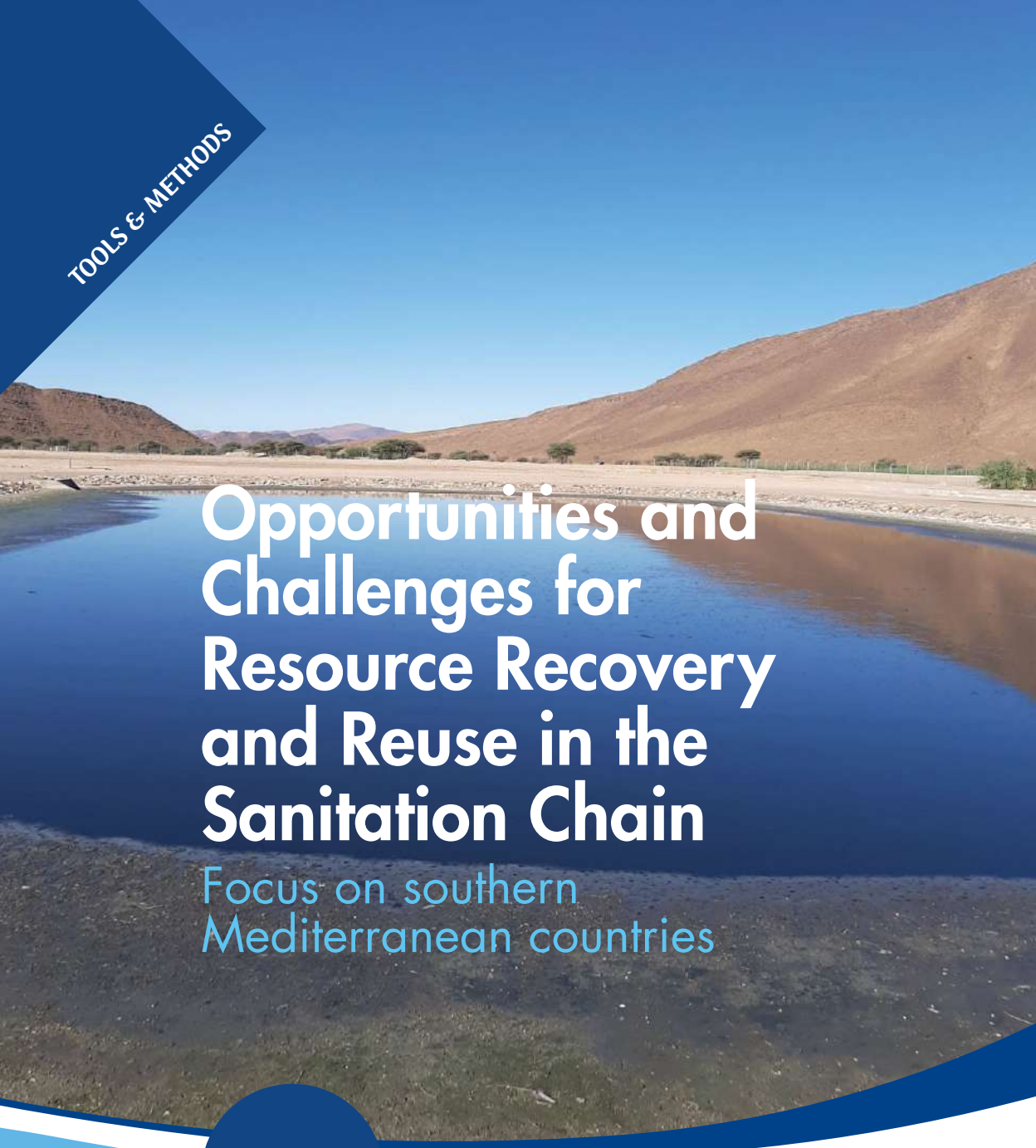
TOOLS & METHODS



Opportunities and Challenges for Resource Recovery and Reuse in the Sanitation Chain

Focus on southern Mediterranean countries

pS-Eau
programme Solidarité-Eau

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Preface

The aim of the sixth of the United Nations 2030 Agenda's 17 Sustainable Development Goals is to achieve universal and equitable access to safe drinking water, sanitation and hygiene. It encourages us to manage this resource sustainably, and urges us to redouble our efforts to help the most vulnerable people suffering from water scarcity. This goal incorporates the notion of cross-border resource management, which is vital for sustainable management of the resource and also promotes peace and cooperation..

Water is at the heart of climate change, the effects of which on water resources and the environment are intensifying, requiring an acceleration in adaptation efforts. This involves strengthening the resilience of natural environments and activities to cope with the reduced availability of water resources, the drying up of soil, the loss of biodiversity, the deterioration in water quality and the increase in natural risks.

To date, policymakers have focused primarily on water supply rather than on water management following its use. However, these two aspects are inseparable. The collection, treatment and reuse of water, and the recovery of sanitation system output products form the basis of a circular economy, reconciling economic development with the sustainable use of resources.

Treated wastewater reuse can improve food security and agricultural resilience to climate change. Recycling sludge for land application or biogas can reduce dependence on chemical fertilisers and fossil fuels. There are also other options available, such as heat recovery or the recovery of phosphorus or nitrates.

Given the growing environmental and health challenges, it is vital that we start thinking differently about how waste and wastewater is managed. This publication explores the opportunities and challenges associated with these practices by focusing on southern Mediterranean countries. It provides a review of current knowledge and practical experiences of resource recovery and reuse in the sanitation chain.

In order for these solutions to be effective, it is essential to work on them very early in the project process to ensure they are adapted to each geographic, climatic and human environment, and thus have the maximum useful and positive impact. This publication is intended to assist with these efforts and as a tool for those wishing to embark on this path.

I hope that the decentralised cooperation programmes being set up around water issues in the Mediterranean basin will find this publication a useful source of inspiration for their projects.

Let us save water!

by Nicolas Mourlon,
Director General of the Rhône-Méditerranée-Corse Water Agency

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
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agence de l'eau
RHÔNE MÉDITERRANÉE CORSE
établissement public de l'État

Introduction

This guide addresses the resource recovery and reuse in the sanitation chain.

It has been developed by pS-Eau as part of a partnership with INRAE (French National Research Institute for Agriculture, Food, and Environment), and has been jointly funded by the Rhône Méditerranée Corse water agency, the French Biodiversity Agency (OFB) and the French Agency for Development (AFD).

It is based on discussions with a range of project leaders and experts, and various members of the pS-Eau network have contributed to and reviewed this publication.

This guide is particularly intended for decentralised cooperation and non-governmental stakeholders, as well as sanitation service authorities and other local partners.

Its aim is to provide keys to understanding and resources for identifying and taking into account:

- The resource recovery and reuse options available for sanitation products by adopting a broad vision that encompasses all possible forms of sanitation and treatment processes, as well as output products and their potential uses;
- The main challenges involved in integrating the reuse and recovery of these output products, which need to be taken into account when designing a wastewater treatment project that includes resource recovery and reuse.

This guide examines the various resource recovery and reuse options, along with their associated challenges, in the context of southern Mediterranean countries, specifically Morocco, Tunisia, Palestine and Lebanon.

It then analyses how these challenges have been addressed in case studies, focusing particularly on these countries.

Throughout the guide:

Incoming and outgoing products are indicated in an arrow.

A color code makes it easy to identify them.

End uses are at a standstill.

120 145 References to a treatment or a use are in tablets.

34 They correspond to pagination.

Co-treatments are indicated by this pictogram.

Information specific to the Mediterranean context by it.

[3] The numerical notes refer to the LEARN + blocks in the form: [3]

Reconsidering the sanitation chain by integrating resource recovery and reuse in the sanitation chain

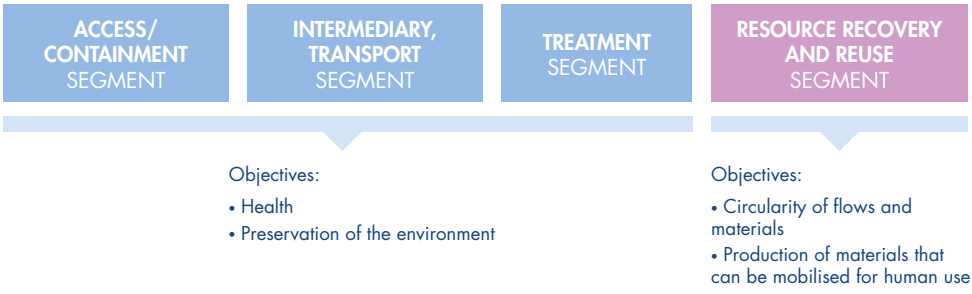
The sanitation chain is commonly considered to consist of 3 segments:

- The access/containment segment, the primary aim of which is to reduce human exposure to excreta in the interests of **health and hygiene**. This segment includes the facilities used to collect and temporarily store wastewater and excreta (potentially also with partial treatment):
  - toilets;
  - handwashing facilities, showers and sinks;
  - if applicable, various types of on-site facilities (septic tanks, soakaways).
- The intermediary, transport segment through which wastewater and faecal sludge is conveyed to a storage and/or treatment facility in the interests of **health and hygiene**. This segment consists of discharging or transporting sanitation products not treated on-site via:
  - a sewer system where facilities are connected to sewerage networks;
  - vacuum trucks for on-site sanitation systems.
- The treatment segment, whose purpose is to reduce environmental impacts. This segment includes technologies for disposing of and treating wastewater and faecal sludge, with or without reuse and recovery. The facilities in this segment are:
  - wastewater treatment plants that receive wastewater directly from the sewer systems;
  - faecal sludge disposal and treatment sites to which vacuum trucks deliver the sludge collected from on-site sanitation systems.

As part of a circular flow approach, sanitation can also be considered as meeting **the goal of improving health and reducing environmental impact**, as well as that of **returning solid and liquid outputs to the soil and the water cycle**, and of **producing materials for reuse** in other production chains. The sanitation chain therefore needs to be redesigned to integrate reuse and recovery, which can be added as a further and separate segment.

The updated sanitation chain will therefore also include:

- An additional 'reuse / recovery' segment that consists of applying processes to wastewater and faecal sludge to ensure the **circularity of flows and materials** and **produce raw materials that can be recovered for use in other production chains**.



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This chapter then provides a broad and comprehensive overview of the resource recovery and reuse options available for all of the sanitation chain products. The approaches currently being considered or implemented, particularly in southern Mediterranean countries, are also highlighted.

This first chapter is illustrated by a "matrix of resource recovery and reuse options for sanitation chain products", which provides an overview of how reuse can be incorporated into the sanitation chain.

This first chapter is illustrated by a "matrix of resource recovery and reuse options for sanitation chain products", which provides an overview of how reuse can be incorporated into the sanitation chain.

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This chapter then looks at a number of key issues involved in integrating a resource recovery and reuse segment into the sanitation chain. A review of the literature, an analysis of feedback and discussions with project developers and experts have led to the identification of a number of key issues. These issues need to be carefully considered for such projects. They are illustrated by examples and comments concerning the Mediterranean context.

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The resource recovery and reuse of sanitation products in Lebanon

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A fourth chapter presents examples of sanitation systems that include a resource recovery and reuse segment in the sanitation chain. These case studies relate to projects carried out as part of decentralised cooperation.

The first two cases are projects carried out in Morocco and Palestine. The third case study concerns a type of system that is little developed in the southern Mediterranean countries but is widespread in West Africa and South-East Asia.

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CASE STUDY 3: Sludge recovery in Fianarantsoa, Madagascar; Decentralised cooperation: Grand Lyon / Haute Matsiatra Region, Fianarantsoa Urban Municipality 228

Lexique et définitions

BOD (Biochemical Oxygen Demand): The amount of oxygen consumed by microorganisms in order to decompose organic matter in water, an indicator of biodegradable organic pollution.

BOD_5 (Biochemical Oxygen Demand after 5 days): BOD measured after a 5 day incubation period, used to estimate short-term biodegradable organic load.

CEC (Cation Exchange Capacity): Total quantity of cations that can be retained on soil particle surfaces, expressed in cmol(+)/kg, indicating its fertility and capacity to retain nutrients.

CFU (Colony Forming Unit): A microbiological unit of measurement used to estimate the number of viable bacteria (or other microorganisms) present in a sample.

COD (Chemical Oxygen Demand): The amount of oxygen required to chemically oxidise organic matter and certain inorganic substances found in water; this is often higher than BOD.

DMC: Dry Matter Content.

Log: The reduction in pathogens is expressed in decimal logarithms, written as Log10 or simply Log. Each Log unit corresponds to a reduction factor of ten. For example, a 1 Log reduction corresponds to inactivating 90% of the target pathogen. If the initial population is 100 (10x10), only 10 microbes will have survived. A 2 Log reduction corresponds to eliminating 99% of the target pathogen, and 3 Log to 99.9%, etc.

MTE (Metal Trace Elements): Metals present in very low concentrations in the environment, sometimes essential in low doses but often toxic in high concentrations.

NH_3 (Ammonia): Reduced gaseous or dissolved form of nitrogen, toxic to aquatic organisms, especially at high pH levels.

NH_4^+ (Ammonium): Less toxic, ionised form of ammonia, stable at acid pH, source of assimilable nitrogen for plants.

NTU (Nephelometric Turbidity Unit): The unit used to measure the turbidity of water based on the scattering of light by suspended particles.

TSS (Total Suspended Solids): Solid particles that remain in suspension in water as they do not dissolve and which can affect water quality and clarity.

VSS (Volatile Suspended Solids): Portion of organic material contained in a sample after drying and ignition, used to estimate organic content in sludge or sediment.

CHAPTER 1

The sanitation products that can be reused and recovered from the sanitation chain and their potential uses, based on the options selected at the various segments

Chapter 1 describes the range of products generated from the sanitation chain and their potential for resource recovery and reuse.

This chapter is not intended to be read in a linear fashion. It is to be consulted after examining the "matrix of resource recovery and reuse options for sanitation chain products".

This matrix provides an overview of the types of sanitation product that can be obtained and how they can be used.

This chapter details the characteristics of the types of sanitation input product.

These characteristics are based on the available literature, which consists predominantly of WHO reference resources.

These are to be considered as general guidelines and estimations. The characteristics of sanitation output products are determined by the characteristics of the input products and are often difficult to define, particularly for faecal sludge. They are also affected by the conditions under which treatment processes and facilities are operated and used: their theoretical capacity for removing pollutants is only assured under optimum operating conditions.

This chapter also provides details of the various potential uses.

These uses must be considered as options for which the risks, advantages, relevance and viability have to be assessed by examining the issues and challenges set out in **chapter 2**. These issues and challenges are highlighted using examples based on experience and practice from Mediterranean countries.

This chapter is set out as follows:

1. Output products from the access/containment segment

   Output products from the treatment segment:

2. Output products from wastewater treatment processes (wastewater treatment plant: WWTP)
3. Output products from WWTP sludge treatment processes and FSTP (faecal sludge treatment plant) faecal sludge treatment
4. Potential uses of sanitation system output products

For each of the facilities or treatment processes in the access and treatment segments (parts 1 to 3), the structure is as follows:

INPUT PRODUCT

Input product characteristics

Input products to a treatment process are the output products of an access/containment facility or of a previously applied treatment process.

DESCRIPTION OF THE FACILITY or THE TREATMENT PROCESS

Brief description of the facility / treatment process

Publications that cover specific facilities and treatment processes are provided in this section.

FOR MORE INFORMATION:

The aim of this guide is not to provide a comprehensive description of the various facilities and treatment processes. For further information, please refer to the following publications:

- Compendium of Sanitation Systems and Technologies – 2nd revised edition, Eawag, WSSCC, IWA, Tilley et al., 2016
- How to Select Appropriate Technical Solutions for Sanitation, pS-Eau, Frenoux et al., 2010
- Wastewater Treatment and Reuse: A Guide to Help Small Towns Select Appropriate Options, World Bank, Brault et al., 2022
- Faecal Sludge Management: Systems Approach for Implementation and Operation, IWA, Strande L., Ronteltap M., Brdjanovic D., 2018

OUTPUT PRODUCTS

OUTPUT PRODUCT

(this includes a breakdown of each Output product)

Output product characteristics

The descriptions of these characteristics, particularly as regards the presence of pathogens, are based on the literature review developed by INRAE under the partnership that led to the publication of this guide:

FOR MORE INFORMATION:

- « État des lieux de l'abattement sur les microorganismes pathogènes par les différents procédés de traitements des produits et sous-produits de l'assainissement », INRAE, A. Meunier, S. Guillaume, S. Besnault, M. Boissel et R. Lombard Latune, 2025.

Potential Output product destinations

Potential additional treatments

Potential additional treatment 120

the headings refer to a further treatment process covered in **parts 2 or 3**.

Potential uses

Potential use 145

the headings refer to uses covered in **part 4**.

The sources from which the input and output product characteristics have been taken are listed at the end of parts 1, 2 and 3.

The structure of part 4 on the potential uses of sanitation system output products is as follows:

REUSED PRODUCT

The product(s) concerned are listed.

POTENTIAL USES

The potential uses for the reused product.

CHALLENGES

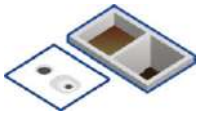
A description of the use-specific issues and challenges to be considered in order to assess whether this use is suited to the context. These issues and challenges are detailed in chapter 2.

ACCESS/CONTAINMENT SEGMENT

23 TOILETS WITH WATER SUPPLY (FLUSHWATER),
- WITH OR WITHOUT URINE DIVERSION,
- CONNECTED TO A WASTEWATER COLLECTION SYSTEM

24 TOILETS WITH OR WITHOUT WATER SUPPLY,
- WITHOUT URINE DIVERSION,
- CONNECTED TO A WATERTIGHT OR NONWATERTIGHT PIT LOCATED BENEATH THE DEFECATION HOLE

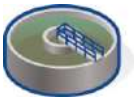
26 TOILETS WITH OR WITHOUT WATER SUPPLY
- WITHOUT URINE DIVERSION
- CONNECTED TO A NON-WATERTIGHT DOUBLE PIT



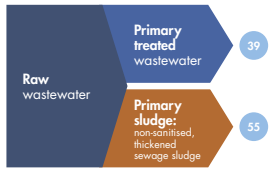
28 TOILETS WITHOUT WATER SUPPLY,
- WITH URINE DIVERSION,
- CONNECTED TO ONE OR TWO WATERTIGHT PITS USED ALTERNATELY TO COLLECT FAECES,
- AND ONE OR TWO STORAGE TANKS FOR URINE COLLECTION

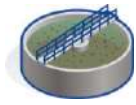
31 TOILETS WITH OR WITHOUT WATER SUPPLY,
- WITH OR WITHOUT URINE DIVERSION,
- CONNECTED TO A SEDIMENTATION AND/OR ANAEROBIC DIGESTION TREATMENT SYSTEM

Wastewater primary treatment

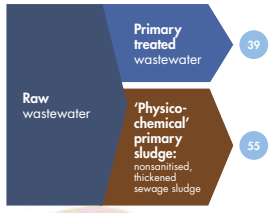


36 SETTLER/ PRIMARY TREATMENT TECHNOLOGY

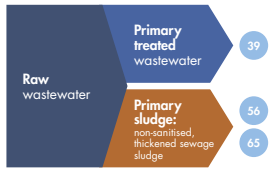




37 IMPROVED PRIMARY TREATMENT: COAGULATION/FLOCCULATION

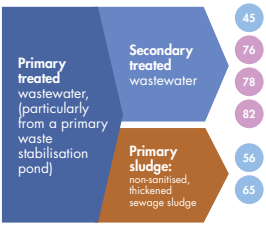


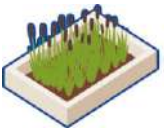
38 PRIMARY WASTE STABILISATION POND



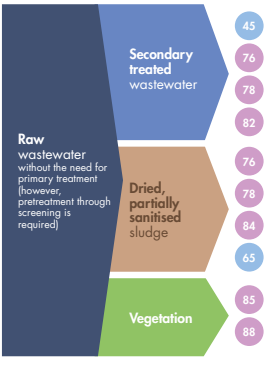
Wastewater secondary treatment

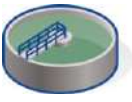
39 SECONDARY WASTE STABILISATION POND



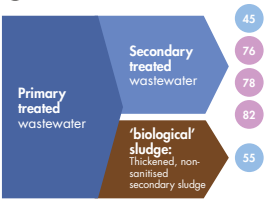


41 PLANTED FILTER BEDS





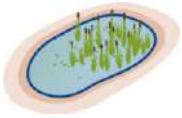
44 ACTIVATED SLUDGE PROCESSES



FROM SANITATION SYSTEMS

TREATMENT SEGMENT

Wastewater tertiary treatment



45 MATURATION POND

Secondary treated wastewater (particularly from a secondary waste stabilisation pond)

- **Tertiary treated** wastewater (with greatly reduced pathogen levels) — 76, 78, 82, 91
- **Primary sludge:** non-sanitised, thickened sewage sludge — 56
- **Macrophytes** (water hyacinths, duckweed, etc.) — 88, 85, 89

47 FILTRATION AND ADSORPTION OVER SAND OR FILTER MATERIAL

Secondary treated wastewater

- **Tertiary treated** wastewater (with greatly reduced pathogen levels) — 76, 78, 82, 91
- **Sludge from filter/material washing**

50 ULTRA-VIOLET (UV) TREATMENT

Secondary effluent, which must have low turbidity

- **Tertiary treated** wastewater (disinfected) — 76, 78, 82, 91

48 MEMBRANE FILTRATION

Effluent that has undergone secondary treatment or a first preliminary tertiary treatment to prevent the membranes from clogging

- **Tertiary treated** wastewater, up to demineralized — 76, 78, 91, 82
- **Filter washing water** — 55

Primary treated wastewater: effluent that has undergone primary treatment

- **Tertiary treated** wastewater (with greatly reduced pathogen levels) — 76, 78, 82, 91
- **Sludge from filter/material washing** — 55

51 OZONATION

Secondary treated wastewater

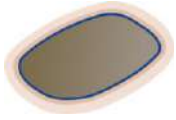
- **Tertiary treated** wastewater (disinfected) — 76, 78, 82, 91

52 CHLORINATION

Secondary effluent

- **Tertiary treated** wastewater (disinfected) — 76, 78, 82, 91

Sludge primary treatment: separation of solids and liquids / thickening



55 SEDIMENTATION/THICKENING POND

- **Non-pretreated faecal sludge** from on-site systems
- Thickened, partially digested sludge from on-site systems
- **Secondary (biological)** sludge

→ **Condensed, thickened, non-sanitised sewage** / faecal sludge — 56, 65

→ **Wastewater** from primary sewage and faecal sludge treatment processes — 39

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- **Wastewater** from primary sewage and faecal sludge treatment processes — 39

61 DRYING BEDS

- **Non-pretreated** faecal sludge
- **Thickened, partially digested** faecal sludge
- **Thickened, non-sanitised** sewage sludge

→ **Dried, partially sanitised** sewage / faecal sludge — 65, 67, 93, 76, 78, 84

- **Condensed, thickened, non-sanitised** sewage/faecal sludge
- **Dewatered, partially stabilised** sewage/ faecal sludge
- **Digested** sewage / faecal sludge: **stabilised, partially sanitised**

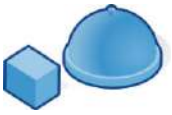
→ Wastewater from sewage or faecal sludge treatment processes **(percolate)** — 39

TREATMENT SEGMENT

Sludge secondary treatment: stabilisation and dewatering

Additional sludge hygienization treatments

Irrigation and soil agricultural and



57 ANAEROBIC DIGESTER

- Non-pretreated faecal sludge
- Thickened, non-sanitised sewage sludge
- Condensed, thickened, non-sanitised sewage/faecal sludge

→ Digested sewage/faecal sludge (digestate): dewatered, stabilised, partially sanitised (76, 78, 84, 65)

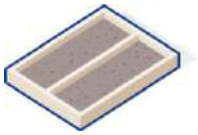
→ Biogas (85)

63 LIME STABILISATION: ALKALINE TREATMENT

- Non-pretreated faecal sludge
- Thickened, partially digested faecal sludge
- Thickened, non-sanitised sewage sludge
- Condensed, thickened, non-sanitised sewage/faecal sludge
- Dewatered, partially stabilised sewage/faecal sludge
- Digested sewage / faecal sludge: stabilised, partially sanitised

→ Lime-stabilised sludge: stabilised and partially sanitised (76, 78, 65)

→ Wastewater = Leachate (39)



65 LONG-TERM STORAGE

- Dewatered, partially stabilised sewage/faecal sludge
- Partially sanitised, dried sewage/faecal sludge
- Lime-stabilised sludge: stabilised and partially sanitised

→ Dried, sanitised sewage / faecal sludge (76, 78, 67)

66 THERMAL DRYING

- Dewatered, partially stabilised sewage/faecal sludge

→ Dried, sanitised sewage / faecal sludge (76, 78, 84, 85, 67)

67 INCINERATION

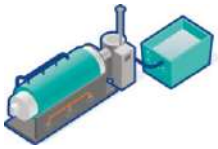
- Partially sanitised sludge

→ Ash (76, 78, 84, 88)

→ Thermal energy (85)

→ Smoke

→ Ciment



69 SLOW PYROLYSIS

- Partially sanitised, dried sewage/faecal sludge (from drying beds)

→ Biochar (76, 78, 84, 88)

→ Oily liquid (85)

→ Biogas (85)

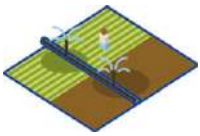
70 CO-COMPOSTING

- Partially sanitised, dried sewage/faecal sludge
- Digested sewage / faecal sludge: stabilised, partially sanitised
- Dewatered, partially stabilised sewage/faecal sludge
- Partially sanitised, dried sewage/faecal sludge

→ Compost (76, 78, 84)

→ Wastewater (Leachate) (39)

→ Larvae, worms (89)



76 IRRIGATION FOR AGRICULTURAL USE

- Secondary to tertiary treated wastewater

→ Farming activities (edible and non-edible crops)

→ Family vegetable gardens

78 IRRIGATION FOR NON-AGRICULTURAL USE

- Secondary to tertiary treated wastewater

→ Irrigation of public green spaces (gardens, parks)

→ Irrigation of privately-owned commercial green spaces (hotel grounds, golf courses)

→ Irrigation of residential green spaces

FROM SANITATION SYSTEMS

RESSOURCE RECOVERY AND REUSE SEGMENT

amendment for non-agricultural uses

79 SOIL AMENDMENT FOR AGRICULTURAL AND NON-AGRICULTURAL USE

- Sewage/ faecal sludge, **compost, ash, biochar**
  - **Soil amendment for farming activities,** (edible and non-edible crops)
  - **Soil amendment for family vegetable gardens**
  - **Irrigation of public green spaces** (gardens, parks)
  - **Irrigation of privately-owned commercial green spaces** (hotel grounds, golf courses)
  - **Soil amendment for forestry**
  - **Home soil amendment** (non-agricultural)
- **Urine after storage**
  - **Soil amendment for family vegetable gardens**

Returning water flows and materials to the water cycle and the soil

82 RETURN TO THE WATER CYCLE

- **Secondary to tertiary treated wastewater**
  - **Low-water flow support for surface water resources**
  - **Downstream (non)human uses**
- **Tertiary wastewater**
  - **Groundwater recharge**

84 SOIL RESTORATION

- Sewage/ faecal sludge, **compost, ash, biochar**
  - **Rehabilitation of mining or industrial areas, restoration of soil damaged by intensive farming**

Use of the output products' energy potential

85 USE OF BIOGAS FOR DOMESTIC, PUBLIC UTILITY OR INDUSTRIAL ACTIVITIES

- **Biogas**
  - **Domestic activities**
  - **Treatment plant energy requirements**
  - **Local public utilities**

86 COMBUSTION OF SANITATION OUTPUT PRODUCTS

- **Biochar**
  - **Domestic activities**
  - **Craft or industrial activities**
- **Plants**
  - **Domestic activities**
  - **Craft or industrial activities**

Use of water and end-products for craft and industrial activities

88 USE OF END-PRODUCTS AS A RAW MATERIAL

- **Biochar, ash**
  - **Local craft or industrial activities: construction material**
- **Plants**
  - **Craft activities** (often informal)

89 USE OF END-PRODUCTS FOR ANIMAL FEED

- **Worms, larvae, flies**
- **Macrophytes**
- **Duckweed**
  - **Livestock breeding** (use of endproducts for animal feed)
- **Secondary to tertiary treated wastewater**
  - **Aquaculture** (use of water in fishponds)

91 USE OF WATER FOR INDUSTRY AND URBAN SPACES

- **Secondary to tertiary treated wastewater**
  - **Washing of roads and networks**
  - **Industrial processes, cooling systems**
- **Biochar, ash**
  - **Industrial processes**

1.

Output products from the access/containment segment

In the access/containment segment, the input products are collected through a user interface (toilet, latrine).

This user interface can be designed to collect urine and faeces separately, and also to collect flushwater or anal cleansing water (blackwater), potentially together with greywater.

The interface can potentially be connected to one or several pits (which are used alternately). Initial treatment of the mixed or separated faeces and urine, either with or without (flush or cleaning) water, takes place during storage in the pit. It is also possible to recover the biogas produced.

Access/containment segment facilities can also be connected to an individual on-site treatment system or to a wastewater collection system.

This section sets out the characteristics of the output products than can be obtained from the access/containment segment based on the options selected and the potential next steps: resource recovery and reuse, subsequent stages of the sanitation chain.

Sanitation chain input products

FAECES

Faeces refers to (semi-solid) faecal matter that is not mixed with urine or water.

On average, one person produces 150g of faeces per day [1]; however, this can vary considerably from one region to another.

Faeces contain water, protein, undigested fat, polysaccharides, bacterial biomass, ash, and undigested food residue.

Faeces is made up of 25% of solid matter (SM). Between 84 and 93% of this solid matter consists of organic solids, which can be broken down as follows:

- 25-54% bacterial biomass;
- 2-25% protein or nitrogenous matter;
- 25% carbohydrate or undigested non-nitrogenous plant matter;
- 2-15% undigested fat.

The 25 to 54% bacterial biomass portion of the organic solids contains both pathogenic and non-pathogenic bacteria.

URINE

The average quantity of urine produced varies from 0.6 to 2.6 litres per person per day, with a median value of 1.4 litres per person per day. [1]

Between 91 and 96% of urine is water. The remaining 4 to 9% is made up of dissolved solids, or of crystals in dried urine.

Urine contains most of the valuable nutrients required for soil amendment that are excreted by the human body (nitrogen, phosphorus, potassium).

Pure urine (uncontaminated by faeces) usually contains only non-pathogenic microorganisms.

In rare cases, urine can, however, be contaminated. One of the main urine-borne diseases is schistosomiasis (or bilharzia), which is mainly found in tropical areas.

There is also a risk of cross-contamination if urine comes into contact with faeces.

EXCREMENT

Together, mixed urine and faeces that has not been diluted with flushwater is referred to as excrement or excreta.

BLACKWATER

Blackwater is the mixture of urine, faeces and flushwater, and/or anal cleansing water (if water is used for cleaning) and/or dry cleansing materials. Blackwater contains pathogens from faeces and nutrients from urine that are diluted in the flushwater.

GREYWATER

Greywater is the water generated from washing food, clothes and dishes, as well as from bathing, but not from toilets.

FLUSHWATER

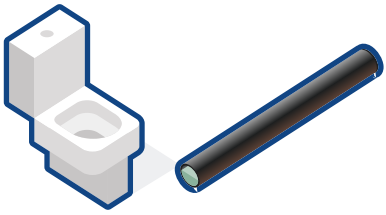
Flushwater is the water used to flush waste down the toilet.

ANAL CLEANSING WATER

Anal cleansing water is the water used to clean oneself after defecation.

1.1 Solutions with basic or no pretreatment

1.1.1 User interface: - toilets with water supply (flushwater), - with or without urine diversion; Connected to a wastewater collection system



INPUT PRODUCTS

BLACKWATER Faeces + urine + flushwater

GREYWATER

DESCRIPTION OF THE FACILITY

Flush toilets for discharge into the sewerage system.

OUTPUT PRODUCT

RAW WASTEWATER

WHO defines raw wastewater as excrement diluted by a factor of 100 in flushwater. Wastewater contains three types of pollution:

- Particulate pollution, also known as settleable pollution (particles larger than 1-10 µm), which contains a mineral component (sand, silt, etc.) and an organic component (organic matter, flocs, biofilm fragments, etc.).
- Colloidal pollution made up of very small particles (0.001 to 1 - 10 µm) that can remain suspended in water for extremely long periods and can even pass through certain filters (clay, bacteria, oxides and hydroxides, etc.). Due to their high stability, they do not naturally stick to each other. Colloidal pollution is the main cause of water turbidity and colour.
- Dissolved pollution, which includes all soluble particles dissolved in water.

Potential destination

Conveyed via a sewerage system to a wastewater treatment plant 36

(if urine diversion is in place) **URINE**

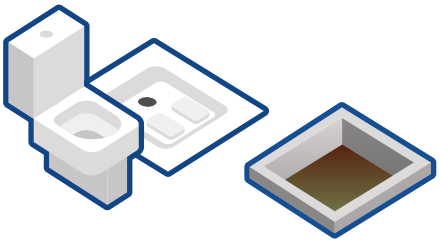
It is rare for flush toilets connected to a sewerage system to include urine diversion.

The characteristics of urine and its potential uses are set out in the User interface "Urine-Diverting Dry Toilets" section (2.2.3).

Potential uses

Soil amendment for family vegetable gardens 79

1.1.2 User interface: - toilets with or without water supply, - without urine diversion; Connected to a watertight or non-watertight pit located beneath the defecation hole



INPUT PRODUCTS:

EXCREMENT Faeces + urine

ANAL CLEANSING WATER

FLUSHWATER Potentially

DESCRIPTION OF THE FACILITY

The pits are abandoned or emptied when full. Excrement from pour flush latrines has more fluid content and so can be pumped from the pit. Pits used with traditional latrines are not emptied, instead a new pit is built next to the pit that is full. The latrine superstructure is then transferred from the old to the new pit.

FOR MORE INFORMATION:

- Compendium des systèmes et technologies d'assainissement 2e édition actualisée, Eawag WSSCC IWA, Elizabeth Tilley, Lukas Ulrich, Christoph Lüthi, Philippe Reymond et Christian Zurbrügg, 2016 : Système 1: Système avec fosse unique et production de boue.

OUTPUT PRODUCTS

Untreated faecal sludge — **UNTREATED FS**

Faecal sludge is heavily loaded with pathogens.

