M2: ecosan – an Approach to Human Dignity, Community Health and Food Security

M 2-2: Closing the Loop between Sanitation and Agriculture

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We thank all individuals and institutions that have provided information for this CD, especially the German Agency for Technical Cooperation GTZ, Ecosanres, Ecosan Norway, the International Water and Sanitation Centre IRC, the Stockholm Environment Institute SEI, the World Health Organisation WHO, the Hesperian Foundation, the Swedish International Development Cooperation Agency SIDA, the Department of Water and Sanitation in Developing Countries SANDEC of the Swiss Federal Institute of Aquatic Science and Technology EAWAG, Sanitation by Communities SANIMAS, the Stockholm International Water Institute SIWI, the Water Supply & Sanitation Collaborative Council WSSCC, the World Water Assessment Programme of the UNESCO, the Tear Fund, WaterAid, and all others that have contributed in some way to this curriculum.

We apologize in advance if references are missing or incorrect, and welcome feedback if errors are detected.

We encourage all feedback on the composition and content of this curriculum. Please direct it either to Johannes.heeb@seecon.eu or petter.jenssen@umb.no, or use the feedback form.
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### Introduction

**Urbanisation:**

Problems: water scarcity, food insecurity and pollution based on the following assumptions:

- there are no limits to resources such as water and land.
- the environment can assimilate the wastes that we produce from using these resources.

→ linear flows of resources and wastes that are not reconnected.

Examples:

- 75% of the natural resources harvested and mined from the Earth were brought to 2.5 percent of the earth's surface, metropolitan areas.
- 80% of the natural resources are converted into waste, which are disposed of (2).

Source: (5)
Introduction

Massive flow of nutrients:
→ Food from rural areas to cities
→ Nutrients (excreta): pits, lakes, waterbodies…

But:
• nutrients and organic matter in excreta are toxic to different life forms living in water (sewage pollution)
• biodiversity is threatened (eutrophication)
• soil fertility declines

Additionally: Urbanisation leads to
→ paving over of land: no rainwater infiltration
→ higher and more energy intense transport costs

Source: (5)

Closing the Loop

“Only if we change our linear attitudes of resources and wastes, towards a circular one, we can reconnect these resources and wastes, and advance towards a recycling society.”

⇒ Sanitation can be a technology that connects the two.

But: almost half of humanity does not even have access to any type of sanitation.

We must apply systems that imitate healthy ecosystems found in nature, and that close the loop – i.e. which bring resources back to where they came from.”

Source: (5)
Closing the Loop

Safe & nutritious food

People

Excreta

Pathogen destruction

Plant

Safe fertiliser & soil conditioner

Transport
Storage
Processing

Harvested crop

Source: (5)

Urbanisation and Food Security

By 2015, about 26 cities in the world are expected to have a population of 10 million people or more.

Source: (35)
Flow Streams

Composition of Household Wastewater

Organics
- kg COD/ (Person\*year)

Nutrient content
- kg N,P,K / (Person\*year)

Volume
- Litres / (Person\*year)

Source: (33)
The contribution of urine, faeces and greywater to the nitrogen, phosphorus and potassium content in wastewater and to the total wastewater flow.

<table>
<thead>
<tr>
<th>Composition of Household Wastewater</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nitrogen</strong></td>
</tr>
<tr>
<td>~ 4-5</td>
</tr>
<tr>
<td>~ 0.75</td>
</tr>
<tr>
<td>~ 1.8</td>
</tr>
<tr>
<td>~ 30</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>Greywater 25,000 - 100,000 l/person/year</td>
</tr>
<tr>
<td>S, Ca, Mg and trace elements</td>
</tr>
<tr>
<td>Reuse / Water Cycle</td>
</tr>
</tbody>
</table>

Graphics: R. Otterpohl, Sources: (21), (22), (23)
### Composition of Individual Fractions

