator Microorganisms

• Routine examination of wastewater samples for the presence of all pathogens is often difficult and time consuming. Thus, ecological engineers often look for indicator organisms. The indicator concept depends on the fact that certain non-pathogenic bacteria occur in the feces of all warm blooded animals. Detection of these bacteria means that fecal contamination has occurred and suggest that enteric pathogens may also be present.

• Keep in mind that the presence of an indicator organism does not, in fact, mean that pathogens are present. Likewise, pathogens (such as viruses) may be present even if bacterial indicators are not.

• Detection in wastewater suggests pathogens
• Assess efficiency of treatment
• Criteria for ideal indicator
  – Useful for all types of water (drinking and recreation)
  – Present whenever enteric pathogens are present
  – Longer survival time than hardiest enteric pathogen
  – Not grow in water
  – Easy to test for
  – Density related to degree of fecal pollution
  – Member of intestinal microflora of warm-blooded animals
Coliforms

• Coliform bacteria, which normally occur in the intestines of all warm-blooded animals, are excreted in great numbers in feces. Through experience it has been learned that absence of those organism in 100 ml of water assumes the prevention of waterborne disease outbreaks.

• Fecal coliforms, in particular E. Coli, have become standard indicator organisms, because they are relatively hardy, with die-off rates depending on the amount and type of organic matter in the water and temperature.

• There are several considerations about using coliforms as indicators, not the least being that their presence in an outdoor system may be the result of animals, not humans.

Coliform Deficiencies

• Regrowth in aquatic environment
• Regrowth in distribution system
  – Bilofilm and pipes
  – Even with disinfectants (e.g. Chlorine)
• Other bacteria may mask growth
• Not indicative of health threat
• No relationship between enteric protozoa

Fecal Indicators

• Fecal coliforms - E. Coli
  – Easily indicates fecal coliforms
  – Does not distinguish human from animal
  – Same limitations of total coliforms
• Fecal streptococci –
  – Can distinguish animal from human
  – Advantages over coliforms and fecal coliforms
    • Rarely multiply in water
    • More resistant to chlorine
    • Persist longer in environment

http://www.cdc.gov/ncidod/diseases/submenus/sub_ecoli.htm
Standards for Indicators

• Bacterial indicators such as coliforms have been used to develop water quality standards, which are both legally enforceable and vary considerably world-wide.

• Guidelines for the reuse of wastewater are controversial. During the past ten years, new epidemiological and risk assessments have been carried out to evaluate WHO guidelines, which have identified the need for new guidelines, e.g. viruses.

• Criteria and guidelines are terms used to describe recommendations for acceptable levels of indicator microorganisms. They are not legally enforceable but serve as guidance indicating that a potential water quality problem exists.

• Note that drinking water and swimming water standards (and guidelines) differ considerably.

• The use of microbial standards requires fair sampling techniques and appropriate expressions of measured values, both of which vary worldwide.

Indicator issues

• What’s the difference?
  – Standard – legally enforceable (fines)
  – Guideline or criteria – recommendations

• Variation
  – Standards & guidelines worldwide
  – Authority: national v.s. local
  – Relationships (e.g. water diseases & (fecal) coliforms)

  – Quantification
    • Sampling methods vary
    • Expression
      – ppm versus mg/l
      – Log reduction
    • Average
      – arithmetic (Most Probable Number)
      – geometric average
Improving water and sanitation facilities does not necessarily lead to a decrease in fecal-related diseases. To bring about real improvements in health, the installation of EcoSan facilities has to go hand in hand with their proper use and maintenance. Hygiene promotion aims to ensure the proper use and maintenance of facilities by motivating people to change their behavior.

Hygiene promotion goes beyond hygiene education. It recognizes that it is not only the potential users of facilities who need to change their behavior; behavioral changes are also needed at other levels. Politicians need to recognize the importance of improving hygiene and work to create a favorable political environment. Implementing agencies need to recognize the need to allocate adequate resources to put policy into practice. Field workers need to be willing and able to understand people’s hygiene behavior and to build on existing motives to encourage people to change where needed.
Human behavior

• Adequate standards of personal hygiene and, in the case of occupational exposure, the wearing of protective clothing can protect against infection even in situations where the risk of infection would otherwise be high. Health education is needed to improve behavioral patterns. However, this is a long-term solution and may not be effective in modifying well-established cultural practices, for example the rating of raw fish.

• Different cultures have evolved different responses to the use of excreta (treated or untreated), ranging from abhorrence through disaffection and indifference to predilection. The same hold true to patterns of hygiene. What some cultures accept as clean, others do not. Pathogens, however, have no opinions: they simply survive or die, depending on the environment.
References

- Carlander, A. 2002- Occurrence, reduction and risk of fecal pathogen transmission during wastewater irrigation or willow vegetation filters. Report 69, Swedish University of Agricultural Sciences, Uppsala, pp. 34.