Potential destination

Treating faecal sludge with wastewater in a wastewater treatment plant can interfere with the WWTP's treatment processes. It is essential to ensure that the treatment plant has been designed to treat this faecal sludge and is not too far from the area from which the faecal sludge is collected.

Transported to a FSTP — 55

Transported to a WWTP to be jointly treated with wastewater — 36

Wastewater from on-site systems — **WASTEWATER**

Potential destination

- **From watertight pits**

Removed via a sewerage system, potentially in conjunction with greywater

- **From non-watertight pits**

Infiltration

Non-watertight pits enable the liquid to slowly infiltrate into the ground, which helps partially eliminate small particles and pathogens. They are suited to areas with permeable soils, and to sparsely populated rural areas with low groundwater tables that are not at risk of being contaminated by the pits.

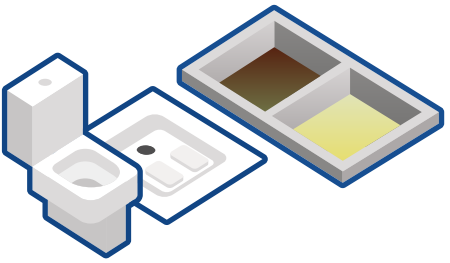
Alternative: Arborloo

A single, shallow pit is used to collect excreta, soil, ash and dry leaves. When the pit is nearly full, it is covered by a thick layer of earth. **A fruit tree is then planted on top of the pit**.

At the same time, a new shallow pit is dug out and the latrine structure is moved and placed over this new pit. The advantage of this process is that the output product is directly reused with minimum exposure to compost or to fresh excrement, which is covered and left in the pit.

1.2 Solutions that provide partial treatment

1.2.1 User interface:
- toilets with or without water supply
- without urine diversion;
Connected to a non-watertight double pit



INPUT PRODUCT

EXCREMENT — Faeces + urine

ANAL CLEANSING WATER

FLUSHWATER — Potentially

DESCRIPTION OF THE FACILITY

Two non-watertight pits are used alternately and are connected to a pour flush toilet with a water seal, or without flush. The liquid component of these pits slowly infiltrates into the ground, which must be permeable and have a low groundwater table to prevent contamination. Some of the pathogens are absorbed into the soil but can be filtered depending on the soil type. The solid component remains trapped in the pit and slowly dries out over time.

FOR MORE INFORMATION:

- Compendium of Sanitation Systems and Technologies – 2nd revised edition, Eawag, WSSCC, IWA, Tilley et al. (2016): System 2 and 3: Waterless Pit System without Sludge Production; Pour Flush Pit System without Sludge Production

OUTPUT PRODUCTS

Dried, partially sanitised sludge — DRIED PART-SAN FS

Internal factors such as the level of oxygen, humidity and the carbon to nitrogen ratio means that there is no real increase in temperature in the pit. As a result, the pit contents are only partially sanitised.

◄ Dry toilet with two non-watertight pits

WHO recommendations to ensure a 6 log reduction are based on ambient temperature:

For temperatures of between 2 and 20°C: a storage period of 1.5 to 2 years can reduce bacteria, viruses and protozoa to below risk levels. Some eggs can survive in small numbers.[2]

For temperatures of between 20 and 35°C: a storage period of over one year inactivates viruses, bacteria, protozoa and most types of helminth eggs (roundworm eggs can survive).[2]

Potential uses and applications

Dried sludge can be beneficial for improving soil and can be used in agriculture. If the sludge has not been stored in optimum conditions, the dried sludge can be transported off-site for subsequent co-composting.

Potential additional treatment processes

There is a risk of bacterial regrowth in the event of re-humidification. Therefore, if when removed the pit contents are wet due to infiltration during the rainy season or to the poorly porous nature of the soil, additional treatment will be required.

Materials such as ash, lime, earth, sawdust, mulch and crushed shells, etc. can be added to excrement to accelerate the drying process and absorb humidity. Sometimes ash or slaked lime are added to help remove bacteria, which helps optimise the removal of certain pathogens and reduce the storage time required. On-site co-composting using organic waste is also an option.

Shorter storage periods can be used for all systems in very dry climates, where humidity is below 20%.

If the pit contents are re-humidified, certain strains can start to redevelop.[4]

◄ Flush toilet with two non-watertight pits

The pit contents from flush toilets require longer storage times than dry toilets (up to two to three years) in order to eliminate the additional liquid from the flushwater.[2]

Soil amendment for family vegetable gardens 79

Home soil amendment (non-agricultural) 81

Additional sanitisation treatment, particularly co-composting, long-term storage (on-site or at a collective facility) 65

Wastewater from on-site systems **WASTEWATER**

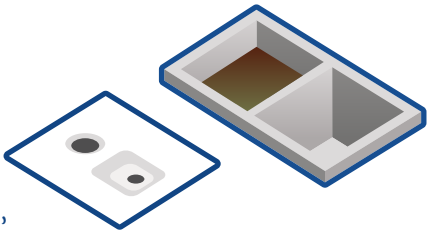
From lack of flush water and two leaking pits

Potential destination

Non-watertight pits enable wastewater to slowly infiltrate into the ground, which helps partially eliminate small particles and pathogens. They are suited to areas with permeable soils, and to sparsely populated rural areas with low groundwater tables that are not at risk of being contaminated by the pits.

Infiltration

1.2.2 User interface: - toilets without water supply, - with urine diversion; Connected to one or two watertight pits used alternately to collect faeces, and one or two storage tanks for urine collection



Common name: "Urine-Diverting Dry Toilet"

INPUT PRODUCTS

URINE

FAECES

Separately

ANAL CLEANSING WATER Potentially, should be kept separate from urine

DESCRIPTION OF THE FACILITY

Two dewatering pits are used for the collection, storage and drying of faeces. These pits are used alternately.

In addition, one or several storage tanks are used alternately to collect urine. It is also possible to install a 3-hole separating toilet with three basins to separately collect faeces, urine, and anal cleansing water.

FOR MORE INFORMATION:

- Compendium of Sanitation Systems and Technologies – 2nd revised edition, Eawag, WSSCC, IWA, Tilley et al. (2016) - System 4: Waterless System with Urine Diversion

OUTPUT PRODUCTS

Under optimum conditions:

Dried, partially sanitised sludge — DRIED PART-SAN FS

Internal factors such as the level of oxygen, humidity and the carbon to nitrogen ratio means that there is no real increase in temperature in the pit. As a result, the pit contents are only partially sanitised.

Potential uses and applications

- Soil amendment for family vegetable gardens — 79
- Home soil amendment (non-agricultural) — 81

Potential additional treatment processes

- Additional in-situ treatments: co-composting, liming, extended storage — 63
- Additional sanitisation treatment, particularly co-composting, long-term storage (on-site or at a collective facility) — 65

URINE

Potential uses and applications

- Soil amendment for family vegetable gardens — 79
- Home soil amendment (non-agricultural) — 81

Pure urine contains no pathogens. However, there is a risk of cross-contamination with faeces. Users may carry viruses and bacteria that subsequently end up in urine.

Therefore, WHO recommends a 6-month storage period for urine (at a temperature of 20°C) prior to use. This storage period can be reduced if the urine is to be applied to

crops not intended for direct human consumption, such as feed crops.

To prevent the volatilisation of NH3 ammonia gas, which helps eliminate pathogens for which NH3 is toxic, it is recommended to store the urine in a hermetically sealed container.

High concentrations of NH3 ammonia gas makes urine an effective treatment for faeces, particularly when it is added to excrement stored in double-pit systems and to composting, for example.[4]

Alternative: adding materials to facilitate pathogen breakdown

Where there is an appropriate and constant source of soil-based materials, ash or organic compounds, such as leaves, grass, coconut shells, rice husks, shavings, etc., these can be used to accelerate the decomposition process and thereby reduce the storage time.

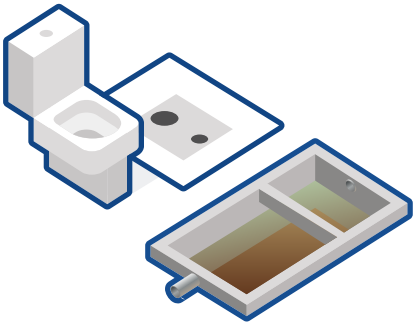
Alternative: Tiger Worm Toilets

With Tiger Worm Toilets (or vermicompost toilets), faeces is directly broken down in the pit by composting worms, without the need for other materials. Oxfam has trialled these toilets in six countries in both emergency and post-disaster settings, and has published a detailed Tiger Worm Toilet Manual. The main limitation of these toilets, however, is that specific skills are required, including those of external specialists, to build and ensure the effective operation of these toilets, as well as to ensure their proper long-term maintenance.

FOR MORE INFORMATION:

- OXFAM website: Tiger Worm Toilets

1.2.3 User interface:
- toilets with or without water supply,
- with or without urine diversion;
Connected to a sedimentation and/or anaerobic digestion treatment system



INPUT PRODUCTS

EXCREMENT	Faeces + urine
ANAL CLEANSING WATER	
FLUSHWATER	Potentially

DESCRIPTION OF THE FACILITY

Septic tank:

A septic tank consists of at least two watertight chambers. The faecal sludge undergoes sedimentation-thickening and anaerobic degradation (through lack of oxygen). However, this anaerobic degradation is only partial as the sludge accumulates faster than it decomposes.

Anaerobic digester:

Anaerobic digestion involves creating the conditions that facilitate anaerobic degradation (through lack of oxygen) by microorganisms inside a reactor or digester in order to produce digestate (a wet substance rich in partially stabilised organic matter) and biogas (a water-saturated gas mixture).

Household anaerobic digesters can be used on farms, particularly where excrement and the other abovementioned input products can be mixed with cattle excrement. This ensures that there is enough biomass to produce sufficient quantities of biogas for use in the home. Cattle excrement also facilitates the anaerobic digestion process.

There are different types of digester available that vary based on the feeding method (discontinuous, semi-continuous or continuous), biogas storage method and substrate dry matter content.

The digestion process in household anaerobic digesters is incomplete as it takes place under mesophilic conditions (<50°C). Therefore, household digesters provide a similar level of treatment to septic tanks, but have the additional advantage of producing biogas.

FOR MORE INFORMATION:

- Compendium of Sanitation Systems and Technologies – 2nd revised edition, Eawag, WSSCC, IWA, Tilley et al.(2016) https://www.pseau.org/outils/ouvrages/eawag_wsscc_compendium_of_sanitation_systems_and_technologies_lowres2014.pdf-Biogas Reactor
- Household Biogas Digesters – A Review, Molecular Diversity Preservation International, Rajendran et al. (2012)

- Guide de dimensionnement et de construction - Le réacteur anaérobie compartimenté et ses variantes (Maroc), Programme AGIRE – Ministry of Water (Morocco), GIZ (2019)
- Guide de dimensionnement, de construction et d'utilisation des sous-produits - Digesteur à dôme fixe, Digesteur parallélépipédique, Programme AGIRE – Ministry of Water (Morocco)

OUTPUT PRODUCTS

Thickened, partially digested sludge — THICKENED PART-DIG FS

Septic tank:

The anaerobic digestion process is extremely incomplete.

Potential additional treatment processes

Additional FSTP treatment 55

Anaerobic digester

Biologically stabilised by anaerobic digestion, the contents of the digester are easier to dry than fresh sludge. The anaerobic process requires the sludge to be rich in nitrogen. However, pathogen load will remain as the household on-site digestion process is unable to reach significantly high temperatures.

Potential uses and applications

Soil amendment for family vegetable gardens 79

Home soil amendment (non-agricultural) 81

Potential additional treatment processes

For use as a land application for agriculture, the sludge needs to have undergone anaerobic digestion for 15 days at a temperature of between 35 and 55°C, or for 60 days at 20°C.[10] If these conditions cannot be met, the sludge will need to be collected for additional treatment in a FSTP.

Additional on-site treatment: co-composting, lime treatment, long-term storage

Additional FSTP treatment 55

Wastewater from on-site systems **WASTEWATER**

Potential destinations or uses

Water discharged by overflow can be infiltrated at home, via an infiltration trench, for example.

Infiltration

Wastewater can also be discharged through a sewerage system, either with or without greywater.

Discharge via a specific sewerage system

Wastewater can be used to irrigate and improve soil.

Soil irrigation for family vegetable gardens 79

BIOGAS

- **Septic tank:**

Biogas is produced in small quantities and is generally released via ventilation.

- **Anaerobic digester:**

Recovery of the biogas produced can be carried out locally.

Potential uses and applications

Use of the energy potential of the output (biogas) 85

Output products from the treatment segment

If they are not recovered on-site (or infiltrated in the case of water), the output products from the access/containment segment are conveyed/transported to a treatment system.

The 'transport' segment is also known as the 'intermediate' segment.

There are two main methods of transporting output products from the access/containment segment:

- Conveyance through a sewerage system: the output transported is raw wastewater ;
- Transported through non-sewerage methods: the output transported is faecal sludge, which may have been pretreated depending on the access/containment facility used to collect it.

There is a range of technical and organisational solutions available, none of which significantly influence the characteristics of the output product or its potential uses. The different technical transport solutions are not detailed in this guide. For further information on this topic, please refer to the following publications.

After having been transported via the intermediate segment, the raw wastewater and faecal sludge, both access/containment segment output products, become input products to the treatment segment.

The raw wastewater is conveyed via the sewerage system to a wastewater treatment plant: WWTP.

The sludge is transported using non-sewerage methods to a faecal sludge treatment plant: FSTP.

The treatment processes used in the WWTP and FSTP separate the liquid from the solids. Thus, both the WWTP and FSTP use water and sludge treatment processes.

The output products of the treatment segment are set out as follows:

Part 2: Output products from wastewater treatment processes.

Part 3: Output products from faecal sludge and sewage sludge treatment processes.

FOR MORE INFORMATION:

- Faecal Sludge Management: Systems Approach for Implementation and Operation, IWA Publishing. Édition française, 2018, Strande L., Ronteltap M., Brdjanovic D
- How to Select Appropriate Technical Solutions for Sanitation, pS-Eau, December 2010

2.

Output products from wastewater treatment processes

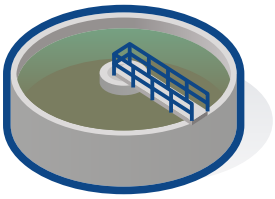
Wastewater treatment processes are carried out inside **wastewater treatment plants: WWTP**. The input products to the treatment system are raw wastewater from an access/containment segment user interface, such as a toilet with water supply (flushwater) with or without urine diversion, and greywater, connected to a sewerage system. This raw wastewater is sometimes collected alongside industrial effluent and stormwater, which also have to be treated in the WWTP.

Wastewater treatment processes can also be used for **water from on-site treatment facilities** if this wastewater is collected via a specific sewerage system.

Wastewater treatment processes are also applied to **water from sewage sludge treatment processes** (covered in **part 3**).

2.1 Waste water primary treatment

2.1.1 Settler/ primary treatment technology



INPUT PRODUCT

RAW WASTEWATER

PROCESS DESCRIPTION

The settling basin is designed to ensure a long hydraulic retention time to enable sedimentation of the largest particles whose settling speed is faster than the flow velocity in the basin. Settleable particles sink to the bottom of the basin, forming what is known as primary sludge, which is removed on a regular basis.

OUTPUT PRODUCTS

Primary treated wastewater → PRIMARY WASTEWATER

Physico-chemical parameters: Settling helps significantly reduce particulate pollution, removing between 55 and 65% of TSS. It also removes 25 to 30% of BOD and COD.

Nitrogen, organic matter and phosphorus are only partially removed (25 to 30%).

Pathogens: Primary settling removes around 90% of pathogens, i.e. a 1 Log reduction. Effluent remains loaded with pathogens, in particular the viruses and bacteria not naturally attached to TSS.[1]

Potential additional treatment processes

Secondary treatment 39

Primary sludge: non-sanitised, thickened sewage sludge → THICKENED NON-SAN SS

DMC: Primary sludge has a dry matter content of 4 to 7%, i.e. a moisture content of 93 to 96%.

Composition: The sludge contains between 40 and 60% VVS.

This primary sludge contains high concentrations of pathogenic microorganisms, which accumulate through settling, in particular helminths, protozoa, as well as smaller quantities of viruses and bacteria naturally associated with TSS.[1] [4]

Potential additional treatment processes

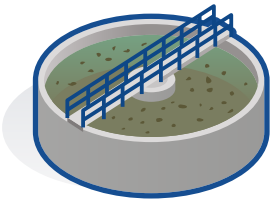
In the case of activated sludge treatment at secondary treatment level, the primary sludge is mixed with the biological secondary sludge (mixed sludge).

Sédimentation, déshydratation 55

Alternative: lamellar settler

The lamellar settler has a larger settling surface area, which helps improve the sedimentation process while, at the same time, reducing both the treatment time and the footprint required. In addition to physical sedimentation, there is a biological process that takes place, namely biodegradation by anaerobic digestion. While this option helps optimise BOD and COD treatment, pathogen reduction remains the same as when using a conventional settler.

2.1.2 Improved primary treatment: Coagulation/flocculation



INPUT PRODUCT

RAW WASTEWATER

PROCESS DESCRIPTION

Improved primary treatment seeks to improve the effectiveness of conventional primary treatment by further reducing colloidal pollution through the addition of coagulants.

OUTPUT PRODUCTS

Primary treated wastewater: PRIMARY WASTEWATER

Physico-chemical parameters: Increased reduction of TSS, from 50-65% to over 70%.[1]

Reduction of BOD and COD, nitrogen and phosphorus is improved by between 55 and 60%.[4]

Pathogens: Primary effluent remains loaded with pathogens.

There is a 1 to 2 log reduction in bacteria, viruses and protozoa, and up to 3 log for helminth eggs.[8]

Potential additional treatment processes

Secondary treatment 39

'Physico-chemical' primary sludge: non-sanitised, thickened sewage sludge

PRIMARY SS

(PHYSICO-CHEMICAL IF COAG. FLOC.)

DMC: This sludge has a dry matter content of around 4 to 7%.[4]

Pathogènes : The sludge contains between 40 and 60% VVS.[4]

In addition to the pathogens mentioned above for the primary sludge from primary settlers, this sludge also contains coagulants/flocculants, which can limit its recovery potential.

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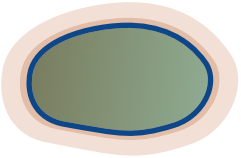
Potential additional treatment processes

Sedimentation, dewatering 55

The primary sludge are mixed with secondary biological sludge (= mixed sludge).

2.1.3 Primary waste stabilisation pond



INPUT PRODUCT

RAW WASTEWATER

PROCESS DESCRIPTION

The effluent to be treated flows slowly under gravity through the relatively deep (2 to 5 metres) anaerobic pond over the course of several days. This pond constitutes the primary treatment stage of a waste stabilisation pond (WSP) system.

OUTPUT PRODUCTS

Primary treated wastewater

PRIMARY WASTEWATER

The quality of the water and sludge resulting from primary WSP treatment is insufficient for direct reuse.

Potential additional treatment processes

Secondary treatment, particularly in a secondary waste stabilisation pond 39

Primary sludge: non-sanitised, thickened sewage sludge → THICKENED NON-SAN SS

This sludge accumulates at the bottom of the pond via settling.

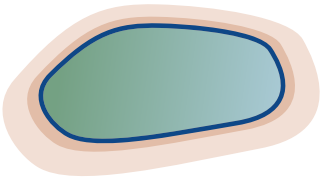
Potential additional treatment processes

Dewatering 56

Sanitisation 65

2.2 Secondary treatment

2.2.1 Secondary waste stabilisation pond



INPUT PRODUCT

PRIMARY WASTEWATER → **Primary treated wastewater,** (particularly from a primary waste stabilisation pond.)

PROCESS DESCRIPTION

The effluent to be treated flows slowly under gravity inside a facultative aerobic/anaerobic pond of intermediate depth (1.5 to 2 metres) over the course of several days. The facultative pond requires a longer retention time than the anaerobic pond, usually 4 to 5 days, and has a large footprint. The lower layer of the pond is anaerobic (without oxygen) and the upper layer is aerobic (with oxygen).

OUTPUT PRODUCT

Secondary treated wastewater → SECONDARY WASTEWATER

Physico-chemical parameters: The secondary waste stabilisation pond serves mainly to remove BOD, achieving reductions of up to 90%, whereas between 30 and 50% of nitrogen is removed.[1]

There is usually less than a 35% reduction in phosphorus.[5] In addition, algae can increase COD and turbidity.

Pathogens: There can be up to a 2 log reduction in bacteria. Nearly all protozoan cysts and helminths are removed. However, there is no significant reduction in free microorganisms that are not attached to particles (viruses and certain bacteria).[5]

Potential additional treatment processes

Tertiary treatment 45

Potential uses and applications

For agricultural use, thresholds for pathogen levels in wastewater imposed by the regulations usually equate to those for tertiary treatment. However, there are certain modes of use that can reduce exposure to pathogens (irrigation method, choice of crops grown, etc.), potentially enabling the use of secondary treated wastewater. In addition, the informal use of secondary treated wastewater is already widespread in many regions of the world. More information on the health risk is provided in chapter 2.

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Return to the water cycle 82

Primary sludge: non-sanitised, thickened sewage sludge — **THICKENED NON-SAN SS**

The sludge is removed from the WSP around once every 10 years. However, this varies widely depending on the environment.

DMC: The sludge has a dry matter content of around 15%.[1]

Composition : The long detention time of several years leads to greater anaerobic degradation, resulting in less than 50% VVS.[5] The sludge is relatively stable/mineralised but remains loaded with pathogens, which accumulate through sedimentation (helminths, protozoa, viruses and bacteria attached to TSS).[1] The liquid sludge also contains nitrogen and phosphorus.

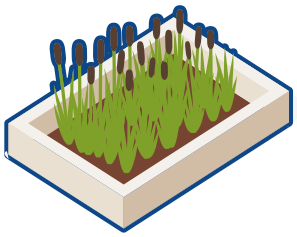
Potential additional treatment processes

Dewatering 56
Sanitisation 65

Alternative: Aerated pond

By mixing the effluent and providing mechanical aeration, aerated ponds reduce retention times and thus can be smaller in both size and footprint. In addition, the aerated pond can directly receive raw wastewater so primary treatment is not necessarily required. However, it is important to note that this option does not significantly improve pathogen removal.

2.2.2 Planted filter beds



INPUT PRODUCTS

RAW WASTEWATER without the need for primary treatment (however, pretreatment through screening is required)

PROCESS DESCRIPTION

Parallel beds are installed so that they can be used alternately, with some being left to rest while others are fed with wastewater. This process promotes the self-regulation of bacteria, thus controlling the biomass that is produced and preventing clogging. A sheet of wastewater several centimetres wide is poured intermittently onto the surface of the beds from above using a mechanical dosing system. The raw wastewater then flows through the filter media before being collected in a drainage pipe. The TSS are filtered on the surface, sifted by the finest layer of gravel, then retained at the surface where they mineralise, forming a layer of deposit. Biofilms form inside the filter, particularly around the roots of the reeds, which triggers biological processes that aerobically degrade dissolved organic carbon and nitrogen compounds.

FOR MORE INFORMATION:

- Les filtres plantés de végétaux pour le traitement des eaux usées domestiques en milieu tropical : Guide de dimensionnement de la filière tropicalisée, INRAE, Lombard Latune & Molle (2017)
- Guide de dimensionnement, de construction et de fonctionnement – Filtre planté horizontal de petite taille, Programme AGIRE – Ministère de l'Équipement et de l'Eau (Maroc, AGIRE (2019)
- Planted Drying Beds for Faecal Sludge Treatment: Lessons Learned Through Scaling Up in Dakar, Senegal, Sandec, Dodane et al. (2011)

OUTPUT PRODUCTS

Secondary treated wastewater **SECONDARY WASTEWATER**

Physico-chemical parameters: Due to its low BOD and low turbidity, this water is suitable for tertiary disinfection treatment.[1]

Composition: Significant concentrations of pathogens remain in the water. Some of these pathogens remain with the TSS that is retained on the filter surface, particularly protozoan cysts, helminths, and the viruses and bacteria adsorbed on the TSS.[1]

A two-stage vertical flow configuration can help improve removal efficiency (3.3 log compared to 1.7 log for a one-stage filter bed).[8]

Potential additional treatment processes

Tertiary treatment 45

Potential uses

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Return to the water cycle 82

For agricultural use, regulations generally impose thresholds for pathogens present in treated wastewater corresponding to a tertiary level of treatment. However, certain conditions of use (irrigation methods, choice of crops, etc.) can reduce exposure to pathogens, making it possible to use secondary-level wastewater. In addition, the use of secondary-level treated wastewater for agricultural irrigation is practised informally in many parts of the world. The issue of health risk is developed in chapter 2.

Dried, partially sanitised sludge

DRIED PART-SAN FS

Small quantities of sludge are produced and accumulate over the course of several years (>10 years in a temperate climate, >15 years in a tropical climate).[1]

DMC: The sludge is partially mineralised and dewatered.

Composition: The sludge remains loaded with pathogens.

Potential uses and applications

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Return to the water cycle 82

Potential additional treatment processes

Sanitisation 65

VEGETATION

The vegetation is cut on a regular basis, mostly for informal use. It is often used by households, for fuel or as raw material for crafts.

Potential uses and applications

Use of the plants' energy potential (combustion) 85
Use of the end product as a raw material 88

Alternatives: Configurations for tropical environments

The design, particularly the depth and number of beds, whether arranged in series or in parallel, can have an impact on the treatment of certain parameters, such as BOD, COD, nitrogen, carbon materials and TSS. However, it does not influence pathogen reduction.

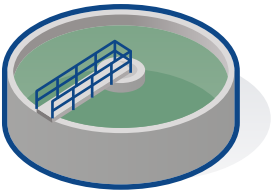
Alternatives: Horizontal flow constructed wetland

The system is constantly fed with wastewater; the upper layer of the bed is aerobic and the lower, deeper layer is anaerobic. Pretreatment through primary settling is required for constructed wetlands designed to partially or exclusively treat blackwater, whether this is mixed with greywater or not. However, this pretreatment is not required for beds designed to treat greywater only or highly diluted liquid effluent.

Alternatives: Constructed wetlands with forced aeration

Perforated pipes are installed at the bottom of the wetland to force air up through the bed either continuously or intermittently. However, this approach foregoes the advantage of low-energy or no energy consumption. Adding forced aeration considerably improves pathogen reduction, particularly in horizontal flow constructed wetlands.[8]

2.2.3 Activated sludge processes



INPUT PRODUCTS

PRIMARY WASTEWATER — Primary treated wastewater

PROCESS DESCRIPTION

A free biomass culture is developed inside a biological reactor that uses sequential aeration to alternate between aerobic and anaerobic conditions. The biological reactions and separation of sludge and effluent can take place inside two separate adjoining chambers (an aeration tank plus clarifier), or within the same chamber with two distinct phases if a Sequencing Batch Reactor (SBR) is used.

OUTPUT PRODUCTS

Secondary treated wastewater — SECONDARY WASTEWATER

Physico-chemical parameters: There is a significant reduction in BOD of between 80 and 95%.[1]

Nitrogen and phosphorus is reduced by between 25 and 30%, with especially high removal rates of between 85 and 95% for nitrogen in the form of ammonia.[5]

Pathogens: Pathogen reduction remains limited: up to 2 log for viruses and bacteria (or 3 log for certain strains), and 1 log for protozoan cysts and helminths.[1]

Potential additional treatment processes

The effluent has low turbidity, making it suitable for tertiary treatment.

Tertiary treatment 45

Potential uses

For agricultural use, regulations generally impose thresholds for pathogens present in treated wastewater corresponding to a tertiary level of treatment. However, certain conditions of use (irrigation methods, choice of crops, etc.) can reduce exposure to pathogens, making it possible to use secondary-level wastewater. In addition, the use of secondary-level treated wastewater for agricultural irrigation is practised informally in many parts of the world. The issue of health risk is developed in chapter 2.

Soil irrigation for agricultural use 76

Soil irrigation for non-agricultural use 78

Return to the water cycle 82

Thickened, non-sanitised secondary sludge, or 'biological sludge' **BIOLOGICAL SS**

DMC: This sludge is liquid in consistency, having a dry matter content of between 1 and 5%.[1]

Composition : It is also rich in organic matter; volatile suspended solids (VSS) can range from 50 to 80%.[4]

Potential additional treatment processes

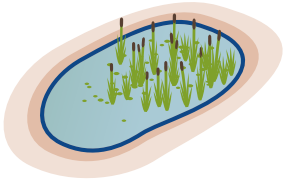
Additional dewatering and sanitisation treatment **55**

Some of the sludge will be reintroduced into the process to seed the new primary effluent. This is known as **recirculation**.

The remaining sludge is transferred to the plant's sludge treatment facilities for further treatment.

2.3 Tertiary treatment

2.3.1 Maturation pond



INPUT PRODUCTS

SECONDARY WASTEWATER **Secondary treated wastewater,** (particularly from a secondary waste stabilisation pond)

PROCESS DESCRIPTION

Maturation ponds are shallower than the secondary, facultative ponds. They are usually between 1 and 1.5 metres deep and have a detention time of 3 to 5 days, depending on temperature conditions [5]. Treatment is via photosynthetic algae that increase dissolved oxygen levels and pH in the water. Treatment is enhanced by the low turbidity of the effluent and the shallowness of the pond, which enables sunlight to penetrate its full depth. The length of exposure to and intensity of the sun's rays are thus key parameters for pathogens.

OUTPUT PRODUCTS

Tertiary treated wastewater, with greatly reduced pathogen levels **TERTIARY WASTEWATER**

Physico-chemical parameters: A reduction in nitrogen of between 70 and 80% is usually observed, rising to 90% in certain conditions.[5]

There is a 60 to 80% reduction in phosphorus due to the shallowness of the pond and high pH (>9)[5].

Pathogens: Pathogens are significantly reduced:

- Up to 5 log for bacteria;
- Up to 4 log for viruses;
- Up to 2 log for protozoa;
- Up to 2 log for helminths, and up to 100% if the pond is specifically designed for helminth and protozoa removal.[1]

The resulting effluent can thus be used directly for certain applications, in accordance with the regulations in force.

Potential uses and applications

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Use for urban spaces and in industry 91
Return to the water cycle 82

Primary sludge: non-sanitised, thickened sewage sludge

THICKENED NON-SAN SS

Sludge accumulates at the bottom of the pond faster than in the primary and secondary waste stabilisation ponds. It therefore needs to be removed more frequently, usually once a year.

DMC: The sludge at the bottom of the pond has less dry matter content than the sludge removed from the primary and secondary ponds, and is usually between around 4 to 6%.[1]

Composition : The sludge is loaded with pathogens, which accumulate through sedimentation.

Potential additional treatment processes

Dewatering 56
Sanitisation 65

Macrophytes (water hyacinths, duckweed, etc.)

VEGETATION : MACROPHYTES

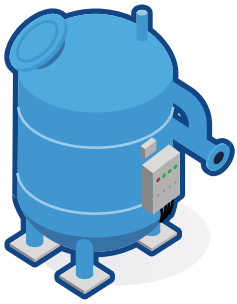
Macrophytes (water hyacinths, duckweed, etc.) are aquatic plants that proliferate rapidly on the surface of bodies of water, especially waste stabilisation maturation ponds.

When harvested, water hyacinths provide a source of fibre that can be used to make rope, textiles, baskets and other products. Duckweed can be used as animal feed, particularly for certain types of herbivorous fish.

Potential uses and applications

Use of the end product as a raw material 88
Use of the end product as fuel 85
Use of the end product as animal feed 89

2.3.2 Filtration and adsorption over sand or filter material



INPUT PRODUCTS

SECONDARY WASTEWATER — Secondary treated wastewater

PROCESS DESCRIPTION

For slow filtration, effluent flows slowly under gravity (2 to 5$m^3/m^2/hr$) through one or several filter beds (placed in parallel or in series) that can contain different types of filter material of varying sizes.

Filtration can take place through a grain filter of sand or gravel. Output product can be improved by adding a coagulation stage, either beforehand or between two filter beds.

If activated carbon is used as the filter material, the process will predominantly involve adsorption. Activated carbon has outstanding adsorption properties and is particularly effective at adsorbing very fine particles, from 0.5 to 50 µm. Not only does it act as a sponge for these pollutants, but it also causes a biofilm to form on the surface of the carbon that degrades pollution via biological reactions. This dual mechanism makes it a popular choice for tertiary finishing treatments as it can remove COD that is resistant to biological secondary treatment, as well as many organic and non-organic micropollutants, such as pesticides and drug residues.

OUTPUT PRODUCTS

Tertiary treated wastewater, with greatly reduced pathogen levels — TERTIARY WASTEWATER

Pathogens: There is a 3 log reduction in bacteria, protozoan viruses and helminths.[12]

Potential uses

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78

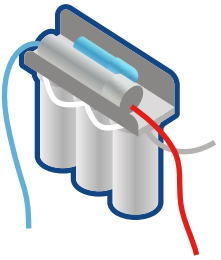
Use for urban spaces and in industry 91

Return to the water cycle 82

Sludge from filter/material washing **RETENTATE**

Pathogens: The pathogens trapped by the physical processes (especially filtration and adsorption) are not usually inactivated, therefore there is a high risk associated with the pathogens that accumulate on the filters.

2.3.3 Membrane filtration



INPUT PRODUCTS

SECONDARY TO TERTIARY WASTEWATER

Effluent that has undergone secondary treatment or a first preliminary tertiary treatment to prevent the membranes from clogging.

PROCESS DESCRIPTION

In this process, the effluent passes through a fine porous filter media. A membrane or fibre is characterised by its cut-off threshold, which indicates its selectivity or separation efficiency. For membranes with low cut-off thresholds, effluent often passes through the membrane under pressure.

OUTPUT PRODUCTS

Tertiary treated wastewater (up to demineralized) **TERTIARY WASTEWATER**

Pathogens:

With microfiltration: this has a high cut-off threshold of between 0.1 and 10 µm, which can remove up to 5 to 6 log of bacteria, helminths, protozoa and 'coarse' colloids; however, it does not usually retain viruses unless these are attached to TSS, which can result in up to a 2 log reduction.[1]

With ultrafiltration: this has a cut-off threshold of between 10 nm and 1 µm, and the finest cut-off thresholds can also retain viruses (up to 6 log), as well as polymers and proteins.[1]

With nanofiltration: all pathogens are retained (7 log), as well as multivalent ionised salts and molecules larger than 1 to 5 nm.[1]

With reverse osmosis: all ions and larger molecules are retained, thereby ensuring the removal of all pathogens (7 log).[1]

Potential additional treatment processes

Remineralisation

Potential uses

Soil irrigation for agricultural use 76

Soil irrigation for non-agricultural use 78

Use for urban spaces and in industry 91

Return to the water cycle 82

Filter washing water **RETENTATE**

Potential additional treatment processes

Return to the sludge treatment stream 55

Filter washing water (retentate) is loaded with predominantly non-inactivated pathogens retained through physical sieving mechanisms. It can undergo further treatment suitable to its destination (disposal or recovery).