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Characteristic</th>
</tr>
</thead>
</table>
| Faeces   | • hygienically critical  
|          | • consist of organics, nutrients and trace elements  
|          | • improve soil quality and increase its water retention capacity  
|          | • average production ca. 50kg/person/year  
|          | • Consist mainly of organics submitted to decomposition processes and a minor proportion of nutrients |
| Urine    | • hygienically uncritical  
|          | • contains the largest proportion of nutrients available to plants  
|          | • may contain hormones or medical residues  
|          | • average production ca. 500 l/person/year  
|          | • consists mainly of nutrients available to plants and very little organics, therefore no need for stabilisation |
| Greywater* | • of no major hygienic concern  
|           | • volumetrically the largest portion of wastewater  
|           | • contains much less nutrients than urine or faeces  
|           | • may contain a vast range of substances  
|           | • average production 25 – 100 m³/cap/a |

*The characteristics of greywater can vary greatly due to individual habits and uses.*

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### Closing the Loop through Source Separation

![Diagram of source separating system](source.png)

Source: P. Jenssen
Nutrient Content of Wastewater & Chemical Fertilizers

- Yearly requirement: 135 Mio tons of mineral fertiliser
- Conventional sanitation dumps 50 Mio tons of fertiliser equivalents - worth 15 Billion US dollar." (9)

Nutrients and Fertilizer Requirements

A high percentage of the nutrient requirements for producing (as an example: 250 kg of cereals) could be met by recovering the nutrients contained in urine and faeces.

Source: (33)
Nutrients and Fertilizer Requirements

![Bar chart showing nutrients and fertilizer requirements](chart.png)


Composition of Fertilizers

Crucial fertilizer elements are:
- **Micronutrients**: nitrogen, phosphorus, and potassium,
- **Micronutrients**: Calcium, magnesium, sulphur as well as copper, zinc, or molybdenum

All major fertilizer components, as well as trace elements, are all available in household wastewater.

Source: (11)
Chemical Fertilizers: Phosphate

- Phosphorus never occurs in its pure form
- Always bonded with other elements (i.e. phosphate rock)
- The process to extract phosphorus is particularly damaging (strip-mining). By-products include radioactive material and air pollution.
- Phosphorus deposits often contaminated by arsenic or cadmium → accumulation in soils
- As phosphate is highly bondable, soil needs to be saturated until free phosphate is available to plants → high demand!
- Recycling of phosphorus from conventional wastewater treatment plants very limited (contamination with heavy metals and micropollutants).

Sources: (10), (1)

http://aquat1.ifas.ufl.edu/guide/humimpac.html

Chemical Fertilizers: Phosphate Reserves

<table>
<thead>
<tr>
<th></th>
<th>Mine production</th>
<th>Reserves</th>
<th>Reserve base</th>
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<td></td>
<td>2001</td>
<td>2002</td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td>31,900</td>
<td>35,800</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Australia</td>
<td>1,850</td>
<td>1,800</td>
<td>77,000</td>
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<tr>
<td>Brazil</td>
<td>4,700</td>
<td>4,700</td>
<td>330,000</td>
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<tr>
<td>Canada</td>
<td>800</td>
<td>1,000</td>
<td>26,000</td>
</tr>
<tr>
<td>China</td>
<td>21,000</td>
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<td>6,400,000</td>
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<tr>
<td>Israel</td>
<td>3,610</td>
<td>3,500</td>
<td>180,000</td>
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<tr>
<td>Jordan</td>
<td>6,860</td>
<td>7,000</td>
<td>900,000</td>
</tr>
<tr>
<td>Morocco and Western Sahara</td>
<td>21,800</td>
<td>24,000</td>
<td>5,200,000</td>
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<tr>
<td>Russia</td>
<td>10,500</td>
<td>10,500</td>
<td>200,000</td>
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<td>Senegal</td>
<td>1,700</td>
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<td>50,000</td>
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<td>South Africa</td>
<td>2,850</td>
<td>2,800</td>
<td>1,500,000</td>
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<td>Syria</td>
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<td>2,400</td>
<td>100,000</td>
</tr>
<tr>
<td>Tunisia</td>
<td>1,060</td>
<td>1,100</td>
<td>30,000</td>
</tr>
<tr>
<td>Other countries</td>
<td>8,210</td>
<td>8,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>World total (rounded)</td>
<td>126,000</td>
<td>133,000</td>
<td>17,000,000</td>
</tr>
</tbody>
</table>
Chemical Fertilizers: Nitrogen