Alternative: membrane bioreactors = secondary biological treatment + secondary membrane treatment

This process enables secondary and tertiary treatment to be carried out at the same time.

INPUT PRODUCTS

PRIMARY WASTEWATER — **Primary treated wastewater: effluent that has undergone primary treatment**

PROCESS DESCRIPTION

As with activated sludge processes, free cultures of aerobic microorganisms in a bioreactor help to breakdown nitrogen and organic matter. However, instead of entering a clarifier, the effluent flows onto microfiltration or ultrafiltration membranes, which are either submerged inside the bioreactor or located outside the bioreactor unit. In addition to the second part of the secondary treatment process (clarification), tertiary treatment is also carried out via the membrane's surface filtration mechanism.

OUTPUT PRODUCTS

Tertiary treated wastewater, low in pathogens → **TERTIARY WASTEWATER**

Pathogens: The effluent has very low concentrations of pathogens, and protozoa, helminths and bacteria are significantly reduced (up to 6 to 7 log). A reduction in viruses of up to 5.8 log has been recorded, despite viruses sometimes being smaller than the cut-off threshold.[1]

Potential uses

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Use for urban spaces and in industry 91
Return to the water cycle 82

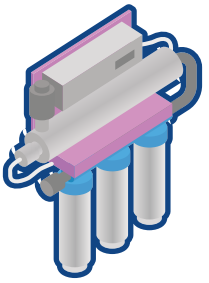
Sludge from filter/material washing → **RETENTATE**

Potential additional treatment processes

The sludge is loaded with slightly inactivated pathogens and requires additional treatment.[1]

Retour à la file boues 55

2.3.4 Ultra-violet (UV) treatment



INPUT PRODUCTS

SECONDARY WASTEWATER → **Secondary effluent,** which must have low turbidity

PROCESS DESCRIPTION

Lamps specially selected for their Ultra-Violet wavelengths are used to irradiate microorganisms. UV radiation has a powerful effect on bacteria, viruses and algae, directly eliminating microorganisms by altering their cellular metabolism, particularly their DNA and RNA chains.

These tube-shaped lamps are installed inside an irradiation chamber. The effluent flows over the lamps, which are separated from the water by silica or quartz sleeves.

UV radiation is measured in milliwatt seconds per square centimetre (mW.s/cm^2).

OUTPUT PRODUCTS

Tertiary treated wastewater (disinfected) → TERTIARY WASTEWATER

Pathogens: UV irradiation is particularly effective at killing bacteria and viruses; however, there are significant disparities in resistance between different strains.

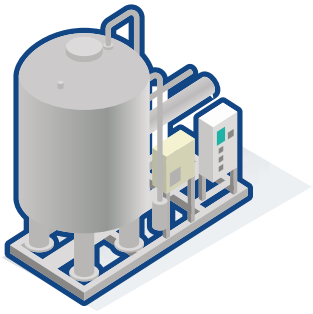
For bacteria, irradiation of between 5 and 25mW.s/cm² provides a 2 log reduction,[1] whereas irradiation of between 90 and 140mW.s/cm² can result in a 4 log reduction.[12] Viruses are more resistant, thus, for a 3 log reduction, irradiation of 100mW.s/cm² is required, and up to 180mW.s/cm² for the most resistant strains (adenovirus).[6] Helminths are resistant to UV radiation.[12]

Potential uses

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Use for urban spaces and in industry 91
Return to the water cycle 82

There are no by-products from this process.

2.3.5 Ozonation



INPUT PRODUCTS

SECONDARY WASTEWATER ← Secondary effluent

PROCESS DESCRIPTION

Ozone (O3) is an unstable and odorous gas usually produced industrially using an ozone generator. This process involves passing air or dry oxygen between two electrodes with high potential difference, often of around 15,000 volts.

OUTPUT PRODUCTS

Tertiary treated wastewater (disinfected) → TERTIARY WASTEWATER

Pathogens: The treated effluent can be considered sanitised, particularly with regard to bacteria. However, the removal of other pathogens depends on their initial concentrations in the effluent to be treated.

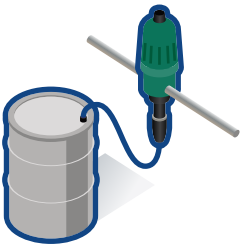
Reductions of 6 log for bacteria and viruses, 4 log for protozoa and 3 log for helminths have been recorded.[1]

Potential uses

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Use for urban spaces and in industry 91
Return to the water cycle 82

There are no by-products from this process.

2.3.6 Chlorination



INPUT PRODUCTS

SECONDARY WASTEWATER — Secondary effluent

PROCESS DESCRIPTION

Chlorine gas, chlorine dioxide and sodium hypochlorite are all chlorinated disinfectants used in water treatment.

Chlorine gas (Cl_2), when dissolved in water, produces hypochlorous acid, which acts as an oxidising agent and inhibits the growth of bacteria and protozoa by altering their cell membranes.

Chlorine dioxide (ClO_2), produced in situ from sodium chlorite and hydrochloric acid, is more selective and is effective against a wider range of pathogens, including spores, bacteria and viruses. It is also faster acting and requires less contact time.

Sodium hypochlorite (NaOCl), or bleach, is diluted in water to create a disinfectant solution. Although it can be kept in storage, it remains stable for a maximum of only two months. Sodium hypochlorite can be produced in situ through salt electrolysis, removing the need for transport and storage.

Calcium hypochlorite ($Ca(ClO)_2$) is a white solid available in various (70%) concentrated forms (powder, granules, tablets), which can be useful for minimising the risks associated with its use; it is toxic and an irritant.

OUTPUT PRODUCTS

Tertiary treated wastewater (disinfected) — TERTIARY WASTEWATER

Pathogens: Chlorination has been proven to kill all bacteria; however, the removal of other pathogens depends on their concentrations in the treated effluent. Chlorination levels must be adjusted in line with the required pathogen reduction and necessary contact time.

The reference values are as follows: 6/3/1.5-3/1 Log reductions for bacteria/viruses/protozoa and helminths respectively.[12]

Protozoan cysts, spores and certain viruses with more resistant outer envelopes are resistant to chlorine Cl2.[7] Chlorine dioxide is more effective than chlorine at killing bacteria and viruses, as well as spores and cysts. It is also fast-acting with a contact time that is 2 to 3 times shorter than chlorine.[8]

Oxidation reactions during the chlorination process can generate by-products. These include THMs (trihalomethanes) and TOX (total organic halogen), which are found in the treated effluent. Studies are being carried out to determine their toxic and epidemiological properties, as well as their impact on health. However, WHO considers that these by-products pose only a low risk to health compared to the risks of inadequate water disinfection.

Potential uses

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Use for urban spaces and in industry 91
Return to the water cycle 82

There are no by-products from this process.

Alternative: Advanced Oxidation Process (AOP)

The advanced oxidation process (AOP), which is still under development, involves a combination of mechanisms and processes, including chemical reactions, UV radiation and cavitation (the formation of vapour-filled cavities) in order to produce more reactive oxidants. Unlike traditional disinfection methods, AOP targets not only pathogens, but also pollutants and micropollutants.

3.

Output products from WWTP sewage sludge treatment processes and FSTP faecal sludge treatment

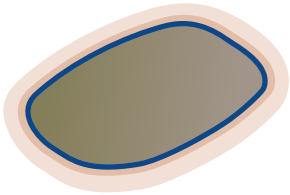
The treatment processes are used for:

1. Sewage sludge from wastewater treatment processes (covered in part 3). These treatment processes are carried out in wastewater treatment plants (WWTP).

2. Faecal sludge from access/containment segment facilities. These treatment processes are carried out in faecal sludge treatment plants (FSTP).

3.1 Primary treatment: separation of solids and liquids / thickening

3.1.1 Sedimentation/thickening pond



INPUT PRODUCTS

NON-PRETREATED FS — **Non-pretreated faecal sludge** (from on-site systems)

THICKENED PART-DIG FS — **Thickened, partially digested sludge** (from on-site systems)

BIOLOGICAL SS — **Secondary (biological) sludge** (from wastewater treatment processes such as activated sludge)

PROCESS DESCRIPTION

The sludge is thickened to make it more condensed and partially stable and to reduce its moisture content, thereby facilitating its dewatering and handling in the next stages of the treatment process. During this stage, the sludge is left to thicken for a period of between a week and one month. Two settling and thickening tanks are usually used, either alternately or in parallel.

OUTPUT PRODUCTS

Helminths, as well as some viruses and bacteria adsorbed to particles, become trapped in the thickened settled sludge, whereas non-adsorbed bacteria and viruses remain in the surface effluent.[1]

Condensed, thickened, non-sanitised sewage / faecal sludge — **CONDENSED FS/SS**

THICKENED, NON-SANITISED

DMC: The sludge remains liquid, having a dry matter content of less than 10%.

Composition: These processes are not primarily designed to inactivate pathogens.

There is only a slight reduction in microorganisms such as protozoan cysts (less than 1 log). WHO applies a value of 3 log for helminths, but this is highly dependent on the detention time.[1]

Potential additional treatment processes

Dewatering 56

Sanitisation 65

Wastewater from primary sewage and faecal sludge treatment processes

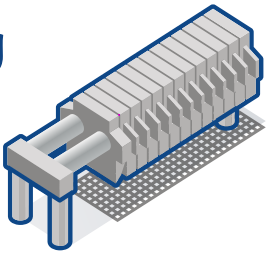
PRIMARY WASTEWATER

This primary treatment can remove around 50 to 60% of the TSS in this effluent.[13] The (supernatant) effluent that is discharged is heavily loaded with pathogens and requires subsequent treatment.

Potential additional treatment processes

WWTP or FSTP: secondary treatments 39

3.2 Secondary treatment: stabilisation and dewatering



3.2.1 Mechanical dewatering

INPUT PRODUCTS

CONDENSED FS/SS

THICKENED, NON-SANITISED

Non-sanitised, condensed, and thickened sewage/ faecal sludge
(from sedimentation tanks)

For WWTP, sewage sludge from activated sludge-type treatment and its variants should ideally be pre-thickened. As it is an energy-consuming process, mechanical dewatering is a less suitable option for treating sewage sludge from waste stabilisation ponds.

Mechanical dewatering can be used in FSTP that treat large quantities of faecal sludge. This sludge should ideally be pre-thickened.

PROCESS DESCRIPTION

This process involves separating the solids from the liquids in order to increase the dry matter content of the sludge. Different technologies can be used to achieve this:

Plate filter press: The thickened sludge is placed between two filter plates that are pressed together using hydraulic jacks to form dry cakes of sludge. The process is repeated in cycles.

Belt filter press: The sludge is compressed between two porous belts, which must be washed on a regular basis to prevent clogging.

Screw filter press: The screw turns inside a perforated cylinder to progressively compress the sludge, which exits the cylinder as a solid plug of dewatered sludge.

Centrifuge: The centrifugation process uses centrifugal force to rapidly rotate the liquid, pushing out the sludge.

OUTPUT PRODUCTS

Partially stabilised, dewatered sewage/ faecal sludge

DEWATERED PART-STAB FS/SS

DMC: A centrifuge produces dewatered sludge with a dry matter content of between 16 and 22%. This stands at between 14 and 18% for a belt filter press, between 30 and 35% for a plate filter press, and between 15 and 25% for a screw filter press.[9]

Composition: The dewatered sludge remains loaded with pathogens, as pathogen removal is not the aim of the mechanical dewatering process.[1]

Potential additional treatment processes

Sanitisation 65

Dewatering is useful for preparing the sludge for subsequent sanitisation treatment. It helps optimise sanitisation treatment by reducing the volume of sludge to be treated.

Wastewater from primary level sewage or faecal sludge treatment processes

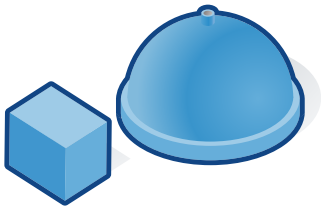
PRIMARY WASTEWATER

This wastewater remains loaded with pathogens and can be piped back into the wastewater treatment plant.

Potential additional treatment processes

Traitements secondaires 39

3.2.2 Anaerobic digester



INPUT PRODUCTS

NON-PRETREATED FS — **Non-pretreated faecal sludge** (from on-site systems)

THICKENED NON-SAN SS — **Sewage sludge: thickened, non-sanitised** (from WSP-type wastewater processes)

CONDENSED FS/SS — **Condensed, thickened, non-sanitised sewage/faecal sludge** (from sedimentation tanks)

THICKENED, NON-SANITISED

The sewage or faecal sludge must be 'fresh' and have high levels of VSS. Pretreated (partially digested) faecal sludge should not therefore be used for this process.

However, regardless of the type of sludge, this should ideally be thickened to ensure it has a dry matter content of between 40 and 50g/L.[10]

PROCESS DESCRIPTION

Anaerobic digestion takes place inside a reactor, or digester, in which microorganisms create the conditions required to facilitate anaerobic degradation (without oxygen), producing a digestate (a slurry rich in partially stabilised organic materials) and biogas (a water-saturated gas mixture).

Anaerobic digesters can be highly sophisticated, with mechanical mixers and a heating system to maintain the thermophilic temperatures required for long retention times (>50-55°C).

They can also be small in size with no mixing or external heating system, thus remaining at an ambient temperature and operating under mesophilic conditions (<50°C).[9]

There are two main types of digester in use:

- **Fixed dome digesters** in which the volume of the sludge inside the reactor remains constant. As gas is produced, it exerts a pressure that pushes the sludge upwards into an expansion chamber. When the gas is removed, the sludge flows back down into the reactor. This model, also known as a Chinese fixed dome plant, has been adopted by a number of Asian and African countries, including Nepal, India, Kenya, Nigeria, Uganda, Tanzania and Ghana.

- **Floating dome digesters** have a dome that rises and falls as the gas is produced and withdrawn. In some models, the dome can also expand, like a balloon. This type of digester is most commonly found in Thailand and India.

FOR MORE INFORMATION:

- Comprehensive Overview of Biogas for Sanitation Options – Training of Trainers, PM Umwelt-Projekt-Management GmbH (UPM), UPM (2021)
- La valorisation des déchets ménagers organiques et des boues de vidange de fosses septiques par digestion anaérobie, International Journal of Innovation and Scientific Research, Ukondalemba et al. (2016)
- La digestion des boues de station d'épuration : état de l'art et paramètres clés, INRAE, Falipou et al. (2020)

External anaerobic co-digestion

The sludge producer can install an anaerobic digester at the treatment plant to use the energy generated and/or sell it on to energy operators. Another option involves transporting the sludge to a third-party digester where it can be anaerobically co-digested with other waste. Anaerobic co-digestion can be useful as sewage sludge has lower methane potential than other organic substrates, such as food waste, vegetable waste and manure.[1]

OUTPUT PRODUCTS

Digested sewage/faecal sludge (digestate): dewatered, stabilised, partially sanitised

DIGESTED PART-SAN FS/SS

Digestate is biologically stabilised and partially sanitised; however, it remains loaded with pathogens, particularly if it has not undergone thermophilic treatment.

The reduction of microorganisms through anaerobic digestion depends on the sludge retention time and the temperature in the reactor: mesophilic (25 to 38°C) or thermophilic temperature conditions (40 to 55°C).[1]

Thermophilic conditions always result in a reduction in bacteria of over 3.5 log, and this can exceed 7 log within a relatively short retention time (of between 4 and 20 days).[11]

Under mesophilic conditions, a longer retention time is required (between 30 and 60 days) to achieve a 5 log reduction.[12]

Thermophilic conditions are also more effective at removing viruses (>3 log).[11]

However, neither mesophilic nor thermophilic anaerobic digestion are able to remove certain strains of (spore-forming) bacteria or protozoan cysts.[11]

For helminth eggs, average inactivation is 0.5 log.[21] [5]

Potential uses

During anaerobic digestion, mineralised nitrogen is largely converted to ammonium (40 to 70%), which is directly available to plants. Digestate has a greater agronomic value than fresh sludge as the nitrogen is more rapidly available to plants.[5] After having undergone additional sanitisation and stabilisation treatment, digestate can be used for agricultural soil amendment.

Potential additional treatment processes

If the digestate produced by the anaerobic digester is dewatered, then most of the nitrogen will be removed with the leachate and the digestate will thus contain less fertiliser (Gay, 2002).

Sludge digestion has the advantage of reducing the volume of sludge requiring further treatment.

Digestion can reduce the calorific value of sludge and make it less self-igniting.

Soil irrigation for agricultural use 76

Soil irrigation for non-agricultural use 78

Soil restoration 84

Sanitisation 65

BIOGAS

Biogas is predominantly a mix of methane (50 to 70%) and carbon dioxide (30 to 40%) and other trace gases, such as hydrogen sulphide (H2S).

Biogas can be converted to heat and electricity for use within the WWTP/FSTP, or it can be exported.

Potential additional treatment processes

Raw biogas has to undergo purification, with the type and extent of the treatment depending on the intended application of the cleaned biogas. This will commonly involve removing the hydrogen sulphide (H2S), as this gas is transformed into sulphur dioxide (SO2) during biogas combustion and can be corrosive. The purification process usually involves water condensation and desulphurisation.

Purification treatment

Potential uses

Use of the energy potential of the biogas for cooking, heating, producing electricity, etc. 85

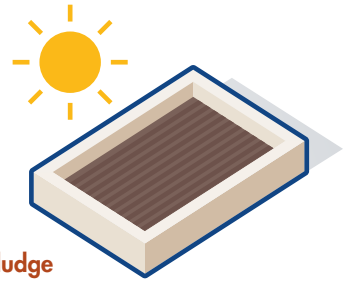
Alternative: Baffled Reactor (ABR)

Which contains chambers separated by baffles, under which the wastewater is forced to flow.

Alternative: Upflow Anaerobic Sludge Blanket Reactor (UASB)

In which wastewater enters the reactor from the bottom and flows up towards the top.

3.2.3 Drying beds



INPUT PRODUCTS

NON-PRETREATED FS — **Non-pretreated faecal sludge** (from on-site systems)

THICKENED PART-DIG FS — **Thickened, partially digested faecal sludge** (from on-site systems)

THICKENED NON-SAN SS — **Thickened, non-sanitised sewage sludge** (from WSP-type wastewater processes)

CONDENSED FS/SS — **Condensed, thickened, non-sanitised sewage/faecal sludge** (from sedimentation tanks)

THICKENED, NON-SANITISED

DEWATERED PART-STAB FS/SS — **Dewatered, partially stabilised sewage/ faecal sludge** (from a mechanical dewatering system)

DIGESTED PART-SAN FS/SS — **Digested sewage / faecal sludge: stabilised, partially sanitised** (from digesters)

The sewage or faecal sludge should ideally undergo primary (thickening or dewatering) treatment prior to being discharged into the drying beds in order to condense the sludge and reduce the drying bed's footprint.

This is less important for sludge from waste stabilisation ponds, which is already more condensed.

Drying beds can, however, be used for non-thickened sewage or faecal sludge, meaning that they can receive all types of sludge. However, the sludge still needs to be screened.

If lime treatment is required, this is usually carried out later.

PROCESS DESCRIPTION

There are three common types of drying bed.

Unplanted drying beds

Sludge is discharged onto a bed of sand covered with gravel, laid over watertight concrete or brick foundations. The sludge is removed once it has the desired solids content.

Covered solar drying beds

Naturally or mechanically ventilated drying beds are constructed in greenhouses, and the sludge in the beds is regularly turned over. As the greenhouse walls block UV light, they prevent disinfection, therefore dewatering, desiccation and higher temperatures are required. The greenhouse also prevents rain from getting in and wetting the sludge.

Planted drying beds

In addition to evaporation, the drying process is enhanced by evapotranspiration from plants. The plants' root systems provide good permeability for the sludge layer and an environment conducive to pollutant degradation by bacteria, thereby further decreasing the sludge volume. The beds are operated continuously rather than in batches, which means that sludge is constantly being poured onto the beds.

OUTPUT PRODUCTS

Dried, partially sanitised sewage / faecal sludge

DRIED PART-SAN FS/SS

DMC: The time required to increase the dry matter content and significantly reduce pathogens depends on the specific characteristics of the sludge, as well as on local climate conditions.[9] To achieve a dry matter content of around 15 to 30%, the retention time required is between 4 and 15 days in hot and arid climates, and between 15 and 30 days in temperate and humid climates.[9]

- Covered solar drying beds: Equivalent dry matter contents are achieved more quickly but with a smaller reduction in pathogens due to the lack of UV.
- Planted drying beds: The dry matter content of the sludge can vary between 25 and 55%, depending on the climate and the characteristics of the sludge entering the beds.[18] [19]

Pathogens: This type of treatment process is not specifically designed for pathogen removal.

There can be a partial inactivation of bacteria of up to 4 log [20], but this is usually less than 1 log, and bacteria can become active again if rehydrated.

Viruses can be reduced by up to 2 log.[20]

As they are sensitive to heat and desiccation, protozoa are removed. Detention times and temperatures have a marked influence on this: it will take between 1 and 6 months to totally eliminate protozoa at temperatures of between 5 and 20°C.

According to WHO, a detention time of 0.3 to 0.6 months is required for a 0.5 log reduction in helminth eggs.

Potential additional treatment and destinations

Additional sanitisation treatment may be required. However, this depends on the pathogen reduction levels achieved, which in turn depend on the sludge's detention time in the beds.

Drying helps raise the dry matter content and decrease the sludge volume, making it easier to transport the sludge for additional treatment (thermal drying, co-composting) or for landfill disposal or incineration.

Sanitisation 65

Incineration 67

Landfill disposal 93

Potential uses

If the sludge has undergone a lengthy drying process to help remove pathogens, it can be used directly for agricultural soil amendment.

Soil irrigation for agricultural use 76

Soil irrigation for non-agricultural use 78

Soil restoration 84

Wastewater from sewage or faecal sludge treatment processes (percolate) **WASTEWATER**

The effluent has undergone substantial treatment but remains loaded with pathogens.

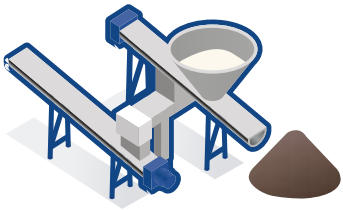
Physico-chemical parameters: Studies have revealed that this wastewater usually contains too many solids, and too much COD and nitrogen for discharge into a watercourse. Planted drying beds are more effective at reducing BOD and COD.[18] [19] [20]

Pathogens: There is a significant reduction in pathogens, particularly helminths and protozoa. However, outcomes are dependent on the bed and filter material design, the type of sludge entering the beds, and on the operating parameters.[9] [19] [20]

Potential additional treatment processes

Additional secondary treatments, or primary treatment if piped back into the treatment plant **39**

3.2.4 Lime stabilisation: alkaline treatment



INPUT PRODUCTS

NON-PRETREATED FS — **Non-pretreated faecal sludge** (from on-site systems)

THICKENED PART-DIG FS — **Thickened, partially digested faecal sludge** (from on-site systems)

THICKENED NON-SAN SS — **Thickened, non-sanitised sewage sludge** (from WSP-type wastewater processes)

CONDENSED FS/SS — **Condensed, thickened, non-sanitised sewage/faecal sludge** (from sedimentation tanks)

THICKENED, NON-SANITISED

DEWATERED PART-STAB FS/SS — **Dewatered, partially stabilised sewage/ faecal sludge** (from a mechanical dewatering system)

DIGESTED PART-SAN FS/SS — **Digested sewage / faecal sludge: stabilised, partially sanitised** (from digesters)

Sludge can either be raw or have undergone a thickening or dewatering treatment. All types of sludge can be treated with lime.

PROCESS DESCRIPTION

Adding lime to sludge increases the pH to 12, thereby inhibiting biological activity, eliminating pathogens and improving the viscosity and physical properties of the sludge.

In WWTP, lime stabilisation can be carried out after thickening and dewatering, or even beforehand to improve the effectiveness of the dewatering treatment. For thicker and drier sludge that has already been dewatered, grinders or mixers will be required to ensure the sludge and lime are properly combined.

For faecal sludge collected for treatment at a FSTP, the lime can be added directly into the vacuum truck. It can also be scattered over land onto which the sludge is to be spread.

OUTPUT PRODUCTS

Lime-stabilised sludge: stabilised and partially sanitised — LIME-STABILISED FS/SS

Composition: All bacteria are removed.

There is a 4 log to 6 log reduction in viruses, depending on the virus type.

Lime has little to no impact on helminth eggs.[9]

By causing an increase in temperature, quicklime can remove all pathogens, including protozoa and helminths; however, it can be dangerous to handle.

Lime-stabilised sludge has a high pH of more than 8.

Potential uses

Lime stabilisation helps to remove soluble heavy metals from the sludge, thereby reducing the amount of heavy metals that can come into contact with the soil and those available to plants.

Given its high pH, the sludge is best suited to acid soils and should not be used on soils that are already alkaline (pH of more than 7). In addition, it is usually richer in nitrogen than other types of sludge as some of the nitrogen is converted into ammoniac during treatment.[9]

Soil irrigation for agricultural use 76

Soil irrigation for non-agricultural use 78

Potential additional treatment processes

In order to ensure all pathogens are removed, lime stabilisation can be followed by another treatment to specifically eliminate helminths and protozoa, such as drying for non-dewatered sludge, and/or long-term storage for already dewatered sludge.

Sanitisation 65

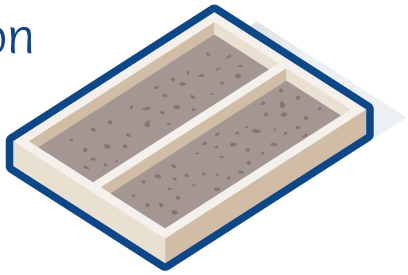
Leachate — WASTEWATER

Lime stabilisation releases significant amounts of liquid, so it is vital that measures are in place to collect and discharge this leachate.

Potential additional treatment processes

Secondary treatments 39

3.3 Additional sanitisation treatment



3.3.1 Long-term storage

INPUT PRODUCTS

DEWATERED PART-STAB FS/SS — Dewatered, partially stabilised sewage/ faecal sludge (from a mechanical dewatering system)

DRIED PART-SAN FS/SS — Partially sanitised, dried sewage/faecal sludge (from drying beds)

LIME-STABILISED FS/SS — Lime-stabilised sludge: stabilised and partially sanitised

Sludge should ideally have undergone primary dewatering in order to reduce the required footprint of the storage facilities. Ideally, digested sludge should also be subsequently dewatered.

It is not necessary to have either dried the sludge in beds or carried out lime stabilisation. Long-term storage is often used to further sanitise the sludge following these treatment processes in order to adapt sanitised sludge production to the time-bound requirements of the sludge recovery segment.

It is to be noted that the on-site long-term storage of sludge from double pit systems enables further sanitisation.

PROCESS DESCRIPTION

No fresh excrement should be added to the sludge during storage, and no water must be able to get in. A drainage system must be put in place to collect the leachate.

OUTPUT PRODUCTS

Dried, sanitised sewage / faecal sludge — **DRIED SAN FS/SS**

DMC: After storage, the sludge takes the form of compact, sometimes dry, solids, and has a dry matter content that often exceeds 85%.[1] It can also be partially or entirely sanitised and biologically stable.

Composition: The storage time required for a 6 log reduction in pathogens (bacteria, viruses, protozoa, helminths) depends on the climatic conditions:

- Ambient temperature of 2-20°C: the required storage time is between 1.5 to 2 years.
- Ambient temperatures of between 20 and 35°C: the required storage time is just one year.

However, some strains can start to grow again if they get wet. Viruses and protozoa are reduced to below risk levels, but some helminth eggs may prove more resistant.[12]

Potential uses

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78

Potential destinations

Incineration 67

3.3.2 Thermal drying

INPUT PRODUCTS

DEWATERED PART-STAB SS — **Dewatered, partially stabilised sewage** (from a mechanical dewatering system)

Sludge intended for incineration must be dry. However, there is no need for sanitisation treatment. As incineration requires sludge of reliable quality, this process is not best suited to faecal sludge.

PROCESS DESCRIPTION

The sludge is exposed to high temperatures of over 50°C in specially designed dryers.

OUTPUT PRODUCTS

Dried, sanitised sewage / faecal sludge — DRIED SAN FS/SS

DMC: The thermally dried sludge has a dry matter content of between 90 and 95.

Composition: All pathogens are removed as long as a constant temperature is maintained throughout the sludge for a sufficiently long time. For example: one hour at 60°C, one day at 50°C and one week at 45°C.[21]

Potential uses

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Soil restoration 84
Use of the sludge's energy potential (combustion) 85

Due to its high calorific value, the dried sludge can be used as a solid fuel.

3.3.3 Incineration

INPUT PRODUCTS

DRIED PART-SAN SS — Partially sanitised sludge (from drying beds)

A minimum dry matter content of between 60 and 80% is recommended for incineration[7], therefore the sludge needs to be dried. Incineration is therefore best suited to sludge from WWTP.

PROCESS DESCRIPTION

The sludge is burned, causing all interstitial water to be evaporated and destroying organic matter as it combusts in the presence of oxygen.

Sludge producers can install an incinerator at the treatment plant. Mono-incinerators have a high investment cost, are expensive to run and complex to operate. These disadvantages can potentially be offset by using the calorific power of the sludge to produce energy.

External co-incineration

Sanitation system operators can also transport the sludge to a third-party facility for co-incineration with other waste.

Incineration in a cement plant

Sewage sludge, particularly contaminated sludge, can be recovered for use as a fuel in cement manufacturing. The sludge intended for this co-incineration must have a high calorific value of between 10 to 12MJ/kg. Only sludge with a high dry matter content can be used.[26]

OUTPUT PRODUCTS

ASH

Although entirely pathogen-free after having been exposed to temperatures of over 80°C for at least one hour[21], the sludge can still contain toxic substances, such as heavy metals or their oxides.

Potential uses

The ash contains significant levels of potassium and phosphorus, making it a heath risk-free agricultural fertiliser and viable for use as a soil conditioner.

Due to its high porosity, ash can be used as a filter material in water treatment, removing pollutants from the water by adsorption.

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Soil restoration 84
Use of the end-product as a raw material 88

THERMAL ENERGY

Potential uses

Use of the energy potential of the sludge (combustion) 85

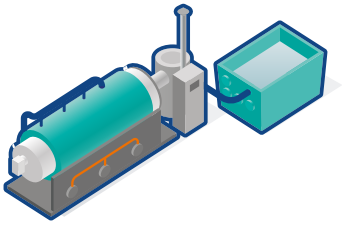
SMOKE

Smoke and fumes must be treated to reduce their environmental impact.

CEMENT

When incinerated in cement kilns, the sludge is incorporated into the end product.

3.3.4 Slow pyrolysis



INPUT PRODUCTS

DRIED PART-SAN FS/SS — **Partially sanitised, dried sewage/ faecal sludge** (from drying beds)

A minimum dry matter content of 60 to 80% is recommended; sewage or faecal sludge therefore needs to be dried.

PROCESS DESCRIPTION

Pyrolysis is a process that degrades an organic compound by heating it to high temperatures in a low-oxygen environment. Flash pyrolysis (carried out at temperatures of between 500°C and 650°C) maximises gas production and minimises the production of biochar (the characteristics of this output are provided below). When temperatures reach 900°C to 1,000°C, this is known as gasification, which produces synthesis gas that contains mainly CO (carbon) and H_2 (hydrogen) and a small proportion of methane.

Slow pyrolysis takes place in an oxygen-free environment at a temperature of at least 200°C over a residence time that is measured in hours. The balance of DMC and temperature enables the system to be potentially energy self-sufficient. Pyrolysis at low temperatures generates greater quantities of biochar, which is a solid, porous and highly sanitised carbon-rich material. The ideal heating temperature to optimise the output and intrinsic energy of the biochar produced is around 300°C.

FOR MORE INFORMATION:

- To char or not to char? Review of technologies to produce solid fuels for resource recovery from faecal sludge, Journal of Water, Sanitation and Hygiene for Development, Andriessen et al. (2019)
- Faecal matter–saw dust composite briquette and pellet fuels: production and characteristics, WEDC Conference Proceedings, Nyaanga et al. (2018)

OUTPUT PRODUCTS

BIOCHAR

The biochar produced is a highly porous and sanitised material.[9]

Potential uses

Biochar is not a fertilizer, but it facilitates and accelerates subsurface chemical reactions. This results in increased activity of microorganisms and nitrogen-fixing bacteria and, consequently, improved soil fertility

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Soil restoration 84
Use of the end-product as a raw material 88

OILY LIQUID

The liquid component is a mix of hydrocarbons and water. The oil from the pyrolysis process can potentially be used as fuel in industrial boilers, replacing petroleum-based fuels, for example.

Potential uses

Use of the energy potential of the sludge (combustion) 85

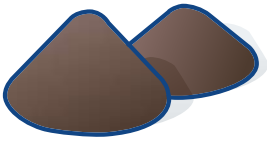
BIOGAS

The gas and liquids can be used to maintain the reactor heating temperature and dry the pyrolysis raw material, thereby ensuring a positive energy balance.

Potential uses

Use of the energy potential of the sludge (combustion) 85

3.3.5 Co-composting



INPUT PRODUCTS

- **DRIED PART-SAN FS** — **Partially sanitised, dried sewage/faecal sludge** (from on-site double pit systems enabling long-term storage, with or without urine diversion)
- **DIGESTED PART-SAN FS/SS** — **Digested sewage / faecal sludge: stabilised, partially sanitised** (from digesters)
- **DEWATERED STAB FS/SS** — **Dewatered, partially stabilised sewage/ faecal sludge** (from a mechanical dewatering system)
- **DRIED PART-SAN FS/SS** — **Partially sanitised, dried sewage/faecal sludge** (from drying beds)

As a minimum, sewage and faecal sludge must be dewatered or dried in the WWTP or FSTP. However, prior lime stabilisation treatment is unnecessary.

Digested sludge should also ideally be dewatered/dried.

It is to be noted that the on-site co-composting of dried sludge from double pit systems enables further sanitisation.

PROCESS DESCRIPTION

Composting is an aerobic fermentation treatment process (in the presence of oxygen). Organic matter is placed in piles (in the open air, and formed into windrows) and left to rest while biological processes raise the temperature inside the piles, thereby removing pathogens. The piles need to be turned on a regular basis to maintain their aerobic conditions.

The composition of the sludge (which contains too much water and too low a ratio of carbon to nitrogen) means that it cannot be composted on its own. **It has to be mixed in with green waste or with household or industrial bio-waste**. Fibrous carbon materials with low moisture content, such as cereal straw, cotton waste, wood shavings, leaves, fruit pods or sawdust can also be used.

FOR MORE INFORMATION:

- Co-composting of Solid Waste and Fecal Sludge for Nutrient and Organic Matter Recovery, International Water Management Institute (IWMI), Cofie et al. (2016)
- Guide de traitement et de valorisation agricole – Boues issues des dispositifs d'épuration en milieu rural marocain, Programme AGIRE – Ministère de l'Équipement et de l'Eau (Maroc), Khiyati (2019)

External co-composting

It can be difficult for a WWTP or FSTP operator to manage co-composting on-site. The operator considers composting to be a form of **disposal**. The **composting facility** operator will therefore oversee composting use and recovery.

OUTPUT PRODUCTS

COMPOST

Composition: Composting can result in up to a 7 log reduction in the four types of pathogen: bacteria, viruses, protozoa and helminths. The output is therefore a sanitised and stabilised compost.

However, these pathogen reductions can only be achieved under strict and controlled conditions. The compost must have a carbon to nitrogen content ratio (C/N ratio) of between 25 and 30, a water content of over 50%, oxygen content of above 5%, and a pH of between 6.5 and 8, and this must be consistent throughout the compost. Temperature is a key parameter. WHO recommends consistent temperatures of between 55°-60°C throughout the compost for one month, followed by a 2 to 4 month maturation period.

If these conditions are not met, the quality of the compost cannot be guaranteed. Therefore, if the technical capacities are not in place to ensure these conditions, composting may be less effective.[13]

Potential uses

Le compost peut être valorisé en tant qu'amendement organique améliorant la structure et la fertilité des sols. C'est sa propriété de conditionneur de sol qui est particulièrement intéressante. Tous les éléments nutritifs du compost ne sont pas immédiatement disponibles pour la plante la première année d'application, ainsi ses propriétés fertilisantes sont moins intéressantes.[14]

Soil irrigation for agricultural use 76
Soil irrigation for non-agricultural use 78
Soil restoration 84

Leachate **WASTEWATER**

Extremely rich in nitrogen, with concentrations similar to urine, this effluent is also loaded with pathogens.

Potential treatment processes and destination

Secondary treatment 39

Alternative: Vermicomposting

Adding earthworms to the organic matter to be treated speeds up the composting process, but makes it impossible to achieve high temperatures, as these would kill off the worms.

It is also possible to use black soldier fly larvae, Hermetia illucens, instead of worms.[25]

OUTPUT PRODUCTS

LARVAE, WORMS

In addition to compost, the worms and larvae can be recovered as they both have nutritional value.

Potential uses

Use of the water and end products for livestock breeding or aquaculture 89

FOR MORE INFORMATION:

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[5] - D. Mara, The design of Pour-Flush-Latrine, PNUD IRBD / The World Bank, 1985.

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4.

Potential uses of sanitation system output products

This section describes the potential uses of sanitation products broken down into different categories.

The situation in Mediterranean countries with regard to these uses is also provided, and is further detailed in **chapter 3**.

The **challenges associated with each of these uses** are outlined.

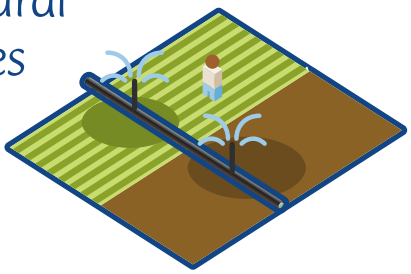
They need to be considered to assess the risks, benefits, relevance and viability of each potential use of a specific output product category.

These challenges, further developed in **chapter 2**, are as follows:

- **Challenge 1:** Positive and negative environmental impacts
- **Challenge 2:** Health risks
- **Challenge 3:** Organisational and financial models
- **Challenge 4:** Impacts and inclusion of sociological aspects

Challenges 1 and 2 apply to some of the uses to varying extents. Challenges 3 and 4 apply to all uses.

4.1 Irrigation and soil amendment for agricultural and non-agricultural uses



4.1.1 Irrigation for agricultural use

REUSED OUTPUT PRODUCT

SECONDARY TO TERTIARY WASTEWATER — Secondary to tertiary treated wastewater

Potential uses

Farming activities (edible and non-edible crops) — FARMING ACTIVITIES

Family vegetable gardens — FAMILY GARDENING

With climate change affecting water resource availability, wastewater reuse is increasingly being employed as a strategy for developing 'new' water resources.

Treated wastewater reuse can also be informal and unregulated, and be carried out using water of all types of quality.

CHALLENGES

Health risk

Chapter 2 : Challenge 2 129

Depending on the treatment processes used and the types of pathogen considered, pathogen levels will have been more or less significantly reduced after secondary and tertiary treatment. Some people may be exposed to the health risks posed by the presence of any remaining pathogens, particularly farm workers and consumers.

For agricultural uses, regulations generally impose pathogen thresholds in treated wastewater corresponding to tertiary treatment levels. However, certain use conditions (irrigation methods, crop selection, etc.) can reduce exposure to pathogens, making it possible to consider using secondary-treated wastewater. Furthermore, the use of secondary-treated wastewater for agricultural irrigation is practiced informally in many regions of the world. The issue of health risk is developed in chapter 2.

→ Positive and negative environmental impacts

Chapter 2 : Challenge 1 110

Treated wastewater reuse for agricultural irrigation can be incorporated into a strategy to develop new water resources.

The nutrients contained in treated wastewater, such as nitrogen, phosphorus and potassium, provide a valuable opportunity for enriching the soil with the nutrients essential for plant growth. If not removed through pathogen-reducing treatment processes, treated wastewater also has fertilising properties, further making it suitable for agricultural irrigation.

Mediterranean Focus

This use could be critical for countries in the Mediterranean basin, who are suffering from increasing water stress and where agriculture is placing severe pressure on water resources. In Tunisia, they have been using wastewater for irrigation for several decades; however, this practice is not yet widespread in Morocco.[A][B] Lebanon has recently started to look into this type of reuse. In Palestine, treated wastewater reuse is also a geopolitical issue as the country's occupation means access to water resources is restricted.

Informal wastewater reuse practices are usually found in areas without fully functional sanitation systems, such as Lebanon, where primary wastewater is used.[C] They are also common in areas that lack sufficient conventional water resources, such as certain regions of Tunisia and Morocco. The environmental, economic and social benefits need to be weighed against the health risk, which cannot always be managed.

The challenges associated with using treated wastewater for agricultural irrigation are detailed in chapter 2.

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B. « Élaboration du Plan Directeur National de Réutilisation des Eaux Usées Traitées en Tunisie – Phase 2 : Prospective de la filière à l'horizon 2050,» Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche, 2022.

C. K. Eid-Sabbagh, S. Roukoz, M.-H. Nassif, N. Velpuri et J. Mateo-Sagasta, «Analysis of Water Reuse Potential for Irrigation in Lebanon,» International Water Management Institute (IWMI), 2022.

4.1.2 Irrigation for non-agricultural use

REUSED OUTPUT PRODUCT

SECONDARY TO TERTIARY WASTEWATER — Secondary to tertiary treated wastewater

Potential uses

Irrigation of public green spaces (gardens, parks) → PUBLIC GREEN SPACES

Treated wastewater can be used for the irrigation of green spaces to reserve drinking water for domestic use.

Irrigation of privately-owned commercial green spaces (hotel grounds, golf courses) → PRIVATE GREEN SPACES

This application can lead to the development of new infrastructure, which can have considerable economic benefits. However, the environmental impact needs to be considered in cases where this wastewater is used in addition to, rather than in place of, other water resources.

Irrigation of residential green spaces → RESIDENTIAL GREEN SPACES

Wastewater from on-site treatment systems can be used for watering, as long as there is no direct human exposure to the treated wastewater.

CHALLENGES

→ **Health risk** Chapter 2 : Challenge 2 129

Depending on the treatment processes used and the types of pathogen considered, pathogen levels will have been more or less significantly reduced after secondary and tertiary treatment.

Although the plants irrigated with wastewater are not ingested (non-agricultural use), different types of people may be exposed to health risks when using the wastewater. The risk of these people coming into contact with pathogens in the treated wastewater can be reduced by identifying both the people at risk and the contamination pathways, and by adapting the irrigation methods used.

→ **Positive and negative environmental impacts** Chapter 2 : Challenge 1 110

The non-agricultural use of treated wastewater can be used as a strategy to develop alternative water resources.

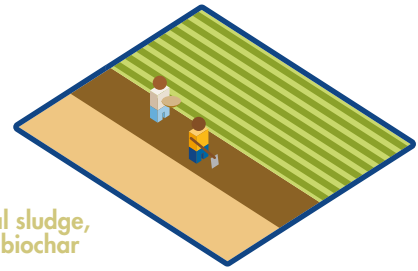
To ensure it is safe for the soil and plants, the quality of the treated wastewater must be assessed, along with the needs and characteristics of the crops irrigated and the properties of the soil. It is also important to determine the hydrogeological characteristics of the soil, the presence of other water resources and potential wastewater runoff or infiltration.

Mediterranean Focus

In Morocco and Tunisia, it is now systematic and compulsory to use treated wastewater to irrigate public green spaces. The irrigation of privately-owned commercial green spaces (hotel grounds, golf courses) is also common and is becoming more widespread. The benefit of this type of irrigation is that, in principle, the users are able and willing to pay for this resource, which can help build financial stability. However, the use of treated wastewater for this type of green space remains limited to certain tourist areas.

The challenges associated with using treated wastewater for non-agricultural irrigation are detailed in chapter 2.

4.1.3 Soil amendment for agricultural and non-agricultural use



REUSED OUTPUT PRODUCT

COMPOST, ASH, BIOCHAR FS/SS

Sewage/faecal sludge, compost, ash, biochar

Treated sewage/faecal sludge has properties that help fertilise and structure the soil. The digestate contains a higher ammonium nitrogen fraction that is directly available to plants.[1] Depending on the sanitisation treatment used, the sludge could still contain pathogens. Furthermore, any metals present in the raw water will be concentrated in the sludge.

Compost has properties that can help improve the structure of the soil. However, it is less effective as a fertiliser. If the composting process has been properly managed, the resulting compost can be considered pathogen-free; however, this can be difficult to achieve, particularly for small treatment systems and on-site facilities.

Biochar: The pores and large surface area of biochar create an environment conducive to the development of microorganisms useful to the soil, thereby helping to fix essential minerals and improving soil quality. Its high carbon content facilitates soil carbon sequestration. The application of 15 tonnes/ha of biochar can improve agricultural yields by 25%.[2] Due to the carbonisation process, biochar is bacteria-free.

Ash: Incinerated sludge ash contains significant amounts of potassium and phosphate. The ash is also highly alkaline and can be used as an amendment for acid soils. Any heavy metals present in the raw water will also be present in the ash.

Potential uses

Soil amendment for farming activities, edible and non-edible crops — FARMING ACTIVITIES

Soil amendment for family vegetable gardens — FAMILY GARDENING

The organic matter resulting from sludge treatment can be used as organic amendments to fertilise farmland. This can provide a valuable resource, particularly in regions with depleted soils or where chemical fertilisers are expensive.

One of the following sewage sludge treatment methods needs to have been used before surface application to farmland[3]:

- Aerobic digestion for 40 days at 20°C or 60 days at 15°C;
- Anaerobic digestion for 15 days at between 35 and 55°C or 60 days at 20°C;
- Air drying for at least three months. Two of these months must have average daily temperatures of above freezing;
- Composting or co-composting at temperatures of over 40°C for five days. The temperature of all the organic matter being composted must exceed 55-65°C for at least four hours over the course of the five days;
- Lime stabilisation to raise the pH to above 12 for 30 minutes, or to raise the pH to above 9 for over six months if the temperature is higher than 35°C and/or humidity is less than 25%.

As it is totally sanitised, compost can be used on a range of crops, whether for human consumption or not, and can help to maintain and restore soil fertility. It can also be used on high value-added crops, such as vetiver, which is often used in the perfume industry.

Irrigation of public green spaces (gardens, parks) — PUBLIC GREEN SPACES

Sludge treatment output products can also be used on public green spaces, such as gardens and parks.

Compost can be used to maintain soil quality and promote plant growth in public gardens and parks. It can be used in place of chemical fertilisers, which helps reduce environmental impacts. When used for urban landscaping projects, compost can help improve the sustainable management of green spaces, while also forming part of organic waste recycling policy.

Irrigation of privately-owned commercial green spaces (hotel grounds, golf courses) — PRIVATE GREEN SPACES

Hotel grounds, golf courses and other private commercial amenities can also benefit from using sludge treatment output products. These green spaces often require intensive care and maintenance to keep the lawns and grounds in good condition. Natural fertilisers from treated wastewater can provide a cost-effective and environmentally-friendly means of meeting these groundskeeping requirements. Most commonly used in tourist areas, they can also provide a targeted marketing opportunity.

Soil amendment for forestry — FORESTRY

Compost promotes tree growth, the wood from which can then be used for heating, construction, or paper pulp production, for example.

Home soil amendment (non-agricultural) **HOME SOIL AMENDMENT**

On a more individual scale, the owners of private gardens can also use these output products for the upkeep of their green spaces. Compost can be used on lawns and vegetable gardens and is a practical and environmentally-friendly domestic soil amendment option.

CHALLENGES

→ **Health risk** Chapter 2 : Challenge 2 129

Depending on the treatment process used, sewage and faecal sludge may still contain pathogens.

→ **Positive and negative environmental impacts** Chapter 2 : Challenge 1 110

The relevance of adding sewage/faecal sludge and their treatment output products to the soil must be assessed based on the soil's characteristics, as well as on the crop requirements when intended for agricultural use. In addition, sewage and faecal sludge treatment output products can be used to replace chemical fertilisers, which can have both environmental and economic benefits.

Any metals in the treatment system input products tend to be concentrated in the treated sludge. This is particularly the case for sludge treated in urban WWTP that collect industrial as well as domestic effluent. This can pose a risk to both health and the environment.

Mediterranean Focus

Sludge application would be hugely beneficial in arid areas of Mediterranean countries, where the soil is often poor in organic matter. Studies have shown that it significantly improves crop yields by increasing the soil's organic matter and providing a sustainable source of nutrients.[D]

The challenges associated with using sewage sludge/faecal sludge/compost to improve soil for agricultural and non-agricultural use are detailed in chapter 2.

REUSED OUTPUT PRODUCT

URINE AFTER STORAGE

Potential uses

Soil amendment for family vegetable gardens **FAMILY GARDENING**

D. B. Soudi, «Amélioration des connaissances sur l'utilisation saine et sécurisée des eaux usées traitées pour le développement du secteur agricole dans les pays du Maghreb – Rapport Maroc,» FAO, 2020.

Urine is an effective fertiliser for crops lacking in nitrogen and can be used on vegetable crops.[4] WHO provides the following recommendations:

- For crops eaten raw: the urine must be stored for at least 6 months at >20°C followed by a one-month suspension period (no other control measures should be necessary if these guidelines are followed);
- For processed food and feed crops: the urine must be stored for at least 1 month at >20°C, or for at least 6 months at 4°C.

CHALLENGES

→ Health risk

Chapter 2 : Challenge 2 129

4.2 Returning water flows and materials to the water cycle and the soil

4.2.1 Return to the water cycle

RECOVERED OUTPUT PRODUCT

SECONDARY TO TERTIARY WASTEWATER — Secondary to tertiary treated wastewater

Potential uses

Low-water flow support for surface water resources — LOW WATER FLOW

Downstream (non)human uses — DOWNSTREAM USES

Returning treated wastewater to the environment, without direct human reuse can be a viable 'recovery' option. The wastewater put back into the water cycle is not lost and will benefit human and non-human users downstream (except where the water flows into the sea).

Discharging treated wastewater into a river or watercourse can help with maintaining their low-water flow. This can be necessary if maintaining this low-flow rate is at risk from natural (variable rainfall, droughts) or human factors (high volumes of water abstracted for drinking water or other uses).

Downstream reuse for human activities is sometimes referred to as 'indirect reuse'.

To expand on this, the concept of ecological recovery covers all types of reuse designed to maintain the health of ecosystems that would otherwise not be preserved. Thus, treated wastewater can be used to feed wetlands, for example. These wetlands play a key water conservation role as they regulate evapotranspiration and, in some cases, also recharge aquifers.

CHALLENGES

→ **Positive and negative environmental impacts** Chapter 2 : Challenge 1 **110**

Mediterranean Focus

In Morocco and other Mediterranean countries, guidance documents recommend prioritising the indirect reuse of treated wastewater wherever possible. This involves completing the water cycle and returning treated wastewater to the natural environment before considering its use for other purposes, particularly agriculture.[E]

In Tunisia, to preserve biodiversity in wetlands, the treated wastewater from some WWTP is discharged into sebkha and lagoons suffering from water shortages. Thus, the Korba and Bizerte lagoons receive treated wastewater in summer to prevent them drying up.[F]

The challenges associated with returning treated wastewater to the water cycle are detailed in chapter 2.

REUSED OUTPUT PRODUCT

TERTIARY WASTEWATER Tertiary treated wastewater

Potential uses

GROUNDWATER RECHARGE

Artificial aquifer recharge is an essential practice in regions where groundwater abstraction rates exceed natural recharge. It can help prevent salt water intrusion in coastal aquifers and supplement groundwater base flows to improve the health of ecosystems.

The downstream reuse for human activities is sometimes referred to as 'indirect reuse'.

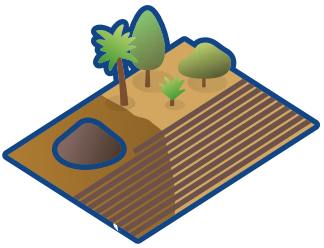
CHALLENGES

→ **Health risk** Chapter 2 : Challenge 2 **129**

E. B. Soudi, «Amélioration des connaissances sur l'utilisation saine et sécurisée des eaux usées traitées pour le développement du secteur agricole dans les pays du Maghreb – Rapport Maroc,» FAO, 2020.

F. « Réutilisation des eaux usées traitées en agriculture : analyse de l'état des lieux et perspectives – cas de la Tunisie » FAO ; Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche Maritime (Tunisie), 2021.

4.2.2 Soil restoration



RECOVERED OUTPUT PRODUCT

COMPOST, ASH, BIOCHAR FS/SS — Sewage/faecal sludge, compost, ash, biochar

Returning organic matter to the environment without direct human use can be a viable 'recovery' option.

Potential uses

Rehabilitation of mining or industrial areas, restoration of soil damaged by intensive farming → **RESTORATION OF SOIL**

Treated sewage and faecal sludge is rich in nutrients that are useful to plants, and can also improve the structure of the soil.

These properties are often used to restore sites damaged by human activity (mines, intensive farming), specifically by improving the infiltration capacity of the soil.

Compost is particularly well-suited to rehabilitating mining or industrial areas, as well as soil degraded by intensive farming.[5]

CHALLENGES

→ **Positive and negative environmental impacts** Chapter 2 : Challenge 1 110

Mediterranean Focus

The organic matter contained in treated sludge could be highly beneficial for restoring soil fertility in the arid and semi-arid areas of Morocco and help tackle desertification.[G]

The challenges associated with returning treated sewage and faecal sludge and compost to the soil are detailed in chapter 2.

G. B. Soudi et W. El Khoumsi, «Valorisation agricole des boues d'épuration dans les pays du Maghreb : potentialités et défis Gestion et valorisation agricole des boues d'épuration au Maroc- Rapport national – Maroc,» FAO, 2024.

4.3 Use of the output products' energy potential

4.3.1 Use of biogas for domestic, public utility or industrial activities

RECOVERED OUTPUT PRODUCT

BIOGAS

As a fuel, biogas can have several domestic uses as it provides an alternative to wood and coal. As an illustration of its energy potential, one cubic metre ($1m^3$) of biogas composed of 60% methane (CH4) equates to: 0.5 litres of diesel, 1.39 kilogrammes of coal, 4.34 kilogrammes of dry wood, 0.42 kilogrammes of butane, and 2 kilowatt-hours (kWh) of electricity.[6]

Potential uses

DOMESTIC ACTIVITIES

Biogas has a range of possible domestic applications, including cooking (stoves, bread ovens), and powering refrigerators, lamps, water heaters and motors.

Cooking makes the most effective domestic use of biogas.

The amount of biogas required for cooking varies from 30 to 45 cubic metres per month on average.

All appliances that run on butane can be converted to run on biogas with just a few adjustments (enlarging the diameter of the nozzle, reducing primary air inlets, ensuring protection from the wind).

Treatment plant energy requirements

TREATMENT PLANT ENERGY

Biogas can be used to produce heat and electricity.

Cogeneration, which combines the production of heat and electricity using gas-powered motors or gas turbines is more effective than just electricity production as, on its own, this has low outputs.

The heat and power produced can be used to meet the treatment plant's energy needs.

They could be used for the digester (heating to thermophilic temperatures where required, power to operate the stirrers), or to run other energy-consuming treatment facilities (dewatering, aeration, etc.).

LOCAL PUBLIC UTILITIES

Local utility services could also be provided with heat and electricity.

The electricity produced through cogeneration can be fed into a public network.

Biogas can also be fed into a public network. However, the biogas must first be desulphurised and all moisture removed to ensure safe and uninterrupted network operation. It then has to go through a purification process to

be transformed into bio-methane, which should have a similar composition to natural gas with a methane content of over 97%.

CHALLENGES

→ **Positive and negative environmental impacts** Chapter 2 : Challenge 1 110

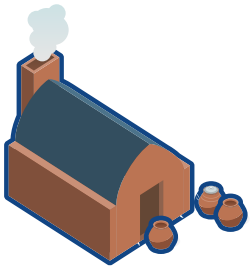
Mediterranean Focus

Household digesters are common in both China and India, but rare in Mediterranean countries. Digesters have been piloted in rural areas of Morocco as part of a GIZ-supported programme. However, their sustainability remains a challenge.[H]

There is very little WWTP-level energy recovery in Mediterranean countries. Projects are currently underway in Tunisia, although some WWTP that already have digesters are experiencing technical difficulties. There are a few WWTP using this recovery method in Morocco. In Fes, methane capture from sludge digestion (nearly 15,000m^3/d of methane) linked to the cogeneration of electrical energy from biogas produces around 22 million kWh/year of electricity, which is enough to cover 50% of the treatment plant's electricity needs.[I]

The challenges associated with energy recovery from sewage sludge are detailed in chapter 2.

4.3.2 Combustion of sanitation output products



Once sludge is dried, its thermal conductivity is significantly reduced.[8] Sludge from drying beds and on-site facilities may contain sand particles picked up during the sludge removal process.[9] Thus, the dried sludge and dried faecal matter does not make good fuel.

H. P. Guillibert et M. Elghali Khiyati, «Guide d'assainissement durable en milieu rural marocain - Catalogue des techniques et outils d'aide à la décision,» GIZ, 2020.

I. B. Soudi et W. El Khoumsi, «Valorisation agricole des boues d'épuration dans les pays du Maghreb : potentialités et défis Gestion et valorisation agricole des boues d'épuration au Maroc, Rapport national – Maroc,» FAO, 2024.

RECOVERED OUTPUT PRODUCT

BIOCHAR

Potential uses

DOMESTIC ACTIVITIES

Craft or industrial activities

CRAFTS OR INDUSTRY

Due to its high carbon content, biochar has a calorific value of 17 to 25 MJ/kg, which is equivalent to coal, and this makes it useful as a source of fuel. This only applies when the moisture content of the biochar briquettes is less than 14%.[10]

The optimum heating temperature to maximise the output and intrinsic energy of biochar is around 300°C. However, the higher calorific power of biochar produced from excrement has been found to diminish as the heating temperature in the pyrolysis reactor rises, which has a negative impact on its potential as a solid fuel.[11]

Biochar can be used as fuel in the form of briquettes. This eliminates the need to use other, less sustainable fuel sources.

A study conducted with 199 households in the Kibera informal settlement in Nairobi revealed that the people producing coal briquettes for domestic use save 70% of the money spent on energy for cooking.[10]

PLANTS: MACROPHYTES, REEDS

Potential uses

DOMESTIC ACTIVITIES

Craft or industrial activities

CRAFTS OR INDUSTRY

Plants can be used as fuel, either on their own or in combination with firewood.

The use of plants as fuel is mostly informal and practiced by households. Thus, there is very little data on local experiences.

The reuse of macrophytes to produce biofuels is still in the experimental stage. Macrophyte tissues are 90% water, which complicates their transformation into fuel.[13]

A study has revealed that certain plants (phragmites spp., Typha spp., A. donax and C. papyrus) can achieve direct combustion energy efficiencies of an average of 18 MJ/kg of dry mass, and can reduce the cooking fuel needs of a village of 200 people by 55%.[12]

CHALLENGES

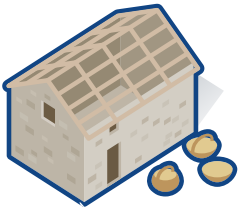
→ **Positive and negative environmental impacts** Chapter 2 : Challenge 1 110

Mediterranean Focus

These uses are not yet widely practiced in Mediterranean countries.

4.4 Use of water and end-products for craft and industrial activities

4.4.1 Use of end-products as a raw material



RECOVERED OUTPUT PRODUCT

BIOCHAR, CENDRES

Potential uses

Local craft or industrial activities: construction material

CRAFTS OR INDUSTRY

Biochar can be used to replace fine aggregates in concrete.

Sludge ash can be used in place of clay to make bricks.[14] Sludge ash that has been incinerated in cement kilns can be used in cement manufacturing, with the sludge being incorporated into the end product. The accumulated organic matter, including heavy metals, contained in the ash are fixed in the clinker. Incorporating sludge ash into the cement manufacturing process can help reduce the costs associated with the traditional raw materials used, and stabilises the polluting heavy metals contained in the ash.[11]

Mediterranean Focus

There is very little information available on the use of biochar as a construction material.

At the Marrakech WWTP in Morocco, dried sludge is recovered for use in the cement manufacturing process: 50 t/day of dried sludge is used to replace 18 t/day of pet coke in the cooking line of the clinker by adding 15 t/day of mineral matter to the clinker ingredients.[J]

J. B. Soudi et W. El Khoumsi, «Valorisation agricole des boues d'épuration dans les pays du Maghreb : potentialités et défis Gestion et valorisation agricole des boues d'épuration au Maroc ? Rapport national – Maroc,» FAO, 2024.

CHALLENGES

Positive and negative environmental impacts Chapter 2 : Challenge 1 110

PLANTS

Potential uses

Craft activities (often informal) CRAFT

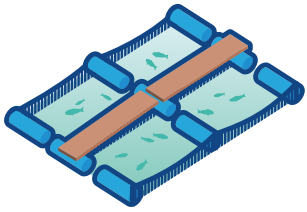
Macrophytes and reeds can be used to make household furniture, such as chairs and mats, and can be used as building materials. These uses are mostly informal and are not structured into economic sectors or public services. As an example of this, there is a market in the wetlands of the Yala swamp in Kenya, where papyrus is transformed into mats, seats, baskets and building materials.[15]

Reed biomass is a source of cellulose and hemicellulose. The cellulose content of reed, which ranges from 33% to 59% depending on environmental factors, can be used to make reed paper. This practice is found in China and India.[16]

Mediterranean Focus

Examples of these uses are rare in Mediterranean countries, where the practice is yet to be developed.

4.4.2 Use of end-products for animal feed



RECOVERED OUTPUT PRODUCT

WORMS, LARVAE, FLIES

MACROPHYTES

DUCKWEED

Potential uses

Livestock breeding (use of end-products for animal feed) LIVESTOCK BREEDING

Worms have a very high nutritional value. They are typically composed of 60 to 70% protein, 7 to 10% fat, 8 to 20% carbohydrate, around 2 to 3% minerals, and also contain vitamins A and B, as well as 8 to 9 essential amino acids. Thus, they are often used as an ingredient in fish and animal feed.[17]

Larvae have a high protein content of between 42 and 45% and also contain fat, the amounts of which can vary from between 10 and 40% depending on the substrate used. Therefore, larvae can also be used in animal feed, particularly as food for poultry, pigs and fish.[17]

Macrophytes that are high in protein can be used, either fresh or dried, as feed for fish or poultry [18]. Duckweed can be used as feed for certain herbivorous fish. However, these applications are rare and there is very little information available on their use.[19]

There are health risks associated with these uses.

As there is very little information on these uses, which are poorly regulated by international standards and national legislation, **they will not be covered in more detail in chapter 2**.

Fish farming in ponds that receive effluent or sludge, where the fish can feed on the plants growing in the ponds, is discussed below.

Mediterranean Focus

These uses are not practiced in Mediterranean countries.

CHALLENGES

→ **Health risk** Chapter 2 : Challenge 2 **129**

SECONDARY TO TERTIARY WASTEWATER

Secondary to tertiary treated wastewater

Potential uses

Aquaculture (use of water in fishponds) AQUACULTURE

Fish can be reared in ponds containing effluent or sludge, where they feed on algae and other organisms that thrive in the nutrient-rich water. Thus, the fish remove nutrients from the wastewater.

It is also possible to fertilise fishponds with effluent or faecal sludge. The fish are reared directly in aerobic ponds. There is currently a wide variety of waste-fed aquaculture practices that involve sludge, fish and aquatic plants.

This type of pond is common in Asia, particularly in China, Indonesia, Vietnam and India. They are often fed by latrines suspended over the fishpond.[20]

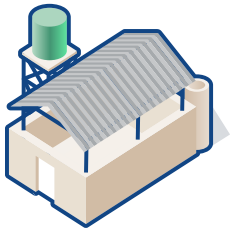
Mediterranean Focus

These uses are not practiced in Mediterranean countries.

CHALLENGES

→ **Health risk** Chapter 2 : Challenge 2 129

4.4.3 Use of water for industry and urban spaces



RECOVERED OUTPUT PRODUCT

SECONDARY TO TERTIARY WASTEWATER — Secondary to tertiary treated wastewater

Potential uses

Washing of roads and networks — URBAN CLEANING

This use is currently under development, particularly in France. It is specifically for urban areas.

CHALLENGES

→ **Health risk** Chapter 2 : Challenge 2 129

→ **Positive and negative environmental impacts** Chapter 2 : Challenge 1 110

Industrial processes, cooling systems — INDUSTRIAL PROCESSES

Water can be sold on to industries for use in production processes. Companies can buy secondary or tertiary treated wastewater and then carry out their own treatments to obtain water that meets their specific quality requirements.

Demineralised water is often required for this. For instance, high-quality water is required for the electronic industry or for **feeding into high-pressure boilers**, where scaling and corrosion of the equipment is the primary concern. Therefore, industries often use tertiary treatment, such as ultrafiltration, nanofiltration or reverse osmosis.[5]

Many of the processes used in the **food and drink industry** require water. Water is particularly used for producing steam and hot water for processing, transporting and cleaning

food products, and for cleaning equipment and containers.

It would be possible to use wastewater for **phosphate production**, for example, as is already the case in Morocco.

There are a few countries around the world where **drinking water is produced** from directly reused treated wastewater, such as in Singapore, Namibia, Australia and the United States. However, these examples are relatively isolated.

Mediterranean Focus

In Morocco, treated wastewater is used to wash phosphate in Benguerir, Khouribga and Youssoufia.[K] In 2015, pilots were carried out in Gabès, Tunisia to develop the industrial use of treated wastewater in partnership with the Groupe chimique Tunisien (GCT).[L]

CHALLENGES

→ **Positive and negative environmental impacts** Chapter 2 : Challenge 1 110

BIOCHAR, CENDRES

Potential uses

Industrial processes **INDUSTRY**

Because of their high porosity, ash and biochar can also be used as filtering materials in wastewater treatment, as they enhance the absorption process and act as a flocculant.

Mediterranean Focus

These uses are not practiced in Mediterranean countries.

K. B. Soudi, « Amélioration des connaissances sur l'utilisation saine et sécurisée des eaux usées traitées pour le développement du secteur agricole dans les pays du Maghreb – Rapport Maroc » FAO, 2020

L. « Réutilisation des eaux usées traitées en agriculture : analyse de l'état des lieux et perspectives – cas de la Tunisie » FAO ; Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche Maritime (Tunisie), 2021.

Landfill disposal

Sewage sludge is sometimes considered **undesirable by-product** of wastewater treatment processes. Sludge producers (treatment plant operators) consider it to be **final waste**. In this instance, the sludge can be disposed of in a landfill if there are suitable facilities in place.

However, the sludge still needs to have been **dewatered to reduce the environmental impact** of storing it in the landfill (runoff, infiltration).

Regardless of the disposal/recovery option selected, disposal in a landfill must always be available as a **back-up solution** in case problems arise with the preferred recovery method.

Landfill sites must be designed to ensure their environmental impacts are properly managed, particularly through leachate management.

FOR MORE INFORMATION:

- **Ressources et bibliographie pour ce chapitre**

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[13] - Constructed wetlands for resource recovery in developing countries, Renewable and Sustainable Energy Reviews, T. Avellán, P. Gremillion, 2019.

[14] - Sewage sludge: a review of business models for resource recovery and reuse, International Water Management Institute (IWMI), A. Taron, S. Singh, P. Drechsel, C. Ravishankar, A. Ulrich, 2023.

[15] - Utilisation and economic valuation of the Yala swamp wetland, Kenya, —, R. Abila, 2002.

[16] - The utilisation of reed (Phragmites australis): a review, —, J. F. Köbbing, N. Thevs, S. Zerbe, 2013.