Farm manure long supplied enough nitrogenous fertilizer for agriculture,

Population growth $\Rightarrow$ increased demand

78% of air is composed of nitrogen. Nitrogen fertilizers today produced in a highly energy consuming process from Nitrogen in the air.

Process is very energy intensive!
$\Rightarrow$ energy supply through fossil fuels (emission of greenhouse gases)

Source: (11)

Chemical Fertilizers: Potassium

Potassium mostly contained in small proportions in a large number of mineral formations,

$\Rightarrow$ expensive and energy consuming to extract.
Global status of human-induced soil degradation.

Soil Degradation

- Globally, 2 billion hectares have been degraded since World War II
  - 23% of globally used land (17).
  - Most degradation in Asia, Africa and South and Central America.

- Consequences:
  - Loss of topsoil from water erosion
  - Fertility decline (18).

- The excreta from 10 people during the course of a year could return more than 60 kg excreta/hectare to soil, restoring fertility.
Soil Degradation

Soil fertility defined through:
- sufficient quantities of nutrients
- balanced form.

Micronutrient problems are often a result of imbalances → soil fertility decline

Loss of soil fertility by a lack of organic content
→ decreased water holding capacity
→ worse soil structure (less pores, less air etc.)

Source: (13)

Review: Linear Systems of Disposal

Linear flow of nutrients!!

Source: (20)
Closing the Loop: Reuse of Urine as Fertilizer

- Urine is a complete fertiliser (rich in nitrogen)
- Can be used in the same way as a nitrogen rich liquid chemical fertiliser.
- Plant availability of the urine nutrients is uniquely high
- To keep the ammonia loss low, it is important to mix the urine into the soil as quickly as possible.

Source: (20)

Closing the Loop: Reuse of Urine as Fertilizer in Agriculture

Barley yields in plots fertilized with human urine and mineral fertilizer, respectively.

⇒ only small difference!

Source: (1)
Closing the Loop: Reuse of Faeces as Fertilizer

- **Faecal matter**: organic fertiliser that is rich in phosphorous, potassium and organic matter.
  - improve soil fertility, water holding capacity & buffering capacity of soil
- **Plant availability** of the nutrients slower than of those in urine.
  - urine and faeces supplement each other well.
  - ecosan fertilisers are **well balanced** complete fertilisers, as they contain the elements in the same ratios as the crops removed them from the fields.
  - the risk of unbalanced fertilisation is far less with ecosan fertilisers than with chemical.
Closing the Loop: Urban Agriculture

- Fertilizer gained from nutrients for use in urban agriculture.
  - close nutrient loops in cities themselves

- Urban agriculture: production of food on so-called unproductive land within the cities (roofs, along or on walls, in pots etc.)

- Food production costs can be reduced
  - improves food security
  - better quality of food (directly harvested)
  - cheaper

Source: (5)

Closing the Loop: Urban Agriculture

- Urban agriculture
  - empowers women, because they can take a leading role in this sector.
  - help to reduce child malnutrition.

- Revival of urban agriculture in the past few decades (34).
  - Moscow: threefold increase
  - Romania: Urban agriculture more than tripled (up 333%) from 1990 to 1996.
  - Great Bangkok: 60% of the land is under cultivation.