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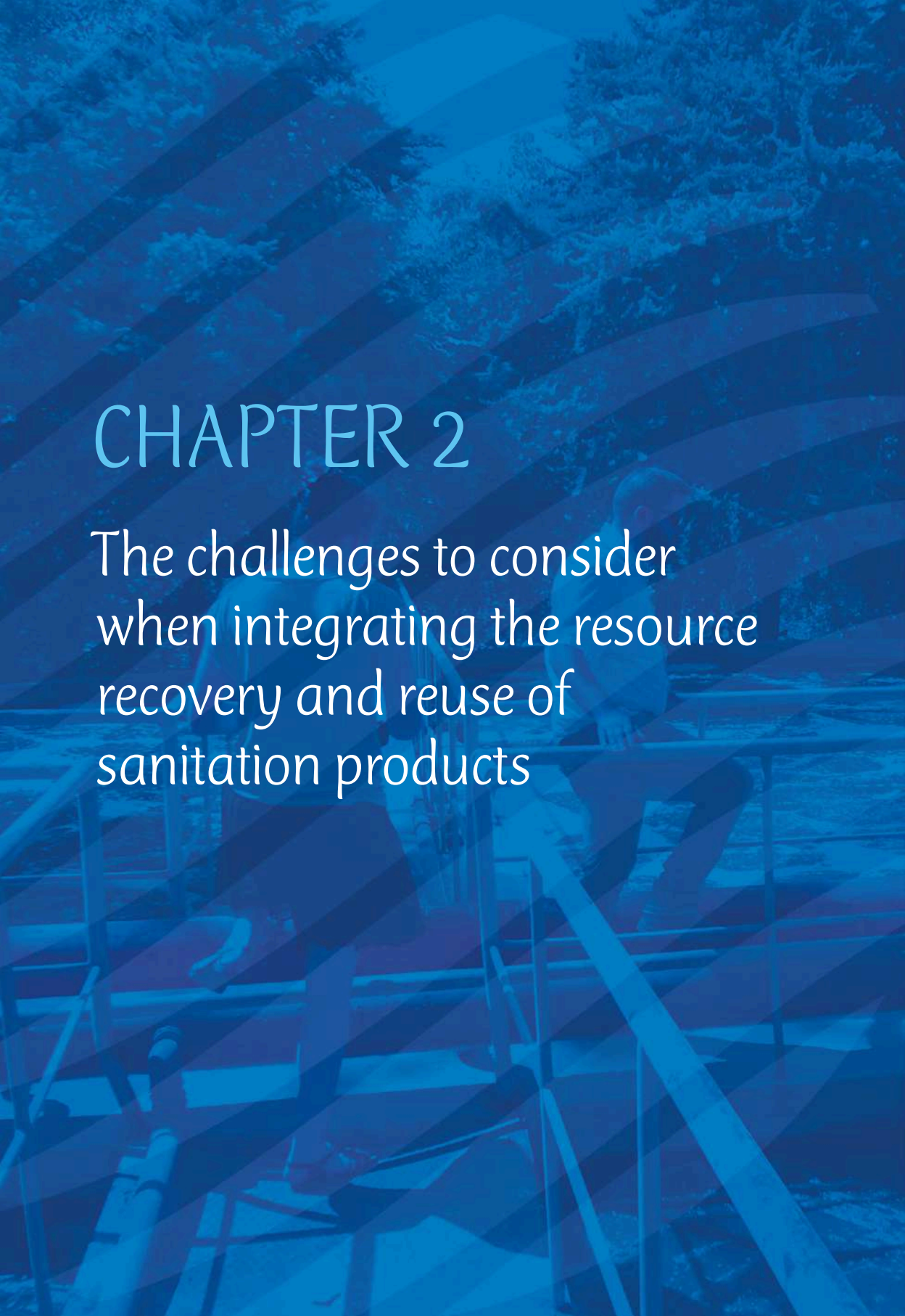
[20] - WHO Guidelines for the safe use of wastewater, excreta and greywater - Volume 3: Wastewater and excreta use in aquaculture, WHO, —, 2013.



CHAPTER 2

The challenges to consider when integrating the resource recovery and reuse of sanitation products

The context-specific parameters to be considered when selecting options for each sanitation chain segment and how they are impacted by resource recovery and reuse

There are a number of key context-related factors to take into account when determining the most appropriate type of sanitation, facility and treatment process option for the different segments of the sanitation chain.

This publication focuses on the challenges associated with introducing a 'resource recovery and reuse' segment into the sanitation chain.

Thus, this first section summarises the factors to be taken into account to guide decision-making for the entire sanitation chain, **and describes how these factors would be affected by the introduction of a resource recovery and reuse segment.**

The key challenges associated with integrating a resource recovery and reuse segment are then detailed in a separate section.

1. Sanitation-related official sector frameworks and practices

Parameter: Regulatory and strategic framework

The regulatory framework of the relevant country must be examined to take account of any wastewater treatment output quality and monitoring regulations and service management procedures.

Parameter: Any pre-existing excreta, urine and greywater management practices

Outside of official frameworks, it is important to identify any local practices that fall outside the scope of these frameworks, which are adopted with local adaptations, or which develop informally.

Consideration of these parameters takes on a whole new dimension when it comes to introducing a resource recovery and reuse segment. Regulations relating to use must also be taken into account, and the health and environmental risks need to be defined.

→ **Health risk** Challenge 2 129

→ **Organisational and financial models** Challenge 3 153

2. Population and housing

Parameter: Demography and type of housing

Demographics and population growth forecasts are key factors for determining the type of sanitation required. Decisions on the **type and design of treatment processes** are related to housing density and changes in housing type.

Housing density has an influence on whether to opt for **sewerage systems or on-site sanitation systems**. In areas of dense housing, there is usually a good network length to service user ratio whereas, in more sparsely populated areas, the investment and operating costs of sewerage systems can be prohibitive.

Furthermore, very narrow streets can make access to latrine pits difficult and may warrant other, smaller means of transport than vacuum trucks, or local mini-sewer systems.

→ No major impact

Parameter: Land availability

For a WWTP or FSTP operator, the possibility of buying land with the required characteristics (outside a flood-risk area, a consistent distance from the collection area, a suitable nearby outlet, good topography, etc.) is a decisive factor. This affects the very feasibility of setting up a sanitation system, as well as the **type of sanitation** to be implemented and the **treatment process options** available.

Land availability and footprint also need to be considered when designing transport-related facilities (networks, intermediate faecal sludge storage facilities).

Extensive secondary water treatment systems (WSP, planted filter beds) have a much larger footprint than intensive secondary treatment systems (such as activated sludge).

Depending on their intended use, sanitation products may require additional disinfection (water) or sanitisation (sewage and faecal sludge) treatment, the amount of land required for the related facilities will vary accordingly.

Land availability is not a concern for tertiary water treatment, except in the case of maturation ponds.

Large plots of land may be required for faecal sludge drying, whereas mechanical dewatering systems are more compact in size.

3. Essential services and craft and industrial activities

Parameter: Water supply and consumption

The choice of **sanitation system type (sewerage or on-site)** is influenced by whether there is a functioning water supply system or not. A sewerage system needs a minimum flow of w astewater in order to function correctly as insufficient volumes can cause clogging; meanwhile, high water consumption means that septic tanks need emptying more often. In addition, water consumption figures provide key data for the **design of all facilities and processes** in all segments of the sanitation chain. Water consumption estimates that are based on an analysis of local practices should be used for this, not theoretical water consumption.

→ No major impact

Parameter: Stormwater and flood management

This parameter specifically influences the **choice of sanitation type (sewerage or on-site systems)**. If wastewater is to be collected with stormwater (combined networks), or if parasitic clear water enters into separate sewerage systems, a larger capacity and/or a more complex collection and treatment system **design** will be required. For sewerage systems, this parameter influences the **treatment process options** available, as some are more resilient to variations in volumes and loads than others.

→ No major impact

Parameter: Solid waste management

The choice of **sanitation system type (sewerage or on-site systems)** is affected by whether there is formal or informal solid waste management in place. Solid waste can enter into the sewerage system, leading to a risk of obstruction. Despite pretreatment by screening, it can even be carried into the treatment plant causing disruption to the treatment process. A faecal sludge collection service could potentially draw on existing solid waste collection systems.

→ No major impact

Parameter: Domestic practices

The characteristics of greywater are determined by household practices (volumes of water consumed, type of cleaning products used).

→ No major impact

Parameter: Craft or industrial activities

The characteristics of non-domestic water will be determined by local craft and industrial activities. Some activities can generate effluent whose pollutant load may cause disruption to sewerage systems and treatment systems (these typically include tanneries, car washes, etc.). Certain activities can result in micropollutants being released into the effluent.

Sanitation products may contain residues of pollutants or micropollutants from these activities.

→ **Health risk**

Challenge 2 129

4. Natural characteristics

Parameter: Pedology, geotechnics, hydrogeology

This parameter influences **the choice of user interface (latrines) and treatment processes** in all segments of the chain.

The geotechnical characteristics, the infiltration and self-purification capacities of the soil, and the presence of groundwater resources, will all influence the choice then the **design** of solutions by determining whether major earthworks, foundations or water infiltration measures are

required. This also determines whether or not the soil can be used to disperse treated wastewater through infiltration and, more broadly, influences the choice of location for treatment systems.

A sewerage system will increase the amount of earthworks required for the transport segment; however, no earthworks are necessary for the associated flush latrines, unlike on-site facilities that include various types of pit.

Depending on the soil type, foundations may be required for intensive treatment systems to ensure the stability of the infrastructure.

If the soil type or presence of a shallow, unsealed water table means there is a risk of groundwater contamination, latrines with non-watertight pits must be avoided.

Any secondary treatment processes required can improve the quality of output products otherwise likely to contaminate water resources through infiltration, but could introduce elements that have a harmful effect on the characteristics of the soil. Sanitation products can also be beneficial for the soil. This parameter is to be considered specifically for resource recovery and reuse sites and should influence their choice.

→ **Positive and negative environmental impacts** Challenge 1 110

◄ Parameter: Topography

Topography influences the choice of sanitation type (sewerage or on-site systems). The preferred option is a gravity-fed transport system to minimise the number of lift stations required. Analysis can result in differentiating between areas in a settlement where a sewerage system is suited to the topography and areas where on-site systems are more appropriate.

Topography is also a parameter that influences **the choice of treatment site and, therefore, the treatment** process, depending on the space available.

→ No major impact

◄ Paramètre : Climatic conditions

Climate is a key factor in the **choice of treatment processes**, especially rainfall, temperature and sunlight.

Rainfall impacts the fill rate of non-watertight latrine pits where water is not channelled into a drainage system, in particular where there are outcropping aquifers. It also affects the emptying frequency and volumes and characteristics of the sludge to be treated. In sewerage systems, rainfall impacts the volumes and concentration of the wastewater to be treated due to parasitic clear water entering the system, although separate sewers are now becoming more common. In combined systems, rainfall also increases runoff and, consequently, heavy metal concentrations (notably from vehicles), which can complicate the treatment process or make it more expensive.

In general, additional disinfection (water) or dewatering (sewage and faecal sludge) treatments can be adapted to the climate context.

Waste stabilisation pond tertiary water treatment systems that use UV rays, and sludge drying beds, are optimised in sunny conditions. However, high temperatures can upset the water balance (a large part of the water is lost through evaporation).

This parameter is also central to the environmental argument for introducing a resource recovery and reuse segment.

→ **Positive and negative environmental impacts** Challenge 1 110

5. Existing local technical and financial capacities and capacity-building opportunities

Stakeholders must be identified at all levels:

- Users of the sewerage system in all their diversity, as well as any different needs they may have (women, children, people in financial difficulty, craft workers, industries, etc.)
- Stakeholders already involved in sanitation (both formally and informally) or required to take on roles within the sanitation chain: latrine pit emptying and transport/sewerage system operation, WWTP / FSTP operation, quality control of output products.
- Stakeholders involved in sanitation service regulation, defining regulations and developing national strategies and policy.

These stakeholders can vary widely depending on the context: state, deconcentrated, decentralised or non-profit stakeholders, large private companies, the self-employed or small businesses.

The users of sanitation products must be taken into consideration.

Any new roles and the stakeholders required to fill them must be taken into account.

Stakeholders involved in regulating the sectors concerned by resource recovery and reuse applications must be involved.

The type of sanitation and treatment processes selected must be aligned with the technical, organisational and financial capacities of the various stakeholders involved. This does not mean that solutions should be selected based on initial capacities: training programmes can be put in place to address any gaps identified and develop these capacities. Nevertheless, both initial knowledge levels and types of training, whether through development projects or local providers (level of expertise, length, possible refresher training, etc.), need to be taken into account to ensure the solutions chosen are feasible.

Local capacities may not be fully taken into account in feasibility studies, particularly if (often international) expertise is provided via development assistance during the project design stage without sufficiently anticipating how the system will be managed once the project is completed. Thus, the costs and technical expertise required to operate and maintain the system must be aligned with the capacity of local stakeholders to carry out the technical operations and develop long-term billing and cost recovery mechanisms.

◄ Parameter: Energy consumption and associated operating costs

Some treatment processes are particularly energy-intensive:
Activated sludge secondary water treatment (due particularly to its aeration system).

While others require little or no electricity:
Extensive secondary water treatments such as WSP and planted filter beds.

For reuse, certain treatment processes are particularly energy-intensive:

- Membrane filter tertiary treatments;
- Mechanical sludge dewatering.

While others require little or no electricity:

- Tertiary water treatment in maturation ponds;

Tertiary water treatment by UV or chlorination (which consume energy but have little impact on the treatment system energy balance);

Sludge sanitisation treatment in drying beds.

In addition, if the biogas is recycled, the energy recovered can be used to meet the treatment system's energy needs.

- Organisational and financial models
- Positive and negative environmental impacts

→ **Organisational and financial models** Challenge 3 **153**

→ **Positive and negative environmental impacts** Challenge 1 **110**

Parameter: Technical sophistication of operations and maintenance tasks

For all treatment processes, the operator has to have a clear understanding of the maintenance and operations tasks to be carried out and their frequency. In the event of a breakdown, the operator must have the knowledge required to identify the causes and take corrective action, or must be able to call upon another stakeholder for assistance.

Some treatment processes require only occasional operations and maintenance tasks that can be carried out with basic training: Extensive secondary water treatments such as WSP and planted filter beds.

Other processes require advanced skills, especially because frequent adjustments are required to the parameters that regulate them: Activated sludge secondary water treatment.

Other processes require advanced skills, especially because frequent adjustments are required to the parameters that regulate them: Activated sludge secondary water treatment.

In the case of reuse/resource recovery, some treatment processes require only infrequent maintenance and operational activities and can be carried out after brief training: tertiary wastewater treatment by maturation ponds, and sludge drying beds.

Other processes require advanced skills, especially because frequent adjustments are required to the parameters that regulate them: Membrane filtration, UV and chlorination tertiary water treatments, Digesters.

→ **Organisational and financial models** Challenge 3 **153**

→ **Sociological aspects** Challenge 4 **168**

Consumption of reagents and equipment renewal

Certain treatment processes require special materials and equipment (often not produced locally), which can be difficult to renew and replace. Replacement and renewal can be further complicated if the site is in a remote location or some distance from a town or city (especially affecting transport and storage). This can also make it impossible to obtain spare parts or reagents, meaning that certain treatment solutions will not be viable.

This parameter is particularly relevant to tertiary disinfection treatment processes: chlorination, ozonation, UV, membrane filtration.

→ **Organisational and financial models** Challenge 3 **153**

6. Sanitation product end uses

These parameters relate specifically to the sanitation chain into which a resource recovery and reuse segment has been introduced.

◄ Parameter: Identifying the hazards associated with the use of certain products, the people exposed to these hazards and the associated risk

This parameter applies to agricultural uses, as well as all uses that involve contact with wastewater, sewage and faecal sludge, plus irrigated/improved soil and crops.

It does not apply to the following uses: energy uses, craft and industrial activities.

→ **Health risk** Challenge 2 **129**

◄ Parameter: There is an environmental benefit to the resource recovery and reuse of sanitation products

This parameter forms part of the 'Pedology, hydrogeology' and 'Climate context' parameters.

→ **Positive and negative environmental impacts** Challenge 1 **110**

◄ Parameter: There is a need, or the opportunity to develop a need, for sanitation product resource recovery and reuse for human activities

Sanitation product end use(s) should be a key consideration when assessing the context as it will ensure feasibility of the entire sanitation chain. The potential users of the product(s) therefore need to be involved as stakeholders.

→ **Organisational and financial models** Challenge 3 **153**

→ **Sociological aspects** Challenge 4 **168**

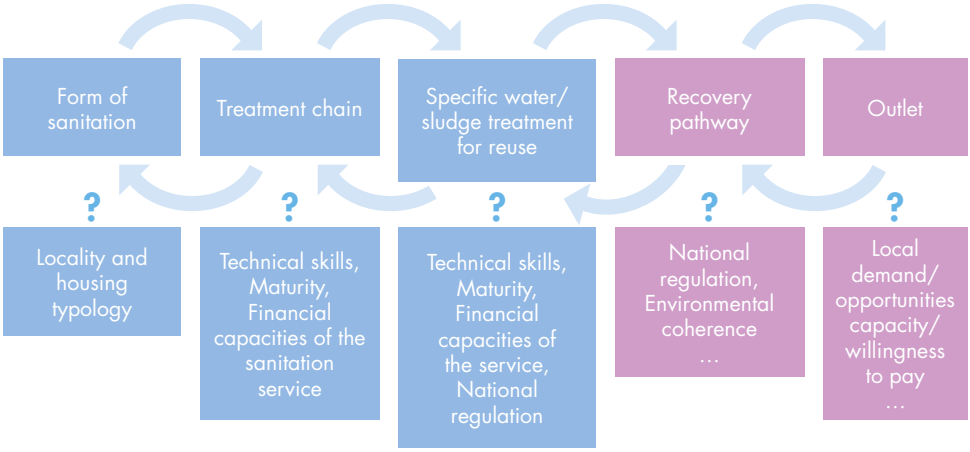
In conclusion, to assist with decision-making:

The choice of sanitation type, facilities and treatment processes, resource recovery and reuse options and applications:

- Is based on a diagnostic that identified and analysed all relevant context-related factors, and results from a feasibility assessment that compared different potential scenarios;
- Results from an approach that involves all stakeholders;
- Includes the facilities and technologies selected, as well as the chosen sanitation chain organisational and financial operating model.

Context-specific factors guide choices in a non-linear, iterative way.

Identifying end uses for sanitation products can be a key factor for defining the options to be considered for the treatment, transport and collection segments.



FOR MORE INFORMATION:

- **On the context-specific parameters to be considered to guide decision-making at each segment of the sanitation chain:**
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Beni Hassen WWTP, Tunisia, © Benjamin Noury

Challenge 1 : Positive and negative environmental impacts

Reusing the diverse range of sanitation products can be a virtuous option for ensuring the circularity of water flows and materials.

The environmental benefits associated with developing a 'new' water resource, returning materials to the soil, and reducing greenhouse gases are often used to justify the rationale of a project seeking to introduce a resource recovery and reuse segment into the sanitation chain.

This section reviews these benefits by examining the positive and negative environmental impacts to be taken into account.

Developing a 'new' water resource

SECONDARY TO TERTIARY WASTEWATER — Secondary to tertiary treated wastewater

Uses

- **Farming activities** (edible and non-edible crops) — FARMING ACTIVITIES
- **Irrigation of public green spaces** (gardens, parks) — PUBLIC GREEN SPACES
- **Irrigation of privately-owned commercial green spaces** (hotel grounds, golf courses) — PRIVATE GREEN SPACES
- **Low-water flow support for surface water resources** — LOW WATER FLOW
- **Downstream (non)human uses** — DOWNSTREAM USES
- **Aquaculture** (use of water in fishponds) — AQUACULTURE
- **Washing of roads and networks** — URBAN CLEANING
- **Industrial processes, cooling systems** — INDUSTRIAL PROCESSES

Positive and negative environmental impacts

Reusing treated wastewater is an effective strategy for **reducing freshwater withdrawals** from aquifers and rivers. This approach seeks to provide a solution to the increasing scarcity of water resources caused by the effects of climate change and the growing pressure exerted by human activities, particularly agriculture.

However, in order to put the real environmental benefits of reusing treated wastewater into perspective, this argument needs to be broken down. Treated wastewater reuse can only form part of a water resource conservation approach if it is considered as an **alternative resource** and not an additional resource.

Treated wastewater can sometimes be considered an additional resource that enables the development of new uses. This can have economic and social benefits; however, at the catchment level, rather than helping preserve water resources, it can place them under greater pressure.

In some contexts, the impact may be neutral. For example, the wastewater discharge flow rate may be negligible compared to the flow rate of the watercourse that forms the receiving environment. Reuse on farmland near to the watercourse can also lead to infiltration into the watercourse's accompanying aquifer. This can have negative impacts if the wastewater discharge flow rate constitutes the low-water flow of the watercourse in sum-

mer, as users downstream may be left without water. In contrast, reusing treated wastewater instead of discharging it into the sea appears to have only positive impacts as it enables freshwater to be reinjected into the water cycle.

Adaptation to the context

The water distributed for domestic uses by water and sanitation services is embedded in the global water cycle and is diverted from its natural course. The reuse of wastewater discharged from a treatment plant entails conveying this water to the site of its reuse rather than discharging it into the often local environment. **Treated wastewater reuse involves redirecting an existing water flow for human use.** The treated wastewater that is not 'reused' is not 'lost'. It returns to the environment and supplies other human and non-human users downstream.

Wastewater reuse needs to be designed in conjunction with an impact assessment that applies Integrated Water Resources Management (IWRM) principles to the project. This will include identifying uses and users and conducting a catchment-level hydrological assessment.

Mediterranean Focus

In Morocco and Tunisia, treated wastewater reuse is a key focus of water and sanitation sector strategy and regulation. Wastewater is considered a non-conventional resource that should be developed to increase 'supply' and help balance 'supply' and 'demand'. Climate change, which is resulting in increasingly frequent episodes of prolonged drought and lower and irregular rainfall, is causing a drop in available conventional water resources and exacerbating water stress. In this context, the use of treated wastewater as an alternative to surface and groundwater is strongly encouraged, and even compulsory, particularly for the irrigation of public green spaces and for tourist amenities, such as hotel grounds and golf courses.

However, the environmental viability of these uses need to be assessed when adopting an IWRM approach. For example, evaluation of a golf course and green space watering project in Marrakech revealed that, with more water being used for watering, the wetland is no longer being maintained and the Tensift wadi is no longer being replenished. This situation has led to farmers either abandoning their livestock breeding and crop growing activities or resorting to using already depleted groundwater ressources.[A]

Meeting the water needs of the agricultural sector is a key challenge, as agricultural use accounts for nearly 80% of the volume consumed for all uses, due both to climate change and intensive farming practices. Agricultural use is not yet widespread in Morocco; however, it has a long history in Tunisia, and is currently being developed in Palestine.

A. B. Soudi, « Amélioration des connaissances sur l'utilisation saine et sécurisée des eaux usées traitées pour le développement du secteur agricole dans les pays du Maghreb – Rapport Maroc,» FAO, 2020

In the West Bank, treated wastewater is considered a vital additional resource to be developed. However, here the aim is not to balance supply and demand, but to proactively develop the use of this resource to ensure it remains in the West Bank. This is underpinned by a strategy to stimulate demand, including in areas that use traditional non-irrigated farming practices.

FOR MORE INFORMATION:

- **On the benefits, risks and context-specific adaptations involved in developing a 'new' water resource:**
  - Guide à la décision pour la mise en œuvre d'un projet de Réutilisation d'Eaux Usées Traitées, BRL, Savey, P., 2022
  - Resource Recovery and Reuse Series n°4 - Global Experiences in Water Reuse, CGIAR, IWMI, Lautze, J.; Stander, E.; Drechsel, P.; da Silva, A. K.; Keraita,B., 2014
  - Water reuse in the Middle East and North Africa, a sourcebook, IWMI, Mateo-Sagasta, J. et al, 2022

Returning materials to the soil

SECONDARY TO TERTIARY WASTEWATER — Secondary to tertiary treated wastewater

Uses

- **Farming activities** (edible and non-edible crops) → FARMING ACTIVITIES
- **Irrigation of public green spaces** (gardens, parks) → PUBLIC GREEN SPACES
- **Irrigation of privately-owned commercial green spaces** (hotel grounds, golf courses) → PRIVATE GREEN SPACES

COMPOST, ASH, BIOCHAR FS/SS — Sewage/faecal sludge, compost, ash, biochar

Uses

- **Farming activities** (edible and non-edible crops) → FARMING ACTIVITIES
- **Irrigation of public green spaces** (gardens, parks) → PUBLIC GREEN SPACES
- **Irrigation of privately-owned commercial green spaces** (hotel grounds, golf courses) → PRIVATE GREEN SPACES
- **Soil amendment for forestry** → FORESTRY
- **Rehabilitation of mining or industrial areas, restoration of soil damaged by intensive farming** → RESTORATION OF SOIL

URINE AFTER STORAGE

Uses

- **Soil amendment for family vegetable gardens** → FAMILY GARDENING

Positive and negative environmental impactss

Type of material	Positive impacts	Negative impacts
Sewage sludge	• Very rich in organic matter (~50% of the dry matter): improves soil structure, promotes water retention and nutrient availability, encourages microbial life • Rich in nutrients: nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), trace elements, etc.	• Long-term heavy metal contamination (MTE). • Surface or groundwater contamination through stagnation, runoff or percolation. • Over-application can lead to soil salinisation, particularly in poorly drained soil. • Soil acidification, depending on the type of sludge used
Treated wastewater	• Richer in organic matter than conventional water if no tertiary treatment • Provides nutrients, in particular nitrogen and phosphorus	• Surface water eutrophication. • Groundwater contamination from (highly mobile) nitrate nitrogen. • Root hypoxia due to waterlogging (too much water). • Soil salinisation: water stress, toxicity. • Soil acidification. • Chlorine residues (>5 mg/L): leaf burn and crop damage
Urine	• Rich in nitrogen, particularly in the form of nitrates: useful for plant nutrition	• Groundwater contamination of by nitrate nitrogen

Mediterranean Focus

The organic matter contained in sludge could be used to effectively restore degraded soils in arid and semi-arid areas by improving the soils' water retention capacity and fertility. Hot climate conditions speed up the mineralisation of nitrogen and phosphorus, which are then more readily available to plants.[B]

B. B. Soudi et W. El Khoumsi, «Valorisation agricole des boues d'épuration dans les pays du Maghreb : potentialités et défis Gestion et valorisation agricole des boues d'épuration au Maroc. Rapport national – Maroc,» FAO, 2024.

Adaptation to the context

To ensure that returning materials to the soil provides real benefit to both soil and plants and causes them no harm, it is vital to take **specific soil characteristics** into account and properly **manage the quantities applied**, both in the short- and long-terms.

Clay-textured soil, which is rich in organic matter, has a good water retention capacity. It can effectively retain nutrients and heavy metals. As a result, few of the nutrients are leached out of the soil and remain available long-term.

Metals tend to bind to the clay-humus complex, making them less available to plants and reducing the risk of toxicity. However, repeated application of output products (sludge, compost, wastewater), can lead to these metals slowly accumulating over time.

Sand-textured soil, which is poor in organic matter, has a low water retention capacity. Nutrients are therefore leached more easily. Heavy metals remain mobile and bioavailable to plants, which increases the risk of toxicity. However, there is less risk of accumulation as more of the metals are washed away.

Acid soil (pH of less than 6) tends to increase the solubility of heavy metals, making them more available and potentially toxic to plants.

Basic soil (pH of more than 7) can render some nutrients less available, causing deficiencies that can stunt crop growth.

For irrigation with treated wastewater, which can lead to nutrient leaching, practices will need to be adapted for sand-textured soil (frequency, volumes, irrigation methods) to prevent the rapid loss of nutrients essential for plant growth.

With this type of soil, extra care must by taken to ensure the wastewater does not contain too much salt. The poor retention capacity of sand-textured soil leads to rapid infiltration, which results in surface evaporation that leaves behind salt deposits.

For sludge application on clay soil that is poor in organic matter, it will be necessary to monitor long-term cumulated sludge quantities to ensure there is no over-accumulation of nutrients and heavy metals.

For sandy soil, the thresholds used to monitor nutrient and heavy metal accumulation can be more flexible. As these elements are more likely to be leached out of the soil, it will instead be necessary to minimise the risk of pollution of nearby water resources (checking the slope of the land, proximity of surface and groundwater resources, etc.). Applying organic matter to this type of soil will progressively improve its water and nutrient retention capacity.

Finally, the application of alkaline, lime-stabilised sludge is not appropriate for basic soil.

For compost, the key properties are its maturity and stability, as immature compost can have negative side effects, such as causing leaf burn on crops. Quality standards generally require a carbon to nitrogen ratio (C/N) of less than 20; compost of good maturity would fall within the 12 to 15 range.

Applying large quantities of compost can lead to a significant increase in the salt content of the soil.

Mediterranean Focus

The use of lime-stabilised sludge (pH >8) is not suitable for soils in North Africa and the Middle East, as they are generally of neutral to basic pH and rich in calcium carbonates. Other flocculants, such as ferric chlorides or nitrites, are therefore recommended.[C] The tolerated thresholds can be higher than those in most northern European countries, where soils are relatively more acidic. Furthermore, in arid and semi-arid climates with high levels of evapotranspiration, there is a greater risk of soil salinisation in sandy soils.

Mediterranean countries do not currently have regulations in place governing the suitability of soils for sludge application. A decree is currently being developed in Morocco.

FOR MORE INFORMATION:

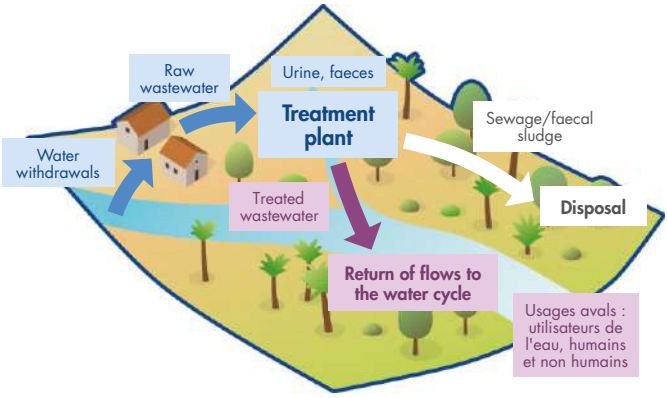
- **On the benefits, risks and context-specific adaptations involved in returning materials to the soil, particularly the wastewater, sludge and soil parameters to be assessed:**
  - Technical Guidance – Water Reuse Risk Management for Agricultural Irrigation Schemes in Europe, Publications Office of the European Union, Maffettone, R.; Gawlik, B.M., 2022
  - Ressource Recovery and Reuse Series 03: Co-composting of Solid Waste and Fecal Sludge for Nutrient and Organic Matter Recovery, CGIAR, International Water Management Institute (IWMI), Cofie, O.; Nikiema, J.; Impraim, R.; Adamtey, N.; Paul, J.; Koné, D., 2016
  - Resource Recovery and Reuse Series 14: Guidelines and Regulations for Fecal Sludge Management from On-site Sanitation Facilities, CGIAR, International Water Management Institute (IWMI), Jayathilake, N.; Drechsel, P.; Keraita, B.; Fernando, S.; Hanjra, M.A., 2019
  - Effet de l'application de boues d'épuration sur la capacité d'infiltration des sols agricoles, Revue Agrobiologia, Volume 10, Numéro 3, Pages 2098–2108, Boughalem, M. ; Ienciu, A.A. ; Belhoucine, L., 2021
  - Valorisation agricole des boues d'épuration dans les pays du Maghreb : potentialités et défis – Rapport national : Maroc, Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO), Soudi, B. ; El Khoumsi, W., 2024

C. « Réutilisation des eaux usées traitées en agriculture : analyse de l'état des lieux et perspectives – cas de la Tunisie » FAO ; Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche Maritime (Tunisie), 2021.

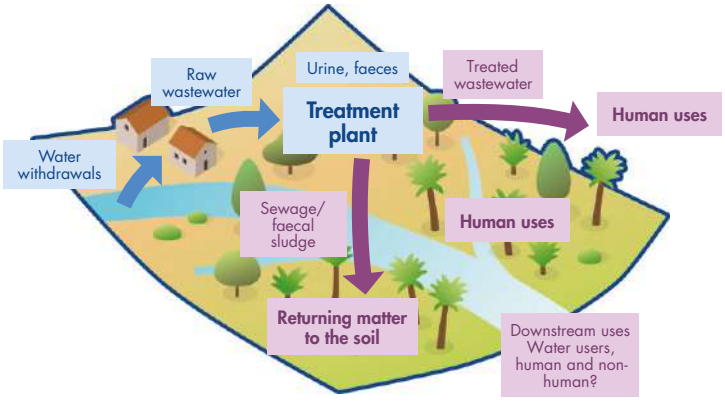
The following types of analysis can be carried out during both the feasibility assessment and operating phases:

<table>
<tr><th></th><th rowspan="2">Analysis objective</th><th colspan="2">Parameters to be analysed</th></tr>
<tr><th>More relevant to sludge application</th><th>More relevant to irrigation using treated wastewater</th></tr>
<tr><td rowspan="4">Characterisation of wastewater / sludge</td><td rowspan="2">Agronomic value of sludge / organic load</td><td colspan="2">• Total nitrogen, ammoniacal nitrogen
• Nutrients and trace elements
• pH</td></tr>
<tr><td>• Organic matter (%)
• C/N ratio</td><td>• Turbidity, TSS, COD, BOD
• Salinity</td></tr>
<tr><td rowspan="2">Metal Trace Elements (MTE)</td><td>• Compliance with thresholds in water / sludge (mg/kg SM)- maximum cumulated flow over 10 years (g/m^2)</td><td></td></tr>
<tr><td colspan="2">Depending on the origin of the raw wastewater, other micropollutants may be detected in the water/sludge</td></tr>
<tr><td></td><td>Pathogens</td><td colspan="2">• Helminth eggs, Coliforms, E. coli</td></tr>
<tr><td>Soil characterisation (soil survey)</td><td>Metal Trace Elements (MTE)</td><td colspan="2">Comparison against the soil's tolerated thresholds (mg/l20kg SM)</td></tr>
<tr><td></td><td>Capacity to retain nutrients;
retain heavy metals;
infiltrate wastewater</td><td>• Organic matter (%)
• C/N ratio</td><td>• Conductivity
• Permeability
• Salinity</td></tr>
<tr><td colspan="2" rowspan="3">Topo-hydro-geological study</td><td colspan="2">• Analysis of the hydrographic network: ditches, wells, springs, boreholes</td></tr>
<tr><td colspan="2">• Assessment of runoff risks</td></tr>
<tr><td colspan="2">• Checking the slope (for sludge application: threshold of ≤7%)</td></tr>
<tr><td colspan="4">Initial analyses before introduction of the resource recovery and reuse chain
> Assessing the suitability of the soil to receive treated wastewater / sludge</td></tr>
<tr><td colspan="4">Monitoring: annual for wastewater/sludge, every 10 years for soil</td></tr>
</table>

The following diagrams illustrate the challenges associated with developing a 'new' resource and returning materials to the soil:



The treatment system receives urine and faeces, potentially mixed with water taken from the environment. Where there is no resource recovery and reuse segment, the treated wastewater is returned to the natural water cycle. This can then be used by human and non-human users downstream. The sewage and faecal sludge, considered a 'by-product', is sent for disposal (to a landfill or for incineration).



When the sanitation chain includes a wastewater resource recovery and reuse segment, this wastewater is transported to its users. This wastewater reuse needs to form part of an Integrated Water Resources Management approach that takes all users into account, both human and non-human.

When the sanitation chain includes a sewage/faecal sludge recovery segment, the matter contained in the sludge is returned to the soil, which can have real environmental benefits if the characteristics and needs of the soil and plants are properly taken into account.

Reducing greenhouse gas (GHG) emissions

The impact of a system on global warming can be assessed by measuring the greenhouse gases entering and leaving the system. This approach can be applied to the sanitation sector. Integrating a resource recovery and reuse segment can help reduce greenhouse gas emissions in the sanitation chain.

Environmental benefits

Avoiding GHG emissions through biogas recovery

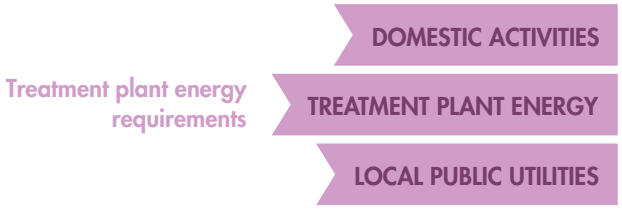
Methane is a powerful greenhouse gas, and has a much higher warming potential than carbon dioxide (CO2). Recovering methane for energy use prevents it from being released into the atmosphere, thereby reducing GHG emissions in the sanitation chain.

Replacing GHG-emitting uses

Where sanitation output products are recovered by a third-party to replace another 'product', or where energy is produced and sold on to a third-party (biogas recovery), the greenhouse gases that would have been released through the processes traditionally used to manufacture this product or produce this same amount of energy are no longer emitted: these are known as avoided emissions.

BIOGAS

Uses



Using biogas helps reduce the extraction, transport and combustion of other fossil fuels, all of which are GHG emission-generating activities. The avoided emissions are those from the production of the same quantity of non-renewable energy.

SECONDARY TO TERTIARY WASTEWATER — Secondary to tertiary treated wastewater

COMPOST, ASH, BIOCHAR FS/SS — Sewage/faecal sludge, compost, ash, biochar

Uses

Soil amendment for farming activities, edible and non-edible crops — FARMING ACTIVITIES

The recovery of nutrients from sanitation output products can be used to supplement or replace chemical fertilisers. The avoided emissions are from the production of the same amount of chemical amendments. Phosphorus recovery can be of particular value, as this is a non-renewable resource mainly obtained from limited deposits found in just a few countries.[D]

At the global level, wastewater reuse in agriculture could provide a 30% reduction in the tonnage of mineral fertilisers applied to farmland (based on the average mineral content of treated wastewater: nitrogen: 50mg/l; phosphorus: 10mg/l; and potassium: 30mg/l (WHO, 2012)).[E]

BIOCHAR, ASH

Uses

Craft or industrial activities — CRAFTS OR INDUSTRY

Craft activities (often informal) — CRAFT

Avoided emissions are from the production of an equivalent quantity of traditional raw materials (cement, briquettes).

Adaptation to the context

However, the benefits of these uses need to be weighed against all GHG emissions from the different sanitation chain segments. The following table outlines the main GHG emissions along with the additional or avoided emissions that result from integrating a resource recovery and reuse segment. (The main GHG emitted are carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O)).

D. Mihelcic et al. 2011, cité par : Mateo-Sagasta, Javier, et al. Water Reuse in the Middle East and North Africa, a Sourcebook. International Water Management Institute (IWMI), 2022.

E. B. Soudi et W. El Khoumsi, «Valorisation agricole des boues d'épuration dans les pays du Maghreb : potentialités et défis Gestion et valorisation agricole des boues d'épuration au Maroc- Rapport national – Maroc,» FAO, 2024.

Sources of GHG emissions	Sanitation chain without a resource recovery and reuse segment	Sanitation chain with a resource recovery and reuse segment
Access/ containment and transport segmen ts	Emissions can be difficult to identify and quantify, particularly for latrines with on-site sludge containment facilities. However, emissions from septic tanks and latrines can be considered higher than those from a WWTP with a properly functioning aerobic treatment process.	No change in emissions.
Treatment segment	Emissions are generated by the treatment plant (WWTP or FSTP). There are data and methodologies that can be used to characterise these emissions for the treatment processes selected, particularly for WWTP.	Emissions are generated by the additional treatment processes carried out to ensure the wastewater and sewage/faecal sludge have the characteristics required for their intended use(s). Where applicable, GHG emissions can be avoided through biogas recovery.
Manufacturing (including the extraction of components), and transport of the chemical products required for treatment processes	These emissions are particularly difficult to estimate as it requires data from outside the sanitation chain and from other, non-sanitation sector, stakeholders.	Emissions from the manufacture and transport of any chemical products required for additional treatment need to be taken into account.
Transport of the output products to their final destination	Emissions are produced by the sewage/faecal sludge disposal segment, if these output products are deemed to be waste and are not recovered: incineration, landfill. Water discharge to an outlet (river, sea, infiltration), generally by gravity, emits few greenhouse gases.	Emissions are generated when transporting water and sewage/faecal sludge to the resource recovery and reuse site. Agricultural recovery of sludge can significantly reduce sludge GHG emissions compared to landfill disposal.[2]
Use of output products (recovery)	Incineration and landfill disposal are used as final destinations and both emit GHG.	Avoided emissions are from the traditional GHG-emitting uses replaced through the recovery of sanitation products.

Mediterranean Focus

Between 2010 and 2022, GHG emissions from the agricultural and sanitation sectors in Morocco rose by 1% and 0.9% respectively. The use of sanitation products forms part of the country's GHG emission reduction approach, which seeks to replace products that emit GHG.[F]

The complete approach therefore consists of identifying the sources of greenhouse gas emissions, qualifying and quantifying these emissions and using these estimates to make environmentally-viable choices at each segment of the sanitation chain, particularly for the resource recovery and reuse segment. This is the approach adopted in a life-cycle assessment (LCA), an environmental evaluation methodology used to assess the impacts associated with all stages of the life cycle of a system, from raw material extraction through to system operation, up to the end of its life (disassembly, waste management, etc.). In practice, this approach is often not feasible for use as a decision-making tool, especially in low and medium-income countries.

Energy (electricity, fuel and natural gas) is one of the main water and sanitation sector GHG emitters. Therefore, a more simple, yet effective and feasible way of assessing the sanitation chain's impact on GHG emissions would be to undertake an energy audit.

F. Rapport National d'Inventaire du Maroc à la convention-cadre des Nations-Unies sur les changements climatiques, Ministry of Energy Transition and Sustainable Development, 2024.

Environmental viability of the sanitation sector based on its energy audit

Treatment plants (WWTP, FSTP) and the means used to transport output products to (intermediate segment) and from these treatment plants (resource recovery and reuse segment) are major sources of energy consumption.

Sources of energy consumption	Sanitation chain without a resource recovery and reuse segment	Sanitation chain with a resource recovery and reuse segment
Intermediate, transport segment	Energy consumption from transporting water (via sewerage systems, particularly if lift stations are required) and pit sludge (vacuum trucks).	
Treatment segment	Energy consumption of the treatment plant (WWTP or FSTP).	Energy consumption of the additional processes carried to ensure the wastewater and sewage/faecal sludge have the characteristics required for their intended use(s). Energy use of biogas produced by digestion.
Transport of the output products to their final destination	Energy consumption from transporting sewage/faecal sludge if these output products are deemed to be waste and are not recovered: incineration, landfill. Water discharge to an outlet (river, sea, infiltration) is generally under gravity.	Energy consumption from transporting sewage/faecal sludge to the resource recovery and reuse site.

Energy consumption of additional processes carried out for resource recovery and reuse

This involves taking into account energy consumption of the treatment processes required to obtain the products for these uses, as well as of transporting these products to the point of use. Some treatment processes are energy-intensive, while others require little or no electricity.

In a 10,000 to 80,000 PE capacity WWTP, tertiary activated sludge treatment can account for between 15% (sand filter filtration) and 65% (ultrafiltration + UV) of the plant's water-related energy consumption. These figures are even higher for tertiary waste stabilisation pond treatment: from 40% (tertiary treatment in a maturation pond + sand filter) to 85% (ultrafiltration).[G]

Sludge treatment uses less energy. However, mechanical sludge dewatering requires around 50 kWh/TSS, whereas very little energy is required for a drying bed.

Energy use of biogas produced by digestion

Biogas (see chapter 1), produced by digestion processes, can provide energy for a range of uses, including for treatment plants (see chapter 1). However, it is important to bear in mind that these processes are only technically and financially viable for WWTP of a reasonable size (around 100,000 PE) with specially trained operating staff, and if the cost of the energy resource is sufficiently high. Furthermore, it is rare for the electricity produced from biogas to cover all the WWTP's needs, the usual range for electricity self-sufficiency from biogas recovery is 40-70%.[3]

Mediterranean Focus

In Khouribga in Morocco, biogas is used for the cogeneration of electrical and thermal energy, covering 100% and between 30 and 40% of the WWTP's thermal energy and electricity needs respectively.[H]

nergy consumption from transporting sanitation products to the point of use

The transport of sanitation products to the point of use must also be taken into account. For a sanitation chain without a resource recovery and reuse segment, this involves transporting output products (treated wastewater, sewage and faecal sludge) to their final destination.

Water is often discharged under gravity near the treatment site, whereas reuse can require an energy-consuming lift system and longer network to convey the treated wastewater if the points of use are further away.

Distance to the point of use is also an important factor in the transport of sewage and faecal sludge from WWTP or FSTP. The distance from recovery sites should be taken into account and compared with other available outlets. The volumes of sewage/faecal sludge to be transported can be optimised by selecting treatment processes that reduce sludge volume (dewatering or drying).

G. « Élaboration du Plan Directeur National de Réutilisation des Eaux Usées Traitées en Tunisie – Phase 2 : Prospective de la filière à l'horizon 2050,» Ministry of Agriculture, Water Resources and Fisheries, 2022.

H. B. Soudi et W. El Khoumsi, «Valorisation agricole des boues d'épuration dans les pays du Maghreb : potentialités et défis Gestion et valorisation agricole des boues d'épuration au Maroc- Rapport national – Maroc,» FAO, 2024.

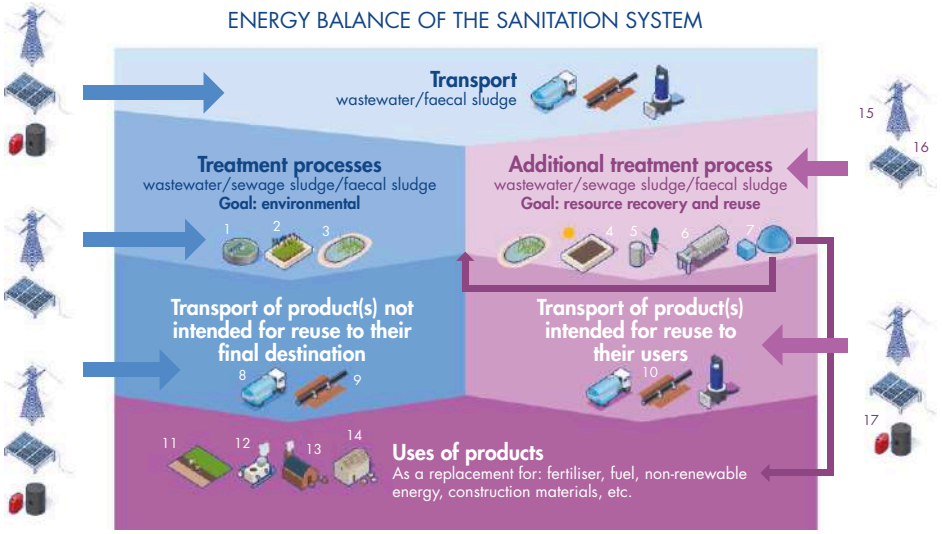
Energy consumption avoided as a result of uses avoided through resource recovery and reuse

When assessing the environmental viability of a project to reuse/recover sanitation products, estimating avoided energy consumption from avoided uses can prove complex. Thus, it is recommended to carry out a detailed energy audit of different resource recovery and reuse scenarios, up to and including transporting the products to their points of use.

Mediterranean Focus

In Morocco, the energy consumption avoided through the annual manufacture of 373,000 Fertiliser Units (FU)[I] equates to nearly 1.42% of total consumption from the electricity grid, and nearly 7.1% of firewood consumption. This also equates to avoided GHG emissions of 168,300 eq CO2/year.[J]

The diagram below summarises the potential energy contributions and savings to be taken into account for a sanitation chain that includes the resource recovery and reuse of sanitation output products.



I. One fertiliser unit (FU) corresponds to the energy value of 1kg of barley, i.e. in terms of net energy: 1,700 kilocalories = 7.11 megajoules.

J. Tonnes of CO2 equivalent (eq CO2) is an index introduced in the IPCC First Assessment Report. This index is used to compare the impacts of GHG on the environment by simplifying comparisons while making it possible to see the combination of these impacts using a single index.

1 Biological treatment
2 Planted filter (constructed wetland)
3 Stabilization ponds
4 Drying beds
5 Water disinfection
6 Mechanical sludge dewatering
7 Anaerobic digestion
8 Transport by vehicles
9 Sewers
10 Pumping
11 Agricultural soil amendment
12 Use of energy for domestic activities
13 Raw materials
14 Industrial uses
15 Electrical energy
16 Solar energy
17 Fossil energy

FOR MORE INFORMATION:

- **On reducing greenhouse gas emissions and on the sanitation chain's environmental viability based on its energy audit:**

- Guide méthodologique des émissions de gaz à effet de serre des services de l'eau et de l'assainissement, ADEME, ASTEE, 2018

- Bilan environnemental des filières de traitement et de valorisation des boues issues du traitement des eaux usées, Approches méthodologiques et bilan des données d'inventaires de gaz à effet de serre, Rapport final, ONEMA, IRSTEA, Pradel, M., Reverdy, A.L., 2013

- WASH Services and Climate Change: Impacts and Responses, pS-Eau, Génevaux C., 2018

- Consommations énergétiques des stations d'épuration françaises, État des lieux et recommandations, AERMC, IRSTEA, 2018

[1] - Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Task Force on National Greenhouse Gas Inventories (TFI), 2019

[2] - The Biosolids Emissions Assessment Model (BEAM): A Method for Determining Greenhouse Gas Emissions, Canadian Biosolids Management Practices, 2009

[3] - Le biogaz de STEP, une énergie de grande classe, suisse énergie, 2006

- Resource Recovery and Reuse Series 09: Energy Recovery from Domestic and Agro-Waste Streams in Uganda: A Socioeconomic Assessment, CGIAR, International Water Management Institute (IWMI), Gebrezgabher, S.; Amewu, S.; Taron, A.; Otoo, M., 2016

Positive and negative environmental impacts: key points

While introducing a resource recovery and reuse segment can help not only replace water resource abstraction, but also return materials to the soil rather than destroying (incineration) or taking the treated sludge to landfill, and recover the energy contained within the sludge, etc., **the environmental benefits cannot be taken for granted and must be examined and reviewed for each context as part of an impact assessment approach**.

Treated wastewater reuse should form part of an Integrated Water Resource Management approach.

Before returning materials to the soil, it is important to ensure that the output product is compatible with the environmental characteristics of the soil and plants.

In addition to the possible use of biogas, a complete energy audit of the sanitation chain should be carried out. This audit should take into account the energy consumption of treatment processes, especially those introduced to ensure the output products have the characteristics required for recovery. The energy consumed to transport products to the resource recovery and reuse site must also be included.

The environmental viability assessment can also be expanded to include uses, examining the extent to which they replace uses that generate greenhouse gases.

Challenge 2: Managing the health risks associated with sanitation product reuse and recovery

Reluctance to develop wastewater and sewage and faecal sludge resource recovery and reuse can often be due to the potential health risks, particularly when output products are used for irrigation and as soil amendments for crops intended for human consumption.

This section covers the dangers associated with the pathogens and chemicals contained in sanitation products, as well as the risks they can pose to the people exposed. The consumers of crops amended/irrigated with sanitation products are not the only group of people exposed to these risks.

This section then describes different health risk management approaches, how these are translated into regulations, and their limitations for application and adaptation to contexts. There are a number of approaches that can be adopted, and these can also be combined:

- Define and monitor quality standards for treatment plant output products
- Take post-treatment barriers into account: sanitation product modes of use
- Restrict uses and modes of use

Danger, exposure and risk

1) The components that pose a potential danger to human health

Agents pathogènes

Type d'agent pathogène	Description	Routes of contamination	Examples of pathogens	Key health risks	Indicators of presence
Virus	Intracellular parasitic microorganisms that need a host cell to multiply	Ingestion (main), inhalation (e.g. coronavirus, influenza), skin (herpes)	Enteroviruses, Rotaviruses, Enteric adenoviruses, Noroviruses, Hepatitis A.	Hepatitis, viral gastroenteritis, water- and food-borne epidemics	Bacteriophages (somatic coliphages, F-RNA coliphages)
Bacteria	Unicellular prokaryotic microorganisms, sometimes pathogenic	Ingestion (main), inhalation (e.g. Legionella)	E. coli pathogens, Salmonella, Shigella, Vibrio cholerae	Diarrhoea, dysentery, typhoid, cholera	Total coliforms, faecal coliforms (E. coli), enterococci
Protozoa	Unicellular eukaryotic parasites that form resistant cysts or oocysts	Ingestion (contaminated food or water)	Cryptosporidium, Giardia	Persistent diarrhoea, waterborne epidemics (e.g. Milwaukee)	Clostridium perfringens spores (BASR)
Helminths	Multicellular parasitic worms	Contact or consumption (excreta/untreated wastewater)	Ascaris, Trichuris, Ankylostomen	Malnutrition, increased susceptibility to infections, digestive disorders	Direct counting of helminth eggs

Chemical pollutants

Very low concentrations of chemical pollutants may remain in sanitation products. These are known as micropollutants.

The majority of micropollutants are found in 'non-domestic' wastewater and sludge, i.e. that come from industrial, craft or agricultural activities. Others are contained in human faeces and urine (drug residues) or in household greywater (cleaning products, hygiene products, cosmetics). Some micropollutants are also naturally present in the soil (particularly metals) or enter the soil as a result of human activities (such as pesticide use in farming). These can enter sanitation facilities through stormwater drainage, or even get

into drinking water, and then into treatment plants that use water.

Treatment processes tend to remove these micropollutants from the liquid phase (tertiary treatment processes, such as membrane filtration with a very low cut-off threshold or adsorption on activated carbon, can even remove them completely from treated wastewater). **They therefore tend to be concentrated in sludge.** This is particularly the case for heavy metals.

Some of the micropollutants found in sanitation products	Origin
Pesticide residue	Agriculture
Heavy metals = Metal Trace Elements (MTE)	Natural, industry, stormwater
Drug residues	Hospitals, domestic use
Microplastics	Industry, domestic use
Per- and poly-fluoroalkyl substances (PFAS)	Industry (if industrial effluent is discharged into the sewerage system)

The health risks from chemical pollutants are mostly associated with **agricultural use**. The people primarily exposed to these risks are the **consumers** of irrigated/amended crops and of fish from aquaculture that uses wastewater. It should also be noted that there is a risk of these pollutants seeping into the groundwater that is abstracted for domestic use.

Despite their low concentrations, the **cumulative effects** of their ingestion can pose a potential health risk.

2) People exposed to these components and routes of exposure

A variety of people can be exposed to the components potentially contained in sanitation products and which pose a danger to human health. The means of exposure (inadvertent ingestion, inhalation, and contact with the skin) will differ depending on the use and on the context in which the person is exposed.

Particular attention must be paid to the health risk posed by the ingestion by consumers of products amended/irrigated using sanitation output products. However, consumers are not the only people who can be exposed to these risks; agricultural use also poses a risk to other groups of people. Thus, these groups of people must also be taken into account. The health risk is to be considered based on the context and the role of the person exposed.

Person exposed / context	Route of exposure
People who transport faecal matter/sewage sludge from a WWTP/FSTP, from household facilities, and to the point of use. Those who manage systems transferring treated wastewater to the point of use, and storing wastewater if applicable. Users who come to collect sewage/faecal sludge from a WWTP/FSTP or an intermediate storage facility.	• Contact • Ingestion, which depends on hygiene practices (handwashing with soap)
People responsible for operating irrigation systems for farmland, green or urban spaces. Those responsible for the land application of sewage and faecal sludge.	
People (park visitors, golf players, local residents, etc.) who occasionally or regularly use irrigated or amended green spaces.	
Farm workers who handle amended/irrigated soil. Maintenance workers responsible for the upkeep of (public or private) irrigated/amended green spaces, street cleaning, etc. People who maintain fish ponds.	• Contact • Ingestion, which depends on hygiene practices (handwashing with soap)
People who harvest and sell (and therefore handle) irrigated/amended products. People who handle the fish from fishponds.	
The consumers of products irrigated or amended with treated wastewater or treated sludge, and of fish bred in fishponds.	• Ingestion
People living near the resource recovery and reuse point of use who use water resources that could have been contaminated by runoff /infiltration.	• Contact/injection

3) Risk and risk assessment

The health risks from using sanitation products are assessed by examining the relationship between a hazard and exposure.

The frequency and duration of exposure need to be taken into account:

- Diffuse exposure due to regular and prolonged use of and/or contact with products containing pathogens.
- Accidental exposure due to a sudden and unforeseen problem within a segment of the sanitation chain. This can be a problem in the treatment plant, with an irrigation system, an extreme weather event, etc.

Quantitative Microbial Risk Assessment (QMRA

This methodology quantifies the relationship between exposure to a pathogen and the probability that this will have undesirable health effects, such as infection, illness or mortality, correlated with epidemiological data for the local area concerned. The results are expressed in disability-adjusted life years (DALY).

This type of methodology is complex to implement and requires accurate data. It is implemented as part of research projects, on which international or national standards are based. WHO (2004) defines the tolerable burden of waterborne disease as being $\leq 10^{-6}$ DALY per person per year. This means, for example, that there is one chance in 100,000 that an individual will contract a fatal cancer in their lifetime; or there is a risk of 1 in 1,000 of contracting mild diarrhoea over the course of one year, and a 1 in 10 risk over a lifetime. These figures are used as the basis of the WHO recommendations, upon which national regulations are based.

Qualitative health risk assessment

The qualitative risk assessment is considered to be the most appropriate and financially viable risk assessment method.

It consists of identifying hazardous events and their likelihood and consequences based on the **judgement and experience of the stakeholders concerned** and data on the endemic nature of diseases. The risks are then ranked in categories, such as very low, low, medium, high, and very high, based on their combined probability and impact.

For this assessment method, all sanitation chain stakeholders, up to and including the resource recovery and reuse segment (see the organisational and financial models section), need to be identified and involved in order to develop a shared vision of the hazards, the people exposed, the frequency of exposure and, thereby, the risk; and to use this vision to jointly develop a health risk management strategy.

Different approaches to health risk management are described below. They can be implemented in combination with each other. Some international standards and national regulations recommend or require the use of these approaches, particularly for the agricultural use of treated wastewater.

- 1st approach : Make uses dependent on the quality of treatment plant output products
- 2nd approach : Take post-treatment barriers into account: sanitation output product modes of use
- 3rd approach : Restrict uses and modes of use

1st approach: Make uses dependent on the quality of treatment plant output products

1) For treated wastewater reuse

Parameters and thresholds for the following uses

SECONDARY TO TERTIARY WASTEWATER — Secondary to tertiary treated wastewater

Uses

- **Farming activities** (edible and non-edible crops) — FARMING ACTIVITIES
- **Irrigation of public green spaces** (gardens, parks) — PUBLIC GREEN SPACES
- **Irrigation of privately-owned commercial green spaces** (hotel grounds, golf courses) — PRIVATE GREEN SPACES
- **Washing of roads and networks** — URBAN CLEANING
- **Industrial processes, cooling systems** — INDUSTRIAL PROCESSES

Some international standards recommend threshold values for various physicochemical and microbiological parameters in wastewater, which vary depending on the type of use. This principle has been incorporated, adapted and detailed in numerous national regulations. It should be noted that these regulations apply predominantly to agricultural uses.

WHO has defined the following recommendations for use in agriculture:

- ≤ 1 helminth eggs per litre of treated wastewater.
- Health protection for children: when children under the age of 15 are exposed by eating raw vegetables grown in fields irrigated with treated wastewater containing ≤1 egg per litre, additional health protection measures must be put in place to ensure their safety.
- Localised irrigation for tall-stemmed crops: for crops irrigated using sprinkler or highly mechanical irrigation systems (crops whose harvested product is not in contact with the soil), it is not necessary to define helminth egg concentration thresholds.

FOR MORE INFORMATION:

- For more information: WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater - Volume II, Wastewater use in Agriculture, WHO, UNEP, FAO, April 2013

Mediterranean Focus

Moroccan, Tunisian and Palestinian regulations are based on specific standards that treated wastewater has to meet depending on its use (see **chapter 3**).

Based on WHO recommendations, the standard in these countries is a helminth egg count of 1/litre or less. The Moroccan standard even requires an egg count of zero for certain uses;

◄ Parameters and thresholds for aquaculture (use of treated wastewater in fishponds)

There are few regulations governing this practice, but the risk of pathogens penetrating fish flesh or muscle is low (with the exception of trematodes, tissue parasites associated with high morbidity).

WHO recommends the following microbial quality targets for water in fish ponds:

- Undetectable trematode eggs;
- ≤104 E. coli (arithmetic mean per 100ml or per g of total solids);
- ≤1 helminth egg (per litre or per g of total solids).

SECONDARY TO TERTIARY WASTEWATER — **Secondary to tertiary treated wastewater**

Uses

Aquaculture (use of water in fishponds) — **AQUACULTURE**

Mediterranean Focus

Although common in Asia, this use is rare in Mediterranean countries.

FOR MORE INFORMATION:

- WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater - Volume III, Wastewater and Excreta use in Aquaculture, WHO, April 2013

◄ Monitoring procedures

WHO recommends the following microbiological testing frequencies:

- In urban areas: once a fortnight for E. coli and once a month for helminth eggs;
- In rural areas: once a month for E. coli and once every 1 to 2 months for helminth eggs.

However, WHO also recommends ensuring that physico-chemical and microbiological parameters can be monitored quickly and easily using analysis methods that are adapted to local technical and financial capacities. For example, given the correlation between suspended solids and intestinal helminth concentrations, monitoring turbidity can provide sufficient information on helminth concentration levels at the treatment process stage.

In addition, depending on the endemic nature of diseases in the area concerned, it may be necessary to look for specific pathogens, such as Ascaris. E. coli is used as an indicator organism to determine the potential presence or absence of pathogens in water. However, no E. coli does not mean there are no pathogens.

Lastly, if the treatment plant receives non-domestic wastewater or sewage, tests to monitor levels of chemical pollutants used in the relevant craft and industrial activities can be carried out. However, many chemical micropollutants, particularly heavy metals, tend to accumulate in sewage and faecal sludge rather than in water.

Mediterranean Focus

Regulations in Mediterranean countries provide information on the parameters to be analysed and the frequency of analyses, but contain little information on where sampling points should be located.

2) For *sewage/faecal sludge reuse*

Regulation of the use of sanitation products and faecal sludge is not yet widespread in low- and middle-income countries, and is the subject of debate in many countries, including France.

Parameters and thresholds for the following uses:

BE/BV — Sewage/faecal sludge

- **Farming activities** (edible and non-edible crops) — FARMING ACTIVITIES
- **Irrigation of public green spaces** (gardens, parks) — PUBLIC GREEN SPACES
- **Irrigation of privately-owned commercial green spaces** (hotel grounds, golf courses) — PRIVATE GREEN SPACES
- **Soil amendment for forestry** — FORESTRY

Bacteria and viruses have a limited lifespan in the soil. In order to use sludge for agriculture, the key parameter to be tested is helminth concentrations in the sludge. WHO recommends monitoring the presence of helminth eggs and E. Coli and uses the following threshold values:

- <1 helminth egg per g of total solids;
- <1,000 E. Coli per g of total solids.

The U.S. Environmental Protection Agency (USEPA) has defined a "class A" category of sewage/ faecal sludge, which is suitable for any type of use:

- Faecal coliform levels in sewage sludge must be less than 1,000 Most Probable Numbers (MPN)[K] - per gram of total solids (based on dry weight);
- Salmonella sp. bacteria levels in sewage sludge must be less than 3MPN per 4 grams of total solids (based on dry weight).

If the sewage/faecal sludge does not meet these standards, it is considered to be "class B". The EPA authorises its use, but only in compliance with certain conditions and restrictions of use. This therefore forms part of the approaches described below, Take post-treatment barriers into account: sanitation output product modes of use and Restrict uses and modes of use.

Where the output product qualifies as **compost**, it must meet the fertiliser requirements approved by the national agency responsible for certifying compost products.

Monitoring mechanisms

In-depth analyses of sludge and soil can be carried out at the implementation stage to validate feasibility of the intended uses.

At the operational stage, the monitoring mechanisms (parameters analysed and frequency of analyses) must be adapted to the local technical and financial capacities of the people involved in the monitoring process.

Sludge can be tracked in 'batches'. This involves recording its origin, quality and destination, so that any causes of contamination can be traced. A batch of sludge can be defined as a quantity of sludge produced under uniform conditions over a given period (start and end dates), which has been clearly identified (name, code or unique batch number), undergone a sludge content analysis, and is of homogeneous composition.

Chemical micropollutants from non-domestic wastewater/sewage input products tend to accumulate in the sludge after treatment rather than in the wastewater. The monitoring of chemical pollutants in sludge, and especially their accumulation in amended soil, is therefore particularly relevant for sewage/faecal sludge reuse.

Mediterranean Focus

Mediterranean countries have very few measures in place for monitoring sludge use, with the partial exception of Tunisia.

K. The MPN method is used to obtain quantitative data on concentrations of discrete items from positive/negative (incidence) data. It involves taking the original solution or sample and subdividing it by orders of magnitude (frequently 10× or 2×) and assessing presence/absence in multiple subdivisions.

3) Defining and monitoring quality standards for treated on-site sanitation system output products leaving the treatment system for domestic reuse

FS Faecal sludge

Uses

- Soil amendment for family vegetable gardens → FAMILY GARDENING
- Home soil amendment (non-agricultural) → HOME SOIL AMENDMENT

URINE AFTER STORAGE

Uses

- Soil amendment for family vegetable gardens → FAMILY GARDENING

There is little mention of this type of reuse in international and national recommendations and regulations, which define the standards in terms of the output products' characteristics.

WHO recommends storage times rather than output product characteristics.

As a reminder, for the agricultural use of sludge:

- Ambient temperature of 2-20°C: storage of approximately 1.5 to 2 years is required;
- Ambient temperatures of between 20 and 35°C: one year of storage will suffice;

of urine:

- 6-months of storage (at a temperature of 20°C) in an airtight container.

Urine collected directly by a household in urine diverting facilities requires no specific treatment for pathogens before being used as a fertiliser. Urine-oral transmission of the disease within the household is much less likely than daily contact between household members.

Mediterranean Focus

There are few regulations governing on-site sanitation in Mediterranean countries. Regulations implicitly cover collective treatment systems only. The Support for Integrated Water Resources Management (AGIRE) programme, carried out as a partnership between Morocco's Ministry of Energy, Mines, Water and the Environment's Water Department, the Tensift, Souss-Massa-Drâa and Oum Er-Rbia water basin agencies and GIZ, focused on sanitation in rural areas of Morocco. A range of on-site facilities were piloted, and the lessons learned published. Discussions are now underway to incorporate on-site sanitation into the current regulations.

4) Defining and monitoring specific quality standards for treatment plant output products from treatment plants that receive non-domestic wastewater/sludge

The sanitation product health risk management strategy needs to include measures to ensure that chemical pollutant concentrations in the soil do not exceed certain thresholds. WHO considers that the probability of these thresholds being exceeded for organic pollutants (e.g. pesticides, pharmaceutical products) is low, but that the accumulation of inorganic pollutants, particularly heavy metals, requires closer monitoring.

Heavy metals are therefore of particular concern as they can enter into the food chain if they accumulate in the soil. Heavy metals are mainly found in industrial effluent from urban areas. In many countries, particularly in the Mediterranean region, urban industrial effluent is collected in sewerage systems and conveyed to WWTP for treatment. During the treatment processes, heavy metals tend to accumulate in the sludge rather than in the water.

Thus, the health risk associated with chemical pollutants stems primarily from the presence of heavy metals in treated sludge from WWTP in urban areas that receive industrial wastewater.

FOR MORE INFORMATION:

- For more information on the maximum concentration thresholds for chemical pollutants in soils recommended by WHO, please see: WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater - Volume II, Wastewater use in Agriculture (p 73), WHO, UNDP, FAO, 2013

Limitations of a health risk management approach based on defining and monitoring the quality of treatment plant output products

A sanitation product quality-focused approach means that health risk management is based on treatment plant performance. The processes applied must be able to reduce pathogens sufficiently to meet the requirements of the intended reuses.

This approach requires:

- Often advanced treatment plants that use disinfection (wastewater) and sanitisation (sewage/faecal sludge) processes;
- Advanced output product quality monitoring mechanisms, with a defined analysis frequency and which include both physico-chemical and microbiological parameters.

At the operations stage, these treatment processes and monitoring mechanisms may not be compatible with the human, technical and financial resources available:

- For the operations and maintenance of the disinfection and sanitisation processes.
- For taking samples, transporting these samples, conducting reliable analyses, interpreting the results and taking corrective action based on these results. In addition, it can take a significant amount of time to obtain the results of microbial performance indicators, at least 24 hours for E. coli, for example.

It is vital that the context-specific parameters associated with 'Existing technical and financial capacities and capacity-building opportunities' used to guide decision-making in each segment of the sanitation chain (see p. 102) are taken into account to verify the feasibility of combining treatment processes and uses.