- Urban agriculture facilitates the closing of the loop to food security. By closing nutrient loops and improving soil fertility and structure:
  - higher yields per spatial unit
  - healthier and more nutritious plants, lower levels of external inputs and less water will be required.
  - Strengthening of local communities.
  - Reduction of post-harvest food losses

Source: (5)
**Closing the Loop: Aquaculture**

- **Aquaculture**: equivalent in fishing to agriculture
  - the rearing of fish, and some aquatic plants to supplement the natural supply (25).

- Aquaculture: nutrient-rich wastewater is used as the medium to raise aquatic plants → plants are fed to fish.

- Loop is closed again → food security can be increased.

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**Closing the Loop: Hydroponics**

**Hydroponics**: cultivation of plants in nutrient-enriched water

**Supporting materials** in water to keep plants upright: gravel or sand, Rock wool, Coconut fiber, Peatmoss, Styrofoam, Coir, or Sawdust, etc… nutrient rich solution can be partially composed of wastewater

→ closing the nutrient cycle

A wide variety of vegetables and flowers can be grown satisfactorily using hydroponics.

Yields are about the same as for soil-grown crops.”

Source: (26)
Closing the Loop: Groundwater Recharge

**Water loop also needs to be closed:**

Bore wells: tapping of groundwater

**Sewers:** groundwater is drained away in waterbodies → falling groundwater levels.

Systems with source separation: large amount of greywater (showers, sinks etc.) which is normally not heavily polluted.

- Local treatment of greywater can be done with simple techniques such as gravel filters, constructed wetlands, ponds, bio-films or activated sludge processes.
- Infiltration of treated greywater into the soil again, thus recharging groundwater
- Use in irrigation, which takes some pressure away from overstressed aquifers.

Groundwater recharge through soil infiltration

Source: (Siegrist et al. 2000)

J. Heeb
Rainwater Harvesting:
Surface collection of water and infiltration/groundwater recharge

Closing the Loop: Biogas production

Energy contained in wastewater can be used for the production of biogas

**Biogas:** controlled fermentation process where produced methane gas is collected and used for:
- electricity
- used directly for cooking, lighting, heating or cooling.

Fermentation: In principle, all organic materials
- faeces (livestock and humans)
- organic waste,
- energy crops
- organically loaded wastewater.

**Biogas production stimulates closed-loop systems in the agricultural**
**Fermentation** and digestion processes sanitize the organic waste in the reactor.
Benefits from Biogas Treatment

WASTE TREATMENT BENEFITS
• Natural waste treatment process
• Requires less land than aerobic composting or landfilling
• Reduces disposed waste volume and weight to be landfilled

ENVIRONMENTAL BENEFITS
• Significantly reduces carbon dioxide and methane emissions
• Eliminates odours
• Produces a sanitised compost and nutrient-rich liquid fertiliser
• Maximises recycling benefits

ENERGY BENEFITS
• Net energy producing process
• Generates high quality renewable fuel
• Biogas proven in numerous end-use applications

ECONOMIC BENEFITS
• Is more cost-effective than other treatment options from a life-cycle perspective

Source: (28)

Conclusion

Leapfrog the conventional centralized sewers -
go straight to modern sanitation based on ecological principles!

Source: P. Jenssen
END OF MODULE M2-2

FOR FURTHER READINGS REFER TO M2-2 TUTORIAL

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++ References


++ References


(16) Jonasson, P.D (2005): Appropriate Sanitation for the developing world. PP-Presentation. Norwegian University of Life Sciences, Department of Mathematical Sciences and Technology


++ References


++ Abbreviations

ACTS  Agriculture, Crafts, Trades and Studies
FAO  Food and Agriculture Organisation of the United Nations
GTZ  German Agency for Technical Cooperation
K  Potassium (derived from the Latin Name Kalium)
mld  Millions of Litres per Day (one million litres equals 1000 m³)
N  Nitrogen
OHW  Organic Household Waste
P  Phosphorus
UPA  Urban and peri-urban agriculture

See glossary for unknown terms & definitions!