Furthermore, this is a top-down approach. It is based on technical standards defined by a national authority or, alternatively, by a project developer who adopts international benchmarks, which are to be applied by local stakeholders who are directly impacted by the uses and associated risks. It does not take into account their perception of these risks, or their practices and knowledge that could influence the risk management strategy: hygiene practices, consumption habits, farming practices, use of irrigated/amended areas, whether or not diseases are endemic, etc.

As a result, while safe from a health perspective, this approach may **hinder the development of sanitation product reuse and recovery**, and even affect the sustainability of existing informal initiatives.

Mediterranean Focus

The cautious wastewater reuse approach adopted in Tunisia limits possible applications to a few specific uses. This rigid framework is hindering the development of other practices, despite the country's growing water resource management needs. In addition, treated wastewater quality monitoring is being hampered by the lack of trained staff and the small number of laboratories qualified to analyse certain critical parameters, such as helminth eggs. Furthermore, laboratory analysis turnaround times do not allow for emergency testing in the event of non-compliance.[L]

In Morocco, project implementation is being delayed by issues encountered in the practical application of many of the current standards. The standard relating to the quality of water used for irrigation, for example, has restrictive thresholds and a high monitoring frequency. For helminth eggs, WHO acknowledges that the tests required to detect a single egg per litre are expensive and difficult to implement, which is also a major obstacle.[M]

L. Guide à la décision pour la mise en œuvre d'un projet REUT - Réutilisation d'Eaux Usées Traitées, BRL, Jun 2022

M. Chantier COSTEA Reuse - Réutilisation des eaux usées en agriculture - rapport de synthèse Maroc, COSTEA Eau, Agriculture et Territoires (ETA), Brahim Soudi et Khaoula Zahraoui, mars 2022

2nd approach: Take post-treatment barriers into account: sanitation product modes of use

Thus, a health risk management approach cannot be limited just to treatment plant pathogen reduction targets and disinfection/sanitisation. Pathogens in wastewater treatment plant output products can be further reduced by specifying sanitation product modes of use.

Rather than focusing on wastewater characteristics, the WHO approach consists of looking at the impact on human health based on the tolerable burden of disease.

The tolerable burden of disease is a health-related measure expressed in DALYs. A DALY is an international measurement unit that equates to one year of life lost due to ill-health, disability or early death. For treated wastewater reuse, WHO defines the tolerable burden of disease as being ≤10–6 DALY per person per year. This is very strict, as it is identical to the target for drinking water.

WHO considers human health to be protected when pathogen reduction is:

- for non-food crops: 3 log for highly mechanised farms; 4 log for labour-intensive farms;
- for food crops: 6-7 log.

These pathogen reduction targets can be achieved not only through the treatment processes applied, but also via 'post-treatment barriers'.

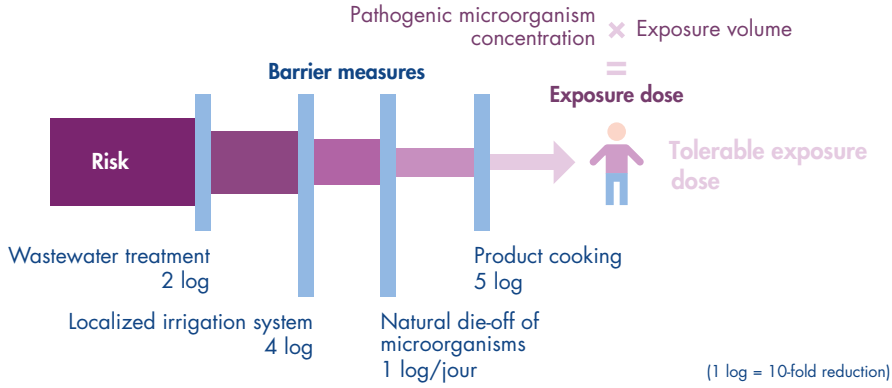


Diagram taken from the thesis written by Alice-Rose Thomas. Application de l'approche Multi-barrières pour la réutilisation des eaux usées traitées : Construction d'un outil de simulation participative pour accompagner l'évaluation et la gestion des risques associés aux micro-organismes pathogènes. Ingénierie de l'environnement. INSA de Lyon, 2024

These barriers, initially developed for treated wastewater, can also be applied to soils amended with treated sewage and faecal sludge.

The tables below list the 'post-treatment' barriers that can be put in place for the various reused/recovered output products, their uses and the categories of person exposed. It also reviews their practical application.

1) Post-treatment barriers (modes of use) for the reuse of treated wastewater

Use	Mode of use	Barrier
IRRIGATION OF GREEN SPACES (PUBLIC SPACES, HOTEL GROUNDS, GOLF COURSES)	Irrigation: Irrigation is usually via a sprinkler system, as the aim is to provide water to the entire area rather than to just a specific location	Irrigation at a minimum distance from housing and busy areas (WHO recommendation: 50 to 100m) (1) Spray drift limits (2) Restrictions on irrigation frequency, irrigation at night (3) Avoid irrigation in strong wind and during heavy rain (4) Restricted access during irrigation: fencing, signage (5)
	Site traffic	Restricted access for a set period after irrigation: fencing, signage
CLEANING OF URBAN SPACES, ROADS AND NETWORKS		Personal protective equipment (PPE)
AGRICULTURAL IRRIGATION	Irrigation	Buried drip system (1) Restricted access during irrigation: fencing, signage (2)
	Harvesting	Personal protective equipment (PPE: gloves, boots; handwashing or bathing (1) Mechanisation (2) Natural pathogen dieback: pre-harvest interval (3)
	Marketing	Natural pathogen dieback: storage before sale (4) Washing with drinking water or with disinfectant (5)
	Consumption (of edible crops)	Washing (1) Peeling (2) Cooking (3)

Stakeholders exposed, to be protected by the barrier	Application	Pathogen reduction (log)
People potentially in direct contact with the wastewater during irrigation: Gardener, unexpected visitors, local residents	Requires the necessary infrastructure (1,2), and good practices on the part of the irrigated site's owner (3,4,5) Recognised in regulations, where these exist	1 log per barrier (1, 2)
People in contact with the irrigated soil: Gardeners, visitors	Requires good practices on the part of the irrigated site's owner and visitors	0.5–2 log / day
People in direct contact with the wastewater: People carrying out cleaning operations, people nearby	Requires good practices on the part of the stakeholder responsible for urban spaces/roads/ networks	
People potentially in direct contact with the wastewater during irrigation: Farm workers, unexpected visitors	Requires the necessary infrastructure (1), and good practices on the part of the farmer (2) Recognised in regulations, where these exist	Low-stemmed crops: 2 log; High-stemmed crops: 4 log (1)
People in contact with the irrigated soil and crops: Farm workers	Requires good practices on the part of the farmer (1,3) and the retailer (4,5), the availability of PPE (1), soap and water (5), the availability of equipment for mechanised agriculture (2)	0.5 to 2 log/day (pathogen dieback) (3,4) 1 log or 2 with disinfectant (5)
People ingesting the irrigated crops: Consumers		
People ingesting the irrigated crops: Consumers	Requires good practices on the part of the consumer	1 log or 2 with disinfectant (1) 2 log (2) 6-7 log (3)

2) Post treatment barriers (conditions of use) for the recovery of sewage sludge /feacal sludge and compost

Use	Mode of use	Barrier
FARMING ACTIVITIES AMENDMENT OF NON-AGRICULTURAL SPACES	Land application	Personal protective equipment (PPE: gloves, boots; handwashing or bathing (1)
		Incorporating the sludge into the soil (2) Restricted site access: fencing, signage (3)
		Minimum distances (housing, water resources, infrastructure) Avoid sloping ground Avoid application in rain/frost Restricted site access (fencing, signage)
FARMING ACTIVITIES	Harvesting	Personal protective equipment (PPE: gloves, boots; handwashing or bathing (1) Mechanisation (2) Natural pathogen dieback: pre-harvest interval (3)
	Marketing	Natural pathogen dieback: storage before sale (3) Washing with drinking water or with disinfectant
	Consumption (of edible crops)	Washing Peeling Cooking

There may be recommendations or guidelines in place for the barriers that require the adoption of good practices; however, it is difficult to ensure they are properly applied. The stakeholders required to adopt these practices should be involved in defining these health risk reduction measures to ensure their understanding and buy-in.

The barriers that require infrastructure are more reliable, but the stakeholders responsible for operating this infrastructure need to be involved in its implementation and provided with the necessary training.

Stakeholders exposed, to be protected by the barrier	Application
People in direct contact with the sludge: Transporter of the sludge to the farm, Farm workers	Requires good practices on the part of the sludge transporter (1), and the farmer (1,2,3)
Pe ople in direct contact with the sludge during its application and people in contact with the amended soil and crops: Farm workers, unexpected visitors	
People in direct contact with the sludge: Farm workers, unexpected visitors Local residents	At the project stage, the choice of site can be influenced by its topographical, hydro-geological and geographical characteristics, and whether the land is being used for human activities. At the operations stage, this barrier requires good practice on the part of the farmer
People in contact with the amended soil and crops: Farm workers	Requires good practices on the part of the farmer (1,3) retailer (4,5), on the availability of PPE /soap and water (1,5), the availability of equipment for mechanised agriculture (2)
People ingesting the irrigated crops: Consumers	
People ingesting the irrigated crops: Consumers	Requires good practices on the part of the consumer

For barriers that require the availability of equipment (PPE, farming equipment) and resources (soap and water), it is important to determine whether these resources and equipment are likely to remain available long-term given the local context.

Limitations of a health risk management approach that takes post-treatment barriers into account: sanitation output product modes of use

This approach seeks to reflect the situation on the ground.

In many contexts, high levels of treatment are not always technically and financially feasible, and wastewater that has not undergone a high level of treatment is already widely reused.

However, this multi-barrier approach remains difficult to implement on the ground, and difficult to formalise and translate into regulations and standards.

The majority of 'post-treatment' barriers involve good practices, the responsibility for which is shared among various stakeholders, both professionals and the general public. These barriers can be simple to implement but difficult to monitor.

It could be argued that the irrigation barrier could be better monitored. This barrier is implemented using infrastructure managed by a defined stakeholder (who needs to be involved to ensure this infrastructure is correctly managed). This barrier is specifically mentioned in existing regulations.

Research is underway to improve implementation of the multi-barrier health risk management approach, specifically by developing participatory approaches to ensure all relevant stakeholders are involved (stakeholder exposed/responsible for applying the barrier).

3rd approach: Restrict uses and modes of use

The identification of barriers has led some decision-makers to adopt restrictive sanitation product usage strategies.

1) Treated wastewater reuse

SECONDARY TO TERTIARY WASTEWATER — Secondary to tertiary treated wastewater

Uses

- **Farming activities** (edible and non-edible crops) — FARMING ACTIVITIES
- **Irrigation of public green spaces** (gardens, parks) — PUBLIC GREEN SPACES
- **Irrigation of privately-owned commercial green spaces** (hotel grounds, golf courses) — PRIVATE GREEN SPACES
- **Washing of roads and networks** — URBAN CLEANING

Rather than integrating different modes of irrigation, harvesting, marketing and consumption into a multi-barrier approach, some regulations restrict irrigation to the following uses:

- the irrigation of non-agricultural land
- the irrigation of farmland, but only for certain crops, for instance:
  - crops not for human consumption, industrial crops (such as cotton), feed crops (for feeding farm animals, after storage);
  - crops consumed cooked;
  - crops that do not grow close to the ground.

Mediterranean Focus

This type of restrictive strategy can be found to varying degrees in the regulations adopted by Tunisia, Morocco and Palestine (see **chapter 3**).

Aquaculture (use of water in fishponds) → AQUACULTURE

As a precaution, reuse can be limited to types of fish eaten cooked or even to those not consumed by humans. Any fish not consumed by humans can be a valuable source of protein for other high-value carnivores (such as prawns), or be converted into fishmeal for pigs and poultry.

2) Sewage/faecal sludge recovery

SS/FS → Sewage/faecal sludge

Uses

Farming activities (edible and non-edible crops) → FARMING ACTIVITIES

Irrigation of public green spaces (gardens, parks) → PUBLIC GREEN SPACES

Irrigation of privately-owned commercial green spaces (hotel grounds, golf courses) → PRIVATE GREEN SPACES

Soil amendment for forestry → FORESTRY

In order to protect visitors to landscaped or natural green spaces, the 'site traffic' barrier could involve prohibiting use on green spaces open to the public.

Some regulations (or project strategies, if there are no regulations in place) also restrict the use of amendments to:

- non-agricultural land;
- farmland used for crops not for human consumption;
- farmland used for crops consumed cooked.

Mediterranean Focus

Regulations in Mediterranean countries do not currently specify which crops can be treated with sewage/faecal sludge. However, regulations are currently being drawn up in Morocco.

This provides an opportunity for developing a health risk management strategy with a pilot project component (see Case Study no. 2).

3) Domestic resource recovery and reuse of on-site sanitation products: faecal sludge and urine after storage

FS Faecal sludge

Uses

- Soil amendment for family vegetable gardens → FAMILY GARDENING
- Home soil amendment (non-agricultural) → HOME SOIL AMENDMENT

URINE AFTER STORAGE

Uses

- Soil amendment for family vegetable gardens → FAMILY GARDENING

Use could be restricted to crops consumed cooked, or not for human consumption (ornamental plants or crops grown for animal feed only).

Limitations of a restrictive approach

This approach can help effectively minimise certain risks.

However, as with quality monitoring and management, this is a top-down approach that does not take into account local stakeholders' perception of risk, practices and knowledge that could influence the risk management strategy: hygiene practices, consumption habits, farming practices, use of irrigated/amended areas, whether or not diseases are endemic, etc.

This approach could therefore limit resource recovery and reuse opportunities and undermine existing initiatives, and all as a precaution that is out of step with the local context.

Mediterranean Focus

Regulations in Morocco, Tunisia and Palestine include restrictions on the use of wastewater and a list of authorised crops.

The regulations in Lebanon also contain restrictions, which are combined with a multi-barrier approach for authorised crops.

Managing the health risks associated with sanitation product reuse and recovery: key points

When developing a project to incorporate a resource recovery and reuse segment into the sanitation chain, the health risk management strategy should take the following into account:

- National regulations (where these exist), which generally demand high quality output products involving advanced treatment processes and impose restrictions on use. However, regulations do not cover all uses (non-agricultural uses are less well-regulated) or all sanitation products (there is less regulation of sewage/faecal sludge reuse). This can provide project developers with both an opportunity and a responsibility to develop a tailored strategy.

- The local context, particularly:
  - o the alignment between the planned additional disinfection (water) / sanitisation (sludge) treatments and the technical and financial capacities of the WWTP/F-STP operators;
  - o the alignment between planned uses and the practices of the target users (farmers, those in charge of green spaces, etc.);
  - o the treatment plant operators' and resource recovery and reuse segment stakeholders' perception of risk;
  - o any existing resource recovery and reuse practices, including both the extent and modes of use;
  - o the presence of endemic diseases in the area concerned.

These aspects all have a significant sociological component, which is further developed in challenge 4.

Without unnecessarily restricting agricultural uses from the outset, it is important to approach health risk management with the understanding that it is less relevant for non-agricultural uses, and there are some uses to which it does not apply at all.

However, when using sanitation products for aquaculture, and irrigation and soil amendment (whether for agricultural use or not), all groups of people exposed to the health risks posed by the potential presence of pathogens in sanitation products need to be taken into account, i.e. not only consumers.

In an attempt to overcome the regulatory obstacles to developing wastewater and sewage/faecal sludge resource recovery and reuse, some projects are focusing on advocacy. Through a process of experimentation, knowledge management and discussion, field projects can help shape how regulations are updated or defined.

FOR MORE INFORMATION ON HEALTH RISK MANAGEMENT

- **WHO guidelines for the safe use of wastewater, excreta and greywater:**
  - WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume I: Policy and Regulatory Aspects, WHO, UNEP, April 2013
  - WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume II: Wastewater Use in Agriculture, WHO, UNEP, FAO, April 2013
  - WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume III: Wastewater and Excreta Use in Aquaculture, WHO, April 2013
  - WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume IV: Excreta and Greywater Use in Agriculture, WHO, January 2012
  - Sanitation Safety Planning, Manual for the Safe Use and Disposal of Wastewater, Greywater and Excreta, WHO, 2016

- **UN Food and Agriculture Organisation (FAO) guidelines**
  - Guidelines for the safe use and reuse of water in food production and processing, FAO/OMS, Codex, Alimentarius Commission, cxg 100-2023, 2023

- **United States Environmental Protection Agency (USEPA) guidelines**
  - Guideline for water reuse, USEPA, USAID, 2012
  - Domestic Septage Regulatory Guidance, USEPA, 1993
  - Guide to Septage Treatment and Disposal, USEPA, 1994
  - Process Design Manual Land Application of Sewage Sludge and Domestic Septage, USEPA, 1995
  - A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, USEPA, 1994

- **Other resources:**
  - L'approche multi-barrière comme gestion alternative des risques pathogènes pour la réutilisation des eaux usées traitées, TSM n°5 2024, A.-R. Thomas, r. Declercq, E. Hassenforder, P. Molle, R. Lombard-Latune, 2024
  - Technical Guidance – Water Reuse Risk Management for Agricultural Irrigation Schemes in Europe, Publications Office of the European Union, Maffettone, R.; Gawlik, B.M., 2022

[4] - Conception des stockages et gestion par lots des boues d'épuration épandues en agriculture, Ingénieries eau-agriculture-territoires, 29, p. 17 - p. 26.J. Wiart. 2002

- Évaluer les rendements des stations d'épuration - Apports méthodologiques et résultats pour les micropolluants en filières conventionnelles et avancées, Techniques Sciences et Méthodes n° 1-2 : 44-62, Choubert J.-M., Martin-Ruel S., Budzinski H., Miège C., Esperanza M. Soulier C., Lagarrigue C., Coquery, M, 2011

Challenge 3: Organisational and financial models

This section describes the challenges involved in ensuring the **sustainable operation of a sanitation chain that includes a resource recovery and reuse segment**. It therefore focuses on organisational and financial operating models.

- For organisational models, this section outlines the new activities introduced into the sanitation chain through integration of a resource recovery and reuse segment and the roles that the various stakeholders can play.
- For financial models, this section details the impact that a resource recovery and reuse segment can have on the income and expenditure of the various stakeholders involved, and which need to be identified and included in the financial model to ensure this is suitably adapted.

Organisational models – who does what ?

Incorporating a resource recovery and reuse segment into the sanitation chain will entail the introduction of new activities that will need to be identified. It will also be important to identify the stakeholders who could help manage these activities, and to define the scope of their new responsibilities.

The activities detailed below help ensure operation of the sanitation chain. For each of these activities, it should be noted that either each role can be filled by a different stakeholder, or the same stakeholder can take on several roles.

This section does not cover the regulatory role of state bodies.

Intermediate transport segment

Activity: transport from users to the treatment plant

Where **wastewater is conveyed through the sewerage system**, the stakeholder in charge of this segment is often the same as the stakeholder responsible for the treatment plant. The same organisational authority is responsible for managing and operating the sewerage system and the WWTP (potentially using different management models). These responsibilities can also be divided between two stakeholders, with one organisational authority responsible for the sewerage system and a second for the WWTP. For large sanitation systems with wastewater collection and wastewater transfer networks, responsibilities can be further divided, with a different stakeholder responsible for each of these systems. In practice, responsibility for this transport segment tends to be assigned to a public organisational authority, who may then delegate its management.

For **faecal sludge collection**, responsibilities are more commonly divided. There are usually stakeholders in charge of transport and a stakeholder responsible for treatment. In some instances, particularly where access to houses is difficult for large vehicles, there is a further division of tasks, with stakeholders responsible for pit emptying and others for transport. The faecal sludge removed from on-site systems is taken to an intermediate storage site for collection by the transport stakeholder responsible for taking the sludge on to its next destination. These are often private or informal stakeholders. However, various setups are possible, with the same stakeholder sometimes being responsible for different sanitation chain segments and segment components.

Introducing a resource recovery and reuse segment influences the choice of technologies and facilities throughout the sanitation chain. Therefore, this activity can also be affected.

Treatment segment

Activity: treatment plant operations

The treatment plant operator is typically responsible for ensuring operation of a treatment plant that discharges products with characteristics that have no adverse effect on the receiving environment. Reuse often entails an additional treatment, as well as transporting the reusable products to their point of use.

This therefore has implications for the scope of the treatment plant operator's responsibility for the plant's financial and organisational operations and management:

Where does the treatment plant operator's responsibility end? Who then manages the "product" up to the point of reuse? Where does the responsibility of the stakeholder benefiting from the reuse begin?

Introducing a resource recovery and reuse segment can complicate this activity as additional treatment is often required in order to obtain a product suitable for recovery/reuse.

Management of an additional treatment process for resource recovery and reuse is considered here to be a new activity, as described below.

Furthermore where separation at source is not feasible for non-domestic input products to WWTP/FSTP, customised pretreatment for specific industrial activities may need to be introduced. This will be all the more important where sanitation products are intended for resource recovery and reuse, as this resource recovery and reuse could be compromised by micropollutants in the industrial wastewater, which are difficult to remove through wastewater and sludge treatment processes alone. Thus, discussions may need to be held between the WWTP operator and industries to encourage industries to install and manage industrial effluent treatment processes upstream of the sewerage systems that will then convey this effluent to the WWTP.

Activity: management of additional disinfection/sanitisation treatment processes

This activity is introduced when a resource recovery and reuse segment is integrated into the sanitation chain.

Where tertiary treatment is required to ensure the products are of suitable quality for their intended use, it usually makes sense for the treatment plant operator to manage and carry out these treatment processes on-site. Therefore, the impact on the plant operator's financial and organisational models (human resources, skills required) will need to be considered, particularly if the technologies used generate additional human resources and energy consumption costs.

Activity: monitoring treatment plant performance and output product quality

At the operations stage, this monitoring can be carried out by the operator as part of a self-monitoring approach regulated by legislation and/or a national regulatory authority.

Introducing a resource recovery and reuse segment can often complicate this activity. For uses that carry health risks, the risk management strategy often involves monitoring microbiological parameters in the treatment plant output products, or in irrigated/amended soils. Some national sector frameworks provide for additional monitoring and support, or this could be introduced where not already the case.

Resource recovery and reuse segment

Activity: intermediate storage

This activity is introduced when a resource recovery and reuse segment is integrated into the sanitation chain.

In order to adapt supply to the timebound (over the course of a day) and seasonal (over the course of the year) requirements of the demand, sanitation products may need to be temporarily stored.

Prior to it reuse for the irrigation of farmland and green spaces, treated wastewater will need to be stored (to adapt to seasonal demand) and, in most cases, filtered. This can be undertaken by the treatment plant operator or by the stakeholder responsible for transporting the treated wastewater to its point of reuse.

Sewage/faecal sludge intended for use on farmland or for soil restoration will also need to be stored to adapt to seasonal demand. This storage can be combined with additional lime stabilisation treatment. It can be carried out by the treatment plant operator or by the stakeholder responsible for transporting the sewage/faecal sludge to its point of use.

Land availability and topography are key parameters for selecting the storage site location, and particularly for determining whether or not the storage facility can be built on the same site as the WWTP/FSTP. For off-site storage facilities, the 'transport of sanitation products' and 'additional co-treatment' activities become two separate components, the first to transport products from the WWTP/FSTP to the storage site, and the second to transport the products from the storage site to the point of use.

Activity: transport of sanitation products to their point of resource recovery and reuse

This activity is additional to the activity of transporting sanitation output products to their final destination. Whereas treated wastewater is often discharged under gravity near the treatment site, the final disposal of sewage/faecal sludge not intended for resource recovery and reuse can require a separate activity undertaken by different stakeholders.

It is rare for all sanitation products to be reused/recovered. Thus, both the transport of sanitation output products without resource recovery and reuse activity and the transport

of sanitation products to their point of resource recovery and reuse activity can be required.

A stakeholder will need to be identified to transport the sanitation products to their point of use.

For the agricultural use of sewage/faecal sludge, this will involve transporting the sludge from the treatment plant (WWTP or FSTP) to the farms.

For treated wastewater conveyed through a network to its point of reuse, such as farmland, this could involve an intermediate network operator, who would be responsible for this network from the treatment plant outlet up to the point of distribution.

Sanitation products suitable for recovery from on-site sanitation facilities can be:

- reused directly by the household concerned. Public or private services could be offered to help households ensure the quality of their sanitation products and select suitable modes of use.
- reused at the community level. A stakeholder will then be required to collect the sanitation products directly from households and transport them to their point of use.

Activity: additional co-treatment

This activity is introduced when a resource recovery and reuse segment is integrated into the sanitation chain.

An additional treatment process, such as co-digestion or co-composting, can be carried out by an intermediate stakeholder.

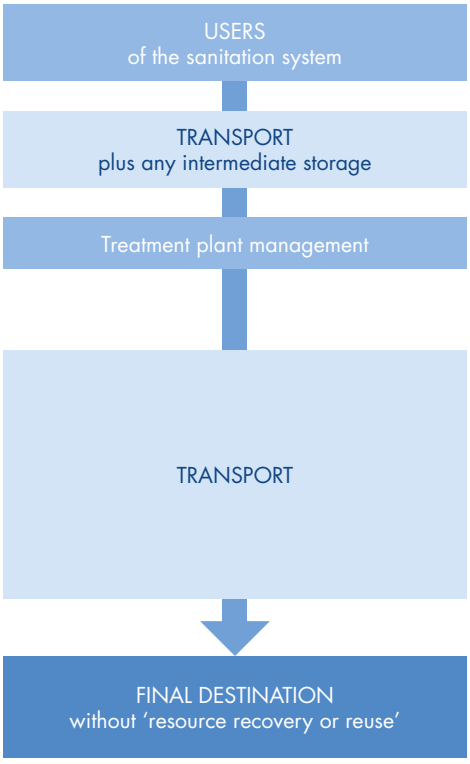
The treatment plant operator transfers the output products to the co-treatment facility operator. The co-digestion or co-composting facility operator needs to take the uses of the end products into account when developing their organisational and financial model.

This is also the case for sludge pyrolysis. The intermediate stakeholder collects the sludge from the FSTP for treatment in their pyrolysis system. This stakeholder then seeks to balance their organisational and financial model by selling the treated sludge for reuse.

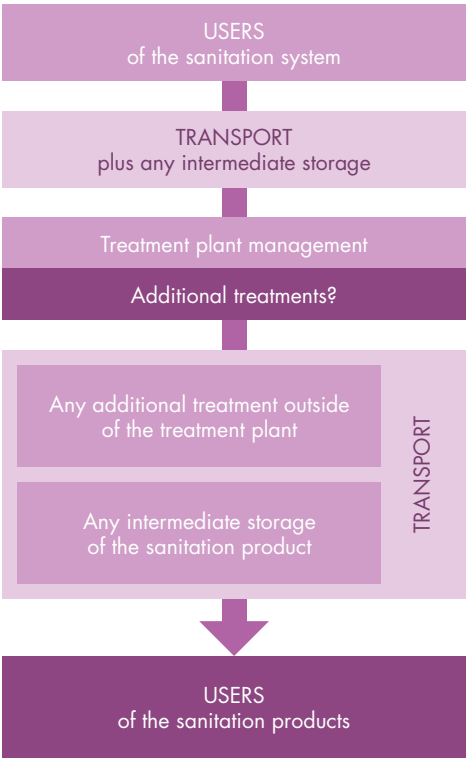
Les schémas suivants synthétisent :

- the main activities involved in the sanitation chain, from the access/containment segment (collection of faeces, excreta and possibly other inputs via a user interface, potentially involving partial or complete on-site treatment), through to the intermediate segment (transport to a treatment site) and treatment segment (in a WWTP or FSTP).
- the new activities introduced by integrating a resource recovery and reuse segment.

SANITATION CHAIN WITHOUT RESOURCE RECOVERY AND REUSE



SANITATION CHAIN WITH RESOURCE RECOVERY AND REUSE



For the resource recovery and reuse of a range of sanitation products, or for several uses of the same product, these additional activities will be multiplied, and should be adapted to each use for each product.

Sanitation output products are not all always reused/recovered, and there must always be a disposal option available in case of issues within the resource recovery and reuse segment that give rise to health or environmental risks. Thus, the transport to a final destination activity can sit alongside these new activities.

Financial model – who pays what, who is paid for what ?

It is crucial that the relevant stakeholders have the investment capacities required to establish a resource recovery and reuse segment.

Conditions conducive to private sector investment must be in place; these are inextricably linked to an enabling institutional environment. Depending on the government's financial capacities, state subsidies could be made available.

With sanitation resource recovery and reuse now gaining momentum, due especially to its environmental benefits, bilateral development aid donors, NGOs and international donors could also provide this type of investment.

The environmental and circular economy aspects of sanitation product resource recovery and reuse are also generating interest among French development aid donors.

This is particularly true of French decentralised cooperation and non-governmental organisations who raise their own funds (via the Oudin-Santini law). Their initiatives are supported by state development aid donors, the French Agency for Development, the French Ministry for Europe and Foreign Affairs, and water agencies.

Mediterranean Focus

There are many international donors supporting treated wastewater reuse projects in Palestine. For instance, the AFD is supporting the Tubas governorate and the operator in the villages west of Jenin to develop treated wastewater reuse as part of a decentralised cooperation project being led by the City of Paris.

In Morocco, the agricultural development fund is subsidising equipment for localised irrigation projects. However, it remains to be seen whether the model will be viable once it enters the operations phase.

Although treated wastewater reuse features highly in Mediterranean countries' sector strategies, there is no clear strategy for accessing financial aid to secure the required investment.

In Tunisia, the World Bank has allocated more than 100 million euros in investment support for the rehabilitation and implementation of tertiary treatment processes in the country's WWTP. WWTP management is centralised through Public-Private Partnerships agreed between Tunisia's national office of sanitation (ONAS: Office National de l'Assainissement) and Suez (14 WWTP in 4 southern governorates) and Águas de Portugal (Grand Tunis). However, in order to ensure viability of the model during the operations phase, the activities to be undertaken by local stakeholders need to be taken into account, particularly the transport of treated wastewater to its point of use.

This section does not cover the challenge of raising funding to support initial resource recovery and reuse segment investment. Instead, it focuses on the challenge that is operational sustainability. This is crucial as, even if solutions are found to finance investment (local, national or international resources), it is just as important to ensure the sustainability of the subsequent service provided.

This section examines the revenue and expenditure associated with the introduction of a resource recovery and reuse segment.

Impact of a resource recovery and reuse segment on expenditure

If the treatment plant operator (WWTP or FSTP) has had to install an additional treatment process, labour, maintenance and energy costs must be included in the operating account. These additional operating costs vary in accordance with the treatment technology used.

The impact of additional operating costs on the treatment plant operator's expenditure should be a key factor in the choice of treatment process and resource recovery and reuse option. If the feasibility study reveals that the treatment plant operator would be unable to achieve financial stability once the projected new expenditure is added to their financial model, then the solution is not operationally viable. Even if its implementation has attracted the attention of local and/or international public and/or private donors and it complies with the country's regulatory frameworks, the solution remains inappropriate for the situation.

Although often difficult to incorporate into operating accounts, the depreciation of investments should ideally be taken into account, as should provisions for the future renewal and replacement of the new facilities.

Sewage and faecal sludge treatment processes that involve dewatering reduce the volumes and weight of sludge to be managed regardless of its intended reuse. This then reduces the need for handling operations, for which machinery and transport is often required.

As seen above in the section on reducing greenhouse gas emissions, energy recovery can often be financially attractive as the energy required to carry out wastewater treatment processes can account for a significant proportion of total operating costs.

Some or all of the **sanitation output product quality monitoring** tasks are undertaken by the treatment plant operator. Depending on the risk management strategy, the health risks associated with certain uses, such as agriculture, can require the additional monitoring of microbiological parameters in treatment plant output products, or irrigated/amended soil analyses. The cost of these analyses can place a financial burden on the treatment plant operator, particularly if there are no laboratories nearby.

The key parameter to be taken into account **for the intermediate stakeholder transporting effluent directly from household latrines or from the FSTP or WWTP to its point of use** is the transport distance. Transport is the main cost factor and must be included in the feasibility study. Transport costs influence the marketability of the sanitation products, and therefore also have an impact on financial viability.

For instance, the main factor for the agricultural reuse of sewage/faecal sludge is the distance between the treatment and storage facilities and the farmland available for its use. The operating costs for this activity are predominantly made up of transport costs, inclu-

ding fuel, truck maintenance costs, and the wages of the truck drivers and pit emptiers. Added to this is the high cost of purchasing a truck, which will often have to be imported from Europe, and usually amounts to between €24,000 and €43,000. Operating costs include labour, fuel, ad hoc repairs and truck maintenance.

For treated wastewater reuse, the key cost factor is the length of the network required to transport this wastewater to its point of use.

Mediterranean Focus

A study carried out for the FAO by Soudi et al. (2016) on the Nador and Al Hoceima WWTP in Morocco revealed that, for distances of over 25km, it is more cost-effective to dry the sludge before transportation.[O]

Care must be taken to ensure that the sanitation products delivered to **intermediate stakeholders managing additional treatment processes** such as co-digestion or co-composting are suitable for the treatment systems and compatible with their performance objectives. The cost items to be considered for co-composting include labour, marketing, sales and distribution, transportation of products, inputs (such as ammonium sulphate), plant and equipment insurance, annual write-off, depreciation of equipment and furniture, as well as the legal and registration costs for the co-composting products.[5]

It is also important to bear in mind that introducing sludge recovery can help the treatment plant operator to reduce landfill disposal costs.

The **intermediate segment stakeholders** involved in transporting the sludge removed from on-site sanitation systems to a FSTP are not directly affected by the introduction of a resource recovery and reuse segment.

For the **users of sanitation products**, there must be a quality-based or financial advantage to choosing this product over other products available for the same use. As detailed in the following section, this decision is largely dependent on the context. In all cases, the users' financial contribution to the overall financial model needs to be defined, whether this is through direct purchase of the product (customer) or through the payment of a fee (user). There are various models that can be applied.

At first glance, **sewerage system users** are also not directly affected by the integration of a resource recovery and reuse segment. However, users with a user interface may be required to make a financial contribution, particularly where the sewerage system operator is responsible for covering the operating costs of additional treatment facilities. Thus, in order to their financial stability, the operator will often pass some of these operating costs onto the sewerage system users.

However, it is households who are responsible for installing and managing the toilets in their homes, as well as any associated pretreatment systems (collection and centralised additional treatment of pretreated output products or advanced treatment to produce output products suitable for direct recovery). The solutions adopted in the access/containment segment can be regulated to varying degrees by standards and regulations, driven by national or local authorities and/or by a development assistance programme.

O. Soudi, B., F. Poncelet et R. Grela. 2016 (Pour la FAO-ONEE) – Maroc. Étude d'opportunités de valorisation des boues des STEP-ONEE : plan prioritaire d'intervention pour les STEPs d'al Hoceima et de Nador

Sanitation chain guidelines for the reuse of sanitation products are also relevant to on-site sanitation system users. On-site sanitation facilities can have substantial investment and maintenance costs. For sanitation chains with a sludge collection component, pit emptying costs are generally borne by households.

Impact of a resource recovery and reuse segment on revenue

Treatment plant operators and stakeholders involved in the various transport and additional treatment activities should consider the feasibility of generating additional income to supplement the revenue received from sanitation service users. The financial models of the different sanitation chain stakeholders, and especially of the treatment plant operator, could include options for collecting revenue from users of the sanitation products.

However, the outputs produced for reuse do not constitute a guaranteed source of revenue able to ensure the wastewater treatment plant operator's financial stability.

Where the sanitation product is to be made available for reuse via a market, its users are customers who will only take up this new offer if its cost is adapted to their capacity-to-pay, and if this offer meets a need for which there are no other more advantageous alternatives.

Sanitation products can also be used by public services. However, if the public service user does not consider themselves in need of the particular sanitation product, they can view themselves as providing a service to the treatment plant operator by giving them an outlet for their product rather than benefiting from a service. The treatment plant operator will not be able to base their financial model on the sale of the product in this instance.

Sanitation products intended for agricultural use must be able to compete on price and quality with fertilisers and soil amendments already available on the market. A progressive pricing structure could be adopted to encourage users to try the new product. However, it can sometimes be difficult to later raise the price. It can also be useful to pilot the product on selected areas of farmland and organise awareness-raising campaigns and information visits to demonstrate the product's effectiveness.

In order to sell treated wastewater, it is important to have an idea of what users are willing to pay. It will be particularly important to assess commercial feasibility when restrictions are placed on products as a partial health protection measure.

The availability of a 'conventional' water resource and its cost have a major impact on the viability of **treated wastewater reuse**. In areas suffering from water stress, there may be no competition from other water resources as the wastewater produced for reuse may be the only resource available. However, in other instances, this wastewater may have to compete with another free or less costly resource.

Consequently, to encourage wastewater reuse, users are often charged less for wastewater than for water from other existing water resources. In some cases, where this is sufficiently offset by the social and environmental benefits, treated wastewater can even be distributed free-of-charge.

Mediterranean Focus

In Tunisia, It has been observed that, when available, conventional resources tend to be preferred to treated wastewater, despite this wastewater being provided at a lower cost.[P]

As a result, it can be difficult for the treatment plant operator and/or intermediate stakeholders to achieve financial stability. Additional treatment processes required to ensure the quality of sanitation products for reuse can increase costs, whereas additional revenue from the users of these products cannot be guaranteed.

Treated sewage and faecal sludge from WWTP or FSTP is often considered to be a 'by-product' and 'final sanitation waste'. Therefore, finding a suitable use for these products may be more important for the treatment plant operator than for any potential users. These products are therefore often provided free-of-charge to farmers. Even if the resource recovery and reuse segment does not always generate additional revenue for treatment plant operators, it provides them with a reliable means of reducing transport costs and developing a sustainable destination for these by-products.

The energy recovered from digestion processes can be directly used for treatment processes. While this does not generate revenue, it helps treatment plant operators recover some of the WWTP/FSTP operating costs. The energy obtained from digestion can also be sold on to external users. Thus, biomass raw materials are converted into high-value products that can be sold on the energy market. However, this advantage has to be weighed against the technical skills required and complexity of operating a digester.

Mediterranean Focus

In Tunisia, treated wastewater leaving the WWTP is available from ONAS free-of-charge. The pumping and transfer of this water to the irrigated area is the responsibility of the Regional Agricultural Development Commissions (CRDA), who come under the supervision of the Ministry of Agriculture and Fisheries, and who deliver the water to one or several agricultural development groups (GDA). Pumping station and water supply infrastructure maintenance costs are borne by the CRDAs. The CRDAs bill the GDAs for the treated wastewater used. Reports show that this symbolic price does not cover the operating costs of the reuse facilities (networks, pumping, storage, any filtration treatment), which are borne by the CRDAs.[Q]

In Lebanon, energy-intensive secondary treatment processes (activated sludge aeration tanks) are frequently at a standstill due to difficulties covering their operating costs. Given this situation, it will be difficult for WWTP operators to cover the costs of any additional dewatering and sludge sanitisation treatments, as these are also energy-intensive.[R]

P. B.,Noury, 07/04/2025

Q. « Réutilisation des eaux usées traitées en agriculture : analyse de l'état des lieux et perspectives – cas de la Tunisie, » FAO ; Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche Maritime (Tunisie), 2021.

R. Mihelcic et al. 2011, cité par : Mateo-Sagasta, Javier, et al. Water Reuse in the Middle East and North Africa, a Sourcebook. International Water Management Institute (IWMI), 2022

Focus on the impact of disinfection/sanitisation and biogas recovery treatments on the parameters relating to 'existing local technical and financial capacities and capacity-building opportunities'

- **Parameter: Energy consumption and associated operating costs**
- **Parameter: Technical sophistication of operations and maintenance tasks**
- **Parameter: Consumption of reagents and equipment renewal**

Tertiary treatment processes must be adapted to the treatment plant operator's technical, organisational and financial capacities.

Some treatment processes are highly energy-intensive and require advanced skills:

- Membrane filtration tertiary treatment
- Mechanical sludge dewatering tertiary treatment

Meanwhile, others require very little to no electricity, and only occasional operations and maintenance, which can be carried out with basic training:

- Maturation pond tertiary treatment
- Sludge drying bed sanitisation treatment

Certain **tertiary** treatment processes (**ozonation, UV, membrane filtration, activated carbon**) require special materials and equipment that are often not produced locally and can be difficult to renew and replace.

The energy produced through anaerobic digestion can be recovered from the **digesters** to meet the energy needs of the treatment plant. However, specific technical skills and considerable human and financial resources are required to operate these digesters, as well as the co-generation systems that produce electricity and heat from biogas. The main technical issues include clogging (in pipes, pumps and recirculation systems, often due to filings) and corrosion (on the metal equipment and structures). The temperature must be strictly controlled as any variations, particularly due to insufficient flow in the heating loop, can disrupt operation of the system.

For **activated carbon adsorption and filtration**, the adsorption capacity of the carbon has to be monitored. Once saturated, it loses its effectiveness and can release the adsorbed pollutants. Saturation can be detected by monitoring the quality of the treated effluent.

Private stakeholder involvement

Public stakeholders act in the public interest under the remits assigned to them by the regulations. Therefore, the financial model defined for the service needs to enable them to balance their operating budget, write off past investment and set aside provisions for future investment. Whereas private stakeholders opt to get involved if they see there is a chance to make a profit.

A distinction can be made between private stakeholders who:

> **1)** propose services to households;
>
> **2.1)** operate equipment and facilities, and a service, on behalf of a public authority;
>
> **2.2)** undertake the same role as in **2.1)** above but have provided part or all of the initial investment.

The activities of the first type of private service provider **1)** may be regulated through a licence issued by a regulatory authority.

The second type of private stakeholder **2)** often operates under a Public-Private Partnership (PPP).

2.1)-type private stakeholders operate under delegation contracts and seek to achieve financial stability by charging customers for their services to cover their operating costs and generate a profit. Private stakeholders focus more on performance than on tasks and operations. They bear part of the risk associated with market fluctuations (cost of fuel and raw materials, demand, unforeseen events, etc.).

2.2)-type private stakeholders operate under concession contracts. However, their involvement extends beyond the operating model, as it is they who take on the debt to finance investment. They recoup these investment costs through the revenue they receive for operating the service.

1) and **2.2)**-type private stakeholders are often in intermediate roles, supplying sanitation output products from on-site sanitation facilities, WWTP or FSTP.

2.1) and **2.2)**-type private stakeholders are often WWTP or FSTP operators, or intermediate stakeholders responsible for additional, post-WWTP/FSTP treatment processes.

Private stakeholders usually have a good understanding of local market demand and should be consulted during the market analysis phase to assess the feasibility of resource recovery and reuse options. The role of private stakeholders within the sanitation chain is sometimes defined in national sector frameworks. Although less common, this can also be the case for the resource recovery and reuse segment.

Mediterranean Focus

Tunisia has recently stepped up its use of Public-Private Partnerships (PPP) for rehabilitating and operating WWTP, and for developing tertiary treatments for wastewater reuse. ONAS has signed a €200 million, 10-year concession contract with a consortium led by SUEZ that covers 14 WWTP in the Sfax, Gabès, Médenine and Tataouine governorates. This private sector involvement has been instrumental in facilitating World Bank support of over €100 million in investment, particularly for tertiary treatment.

In Morocco, the regionalisation of water and sanitation service management introduced in 2024 via the creation of regional multiservice organisations (SRM: Sociétés Régionales Multiservices) has led to a return to direct management by these SRMs of WWTP previously managed by a private company under a PPP. Thus, Veolia has sold its shares in Lydec to the Casablanca-Settat SRM. The SRMs are now wholly publicly owned, with shares held by the State, local authorities or groups of local authorities, and the Office National d'Électricité et d'Eau Potable.

Organisational and financial models: key points

To ensure sustainable operation of the sanitation chain, the various organisational arrangements must be accompanied by a financial set-up that:

- is adapted to existing local technical and financial capacities and capacity-building opportunities;
- enables each stakeholder to achieve financial stability, or to make a profit in the case of private stakeholders;
- is beneficial and affordable for users at the start (sewerage system users) and at the end of the sanitation chain (users of the treatment plant output products).

The introduction of new additional treatment processes, and activities to transport products for resource recovery and reuse, will increase the costs to be borne by the stakeholders responsible (but also provide them with opportunities to reduce certain expenses).

Project partners and the stakeholders responsible for these activities may assume that the sale of products for resource recovery and reuse will generate enough revenue to offset these new costs. This assumption should be viewed with caution and in relation to the demand for resource recovery and reuse and to competition from other existing practices.

Challenge 4: Impact and consideration of sociological aspects

Focusing in particular on the users of sanitation output products, this section explains why it is important to take sociological aspects into consideration when developing a sanitation chain that includes a resource recovery and reuse segment.

This section also describes the approaches that can be adopted for incorporating these sociological aspects, which are based on identifying and involving all stakeholders.

The sociological aspects to be taken into consideration:

Perception of the health risks

Even when the health risk is low because advanced treatment processes are used, negative perceptions among resource recovery and reuse segment stakeholders can still cause a project to fail.

Users and potential consumers can be reluctant to use fertilisers derived from human excrement. Farmers fear the stigma attached to this practice and worry that they will see a drop in demand or market prices for their produce.

Religion is often cited as contributing to this reluctance. However, there is no international data available to measure the extent to which religion influences social acceptance.

Mediterranean Focus

In the various studies conducted on this topic in Tunisia, none of the farmers mentioned religion as a factor.

In Palestine, religious leaders are involved in informing people about the potential for reusing treated wastewater if health and hygiene practices are in place and water treatment processes are properly carried out. They are therefore helping to raise awareness and popularise wastewater reuse.[S]

Perception of the benefits

Paradoxically, although poorly studied and documented, the informal use of wastewater and sludge is widespread. Where there is a need, the benefits of using wastewater and sludge take precedence. Users surveyed are satisfied with their effectiveness on crops.

Where chemical fertilisers/water resources are available at low cost or free-of-charge, the willingness to pay for treated or composted sewage/faecal sludge or treated wastewater is compromised as this use does not meet a need.

Conversely, demand for treated wastewater is high in areas of water stress. Its continuous availability is also an advantage in areas where water availability fluctuates throughout the year.

S. B. Soudi et W. El Khoumsi, «Valorisation agricole des boues d'épuration dans les pays du Maghreb : potentialités et défis Gestion et valorisation agricole des boues d'épuration au Maroc, Rapport national – Maroc,» FAO, 2024.

Mediterranean Focus

In Morocco, local farmers regularly take wastewater from the WWTP[T] in areas of water stress, such as the urban valley of Ouislane.[U]

In Lebanon's Bekaa valley, freshwater is limited, so farmers have to find alternative water sources, such as treated wastewater, to irrigate their crops.[V]

However, informal and unregulated farming practices using partially treated wastewater and sludge tend to develop where there is demand. This sludge and wastewater is free to use, which can make it difficult to introduce a resource recovery and reuse segment that would place a price on this usage, even though it would mean that the health risk would be properly managed.

Mediterranean Focus

In Palestine, the willingness of users to pay for treated wastewater is low where raw or treated wastewater was already being reused free-of-charge before the planned projects were designed. This reuse was either direct or indirect. Pumps were placed in watercourses that receive effluent and so farmers were not charged for this water.[W]

Changes in practices required for resource recovery and reuse

For the end-users:

The reluctance of some users is not always due to the origin of the sanitation product, but to the need for a change in practices that the resource recovery and reuse of these products entails.

For agricultural irrigation/soil amendment resource recovery and reuse, health risk management measures will require farmers to change their practices. These new practices, which can include wearing protective clothing, using localised irrigation equipment, complying with the lag time between application and harvesting, and even growing new crops, may be very different to their existing practices and give rise to reluctance or resistance.

Using treated wastewater and sewage/faecal sludge for the irrigation and amendment of non-agricultural green spaces will also require a change in practices. For example, restricting access to public parks following the application of recovered sanitation products would need to be accepted by both a park's manager and its users.

T. S. Brahim, Projet de Renforcement des Capacités sur l'Utilisation sans danger des Eaux Usées en Agriculture. Rapport National du Maroc, 2011

U. F. Rossel, Les agriculteurs de la vallée urbaine de Ouislane (Maroc) contraints à l'usage d'eaux usées non traitées dans un contexte de transition agroécologique, REUSE EUROMED 2024, 2024

V. M.T. Abi Saab, Treated municipal wastewater reuse for eggplant irrigation, AJCS, 2021

W. Chantier COSTEA "REUSE" - Réutilisation des eaux usées en agriculture - rapport de synthèse Palestine, COSTEA , 2022

Mediterranean Focus

Surveys carried out in Tunisia show that farmers consider crop restrictions to be a major obstacle.[X]

In Palestine, treated wastewater reuse, carried out in accordance with the regulations, is restricted to certain crops, mainly feed crops. This requires farmers who previously practised rain-fed agriculture to change their farming practices. Training programmes are in place to help farmers with this transition.

For the stakeholders responsible for the various sanitation chain activities:

These changes in practices relate to the new operations and maintenance activities to be carried out for the additional treatment processes, as well as to the protective measures introduced to reduce health risks (wearing personal protective equipment, handwashing, etc.).

Sanitation chain workers' perception of these changes in practice need to be taken into account.

The many types of stakeholder involved

Integrating a resource recovery and reuse segment into the sanitation chain will require the involvement of stakeholders from sectors other than sanitation, such as the agricultural, energy, forestry, health sectors, etc.

The sanitation authority and any regulatory authority are not the only coordinators of resource recovery and reuse development projects. Inter-sector coordination is required.

Those also involved include institutional, centralised, deconcentrated or decentralised stakeholders and any private stakeholders they later appoint, as well as civil society organisations. They represent the sewerage system users (access segment), and users of the sanitation products (farmers, industries, green space managers, forestry managers, etc.).

Where available, national sector sanitation and sanitation product reuse frameworks may specify the theoretical scope of these stakeholders' involvement.

However, sector frameworks do not contain comprehensive definitions of the role of each stakeholder, and the regulation of some types of sanitation segment and recovery channels can be unclear or even non-existent.

Regardless of whether these frameworks are in place or not, the role of the various stakeholders involved in the sanitation chain and its resource recovery and reuse segment must

X. Élaboration du Plan Directeur National de Réutilisation des Eaux Usées Traitées en Tunisie – « WATER REUSE 2050 » : Phase 1 : Diagnostic de la filière et élaboration des orientations de base, Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche, AFD, 2020

be properly analysed to improve upon the theoretical definition of their involvement, which can be ambiguous at best.

The needs, constraints, interests and influence of each of these stakeholders may complement, contradict, support or oppose the various resource recovery and reuse scenarios.

Moreover, where resource recovery and reuse initiatives were already in place prior to the project, outside the scope of sector frameworks, the stakeholders involved in these 'informal' initiatives also need to be taken into consideration.

- User demand, and thus willingness to pay, are influenced by perceptions of the benefits of the sanitation product and the risks associated with its use, as well as the changes in practice required. This therefore has an impact on the parameter: 'There is a need, or the opportunity to develop a need, for sanitation product resource recovery and reuse for human activities'.

- The changes in practices required of the stakeholders responsible for the different sanitation chain activities and the many types of stakeholder involved have an impact on the parameter: 'Existing local technical and financial capacities and capacity-building opportunities'.

How to incorporate sociological aspects

Co-construct an organisational model

The involvement of stakeholders should facilitate the joint development of a management model and a financial model.

It is especially important that the users of the sanitation products are involved in this process as their role is key to the viability of these sanitation chain organisational and financial models.

As with any participatory approach, this co-construction process can be formalised or even regulated.

The division of stakeholder roles and responsibilities must be formalised. This can be via agreements or contracts, depending on the type of stakeholder concerned.

Y. Élaboration du Plan Directeur National de Réutilisation des Eaux Usées Traitées en Tunisie – « WATER REUSE 2050 » : Phase 1 : Diagnostic de la filière et élaboration des orientations de base, Ministère de l'Agriculture, des Ressources Hydrauliques et de la Pêche, AFD, 2020

Mediterranean Focus

In Tunisia, there is a national strategy to promote the use of participatory approaches, which includes staff training and pilot components. However, cost-sharing among producers, users and local authorities to cover WWTP operating costs remains a sensitive issue.[Y]

In Morocco, the use of wastewater for forest irrigation benefits shepherds, who use these areas for livestock grazing. This practice is supported by a 'participatory' approach that forms part of the national forestry plan. Shepherds are thus provided with information on their rights and duties with regard to their use of these irrigated forest areas (see **chapter 4**, Case Study no.1).

An agreement will bind together stakeholders responsible for the different segments of the sanitation-reuse-recovery chain under the sector framework. It will clarify the scope of their roles and responsibilities specifically for the operation of a sanitation chain with a resource recovery and reuse segment. For example, an agreement could be established with a national sanitation operator or an agricultural water users' association that operates a treated wastewater system to water their crops. An agreement is entered into on a voluntary basis and in the mutual interest of all parties following a negotiation process.

A contract will bind a stakeholder with responsibilities within the sanitation chain to a private stakeholder tasked with operating part of the system. This could include a contract between a treatment plant operator and a private stakeholder in charge of collecting the sludge produced and delivering it to farmers. A contract is awarded following a tender process, through which the public stakeholder sets out its requirements in order to select the service provider with the most attractive technical and financial bids.

The operational scope of responsibilities, and the financial flows between the various parties involved, must be formally defined in the terms of these agreements and contracts.

◄ Provide information on and raise awareness of the health risk

In addition to the project sponsor's risk assessment, all stakeholders' perceptions of the risks must be taken into account. Scientific information can be provided if the project developer considers that this perception is inaccurate; however, it is important to recognise that resistance to the use of sanitation products may remain. Should this be the case, it will be necessary to adapt the treatment/recovery solution proposed.

Awareness-raising and hygiene promotion campaigns can help overcome any resistance. These campaigns must target all stakeholders exposed to health risks (see the section on managing the health risks): farm workers, people handling the sanitation products, retailers and consumers. It is essential to encourage handwashing to prevent exposure through contact leading to exposure through ingestion.

It is important to use language that does not stigmatise recycled water when communicating with the public. Terms such as 'wastewater reuse' or 'reused water' can have negative connotations, whereas expressions such as 'water recycling', 'new water' or 'purified water' are seen as more attractive and can help improve public acceptance (Macpherson 2012).

Co-construct a health risk management strategy

As detailed in the section on managing the health risks, it is vital that the stakeholders exposed to these risks are involved in developing the risk management strategy.

If high quality standards need to be put in place to manage the health risk from treatment plant output products, then the stakeholders responsible for the WWTP/FSTP need to be involved in order to jointly identify their technical and financial capacities for meeting these standards. Where feasible, training programmes can be developed to build WWTP/FSTP operator capacities to operate the advanced treatment systems required. If these capacities are not properly aligned with the technical sophistication and additional operating costs of the planned treatment systems, the proposed resource recovery and reuse treatment solution may well not be viable. The same applies to the stakeholders identified to conduct sanitation product quality monitoring during the operations phase. Health risk management is therefore based on the performance of the treatment plant, which must operate under optimal conditions. It also requires the proper implementation of a monitoring procedure to ensure the quality of the sanitation products leaving the treatment plant.

If the health risk management strategy includes consideration of the reused/recovered products' modes of use, then the stakeholders exposed to health risks, and those responsible for applying measures to minimise this exposure (the 'post-treatment' barriers), must also be involved in the strategy development process.

It is important to identify the hygiene practices of all stakeholders who may come into contact with sanitation products, as well as their farming practices where applicable, and use these as a basis to jointly develop the health risk management strategy. They should be provided with information on the risks (danger, exposure) associated with their practices and on the practices to be recommended or imposed. Stakeholders affected by the health risks should be asked to identify and share any situations in which the proposed treatment and resource recovery and reuse solution could result in either continuous or accidental exposure to health risks.

Identify or stimulate a market

A socio-economic analysis should be conducted to assess the existing or potential market for the sanitation products by identifying potential users and determining their willingness/capacity to pay.

To accurately identify these various potential users, their actual and potential numbers and their level of satisfaction, an analysis by market segment should be carried out. Analysis of the market structure can help determine the extent of the product's long-term viability on the market, taking into account existing or expected competition, as well as other comparable products used for the same purpose and which are available at a low cost or free-of-charge ('conventional' water, chemical fertilisers, etc.).

In order to determine how much a respondent is willing to pay for a given quantity of a new product, experienced interviewers will be required, both to conduct the surveys and interpret the results. However, these results will need to be viewed with caution. There is often a disparity between respondents' stated intentions and interest in using treated wastewater/sludge and in adopting the required behaviour change, which is still theoretical and abstract during the survey phase, and their actual application of these intentions once the project is implemented.

Mediterranean Focus

In Mediterranean countries, small farmers have low capacity to pay the real price of treated wastewater. It is unrealistic to expect the payments made by farmers to cover additional treatment and related treated wastewater reuse facilities operating costs, or the costs of water quality monitoring.

For private stakeholders with greater financial capacity (industries, golf club managers, hoteliers, for instance), willingness to pay is more assured. Nevertheless, in Tunisia, treated wastewater is provided to golf club managers free-of-charge; however, it is the golf club managers who cover the cost of their reuse facilities.

Demonstrate the benefits of using the product

Initiatives to demonstrate the effectiveness of sanitation products for irrigation or soil amendment can be carried out. Demonstration units, where future users can try out and test different technologies, are essential for gaining acceptance and for convincing farmers of the effectiveness of the new approaches. This type of initiative is often carried out as part of funded pilot projects, so it will also be necessary to assess their viability and sustainability.

To encourage the reuse of treated wastewater, it will be vital to raise farmers' awareness of the environmental challenges and growing pressures affecting water resources, particularly due to climate change.

Support changes in practices

When defining the health risk management strategy, the various stakeholders exposed to health risks need to be involved to ensure the feasibility of the changes in practice required to implement the measures proposed. This approach could include support in the form of training, or result in the solution being ruled out if found to be unsuited to the context.

For instance, imposing restrictions on crops for health protection purposes sometimes runs counter to market forces and may not be accepted by farmers: fresh vegetables can fetch a higher price than feed crops, for example.

Incorporating sociological aspects: key points

It is essential to identify the stakeholders, and their interests and influence (with regard to both the project and future operation of the system), and to involve them from the assessment and feasibility study phase to examine the different scenarios.

Although participatory processes can be time-consuming and involve additional costs, it is vital to ensure all relevant institutions and stakeholders are explicitly involved in the planning and design phases of sanitation product resource recovery and reuse projects. This process helps to guide decision-making to ensure that the technical, organisational, financial and health risk management choices made maximise the system's potential to operate sustainably and meet the needs of each stakeholder throughout the sanitation chain.

Users of sanitation products are crucial stakeholders, therefore their motivations and reservations will need to be assessed.

To determine feasible resource recovery and reuse opportunities for sanitation products, it is first essential to identify potential users and assess demand, willingness and capacity to pay and users' perception of risk. These can impact the choices made across all segments of the sanitation chain. These analyses can also identify opportunities for developing demand, for instance, by highlighting the benefits of the product through an information and awareness-raising, or even a marketing, campaign.

FOR MORE INFORMATION ON ORGANISATIONAL AND FINANCIAL MODELS AND ON INCORPORATING THE SOCIOLOGICAL ASPECTS

- **Resource Recovery and Reuse Series:**
  The Resource Recovery and Reuse series has been published by the International Water Management Institute (IWMI) under the CGIAR Research Program on Water, Land and Ecosystems as part of the Resource Recovery and Reuse (RRR) sub-programme to present applied research on the safe recovery of water, nutrients and energy from domestic and agro-industrial waste streams

  - **Resource Recovery and Reuse Series n°4 - Global Experiences in Water Reuse**, CGIAR, IWMI, Lautze, J.; Stander, E.; Drechsel, P.; da Silva, A. K.; Keraita,B., 2014

  - **Resource Recovery and Reuse Series n°6 - Business models for fecal sludge management**, CGIAR, IWMI, Rao, K. C.; Kvarnström, E.; Di Mario, L.; Drechsel, 2016

  - **Resource Recovery and Reuse Series n°10 - Testing the Implementation Potential of Resource Recovery and Reuse Business Models: from baseline surveys to feasibility studies and business plans**, CGIAR, IWMI, Otoo, M.; Drechsel, P.; Danso, G.; Gebrezgabher, S.; Rao, K.; Madurangi, G., 2016

  - **Resource Recovery and Reuse Series n°11- Financing resource recovery and reuse in developing and emerging economies: enabling environment, financing sources and cost recovery**, CGIAR, IWMI, Lazurko, A.; Drechsel, P.; Hanjra, M. A., 2018

  - **Resource Recovery and Reuse Series n°12 - Market adoption and diffusion of fecal sludge-based fertilizer in developing countries: crosscountry analyse**, CGIAR, IWMI, Otoo, M.; Gebrezgabher, S.; Danso, G.; Amewu, S.; Amirova, I.; 2018

  - **Resource Recovery and Reuse Series n°13- Assessing the value of resource recovery and reuse: social, environmental and economic costs and benefits for value creation and human well-being**, CGIAR, IWMI, Lazurko, A., 2018

[5] - **Resource Recovery and Reuse Series n°17- Introducing co-composting to fecal sludge treatment plants in Benin and Burkina Faso: a logistical and financial assessment**, CGIAR, IWMI, Nikiema, J.; Tanoh-Nguessan, R.; Abiola, F.; Cofie, O., 2020.

  - **Resource Recovery & Reuse – n°22 : Public-private partnerships for the circular bio-economy in the Global South: lessons learned**, CGIAR, IWMI, Taron, A.; Majumder, A.; Bodach, S.; Agbefu, D., 2023

  - **Resource Recovery & Reuse – n°23 - Sewage sludge: a review of business models for resource recovery and reuse**, CGIAR, IWMI, Taron, A.; Singh, S.; Drechsel, P.; Ravishankar, C.; Ulrich, A. 2023.

- **Other ressources:**

  - **Faecal Sludge Management Systems Approach for Implementation and Operation**, IWA, Strande L., Ronteltap M., Brdjanovic D., 2018, anglais

  - **Resource Recovery from Waste: Business Models for Energy, Nutrient and Water Reuse in Low- and Middle-income Countries**, Swiss Agency for Development and Cooperation (SDC), International Fund for Agricultural Development (IFAD), CGIAR Research Program on Water, Land and Ecosystems (WLE), M. Otoo, P. Drechsel, 2018.

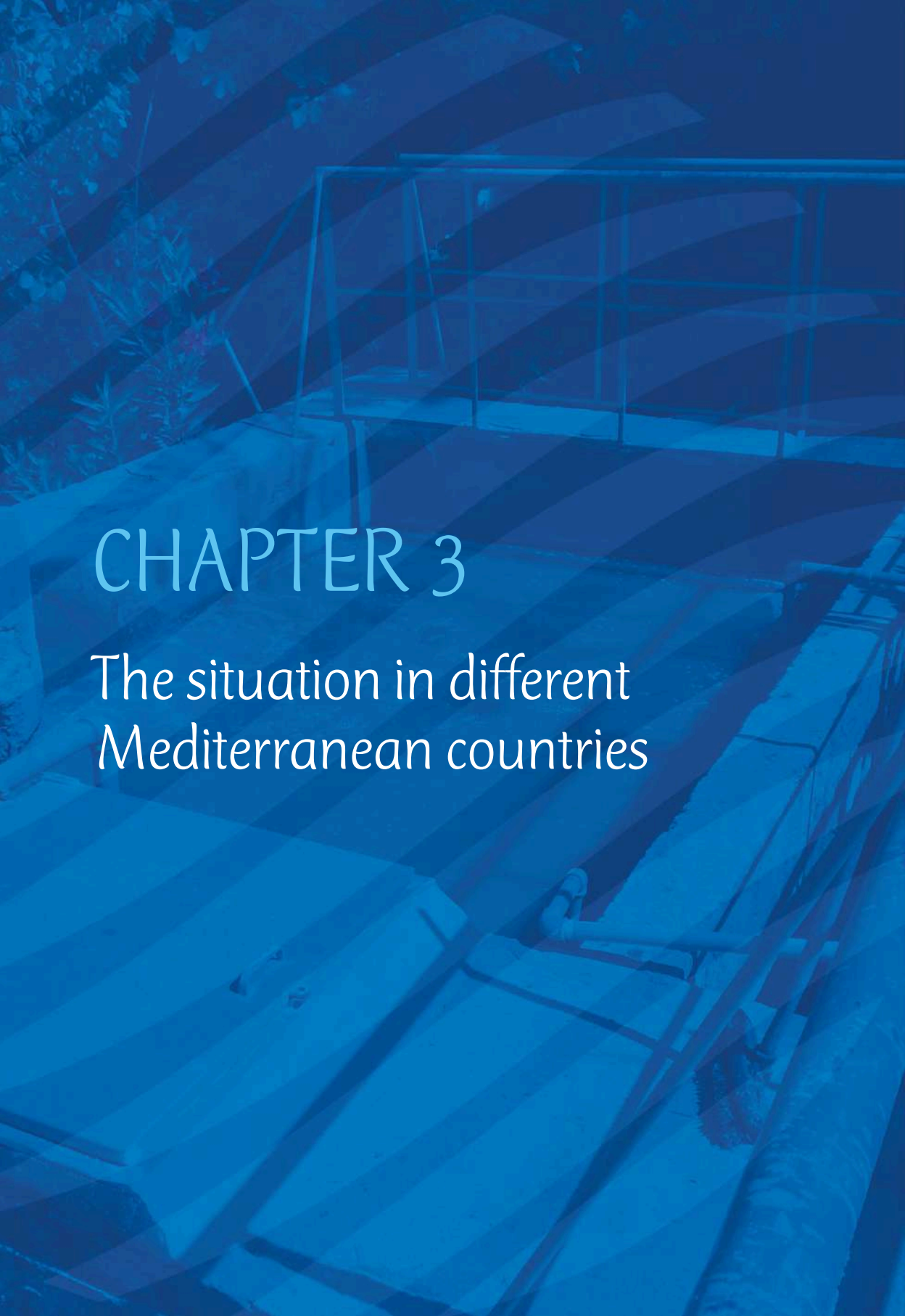
  - **Business Models for Rural Fecal Sludge Management (FSM): A Desk Review**, USAID, Agarwal, R.; Chennuri, S., 2024

  - **Sanitation, Wastewater Management and Sustainability: from Waste Disposal to Resource Recovery. 2nd edition**. United Nations Environment Programme and Stockholm Environment Institute, Andersson, K., Rosemarin, A., Lamizana, B., Kvarnström, E., McConville, J., Seidu, R., Dickin, S. and Trimmer, C., 2020

  - **Need to educate farmers about the benefits of using treated wastewater for agriculture**, World Water Council, IWA, Baanu, B. B.; Babu, K. S. J.; Baskaran, A., 2022

  - **Gestion des eaux usées et des boues de vidange - identification des besoins en formation et élaboration du référentiel métier/emploi**, GIZ, programme eau et assainissement au Bénin (AGIR-Eau), Cissé, S., 2022.

Treated wastewater storage tank, Djerba WWTP, Tunisia, © ANAMANA



CHAPTER 3

The situation in different Mediterranean countries

This section presents the context of several Mediterranean countries — Morocco, Tunisia, Lebanon and Palestine — with regard to reuse and resource recovery in the sanitation sector. These are Mediterranean countries in which decentralized cooperation is active. The situation in each country is described based on the issues discussed in Chapter 2. The information reflects the status as of the date of publication of this guide.

The resource recovery and reuse of sanitation products in Morocco

Inclusion of resource recovery and reuse in national strategies

The sanitation sector in Morocco

Morocco has considerably developed its sanitation infrastructure following implementation of the national sanitation plan (PNA) in 2006 and the shared national sanitation plan (PNAM) in 2019.

In 2020, there were 209 wastewater treatment plants, 187 of which were already in operation and 22 were under construction (128 WWTP in urban areas and 59 in rural areas). The wastewater treatment rate has risen from 7% in 2006 to over 57.5% in 2024. The volume of water treated in the country's wastewater treatment plants is estimated to be around 443 million m^3/year.

The sewerage system connection rate has increased from 70% in 2005 to 83.5% in 2020.

WWTP in urban areas generally use activated sludge and bacterial bed treatment processes, whereas WWTP in small settlements often use WSP or planted filter beds.

Sewerage systems are currently being installed in 1,200 central douars in rural areas of Morocco under the PNAM.

FOR MORE INFORMATION:

- For more information on the stakeholders involved in water and sanitation management in Morocco, please see the pS-Eau country factsheet for Morocco

Treated wastewater reuse in Morocco: inclusion in strategies and situation assessments

According to water demand projections, there will be a deficit of 5 billion m^3/year by 2030. The strategies therefore aim to reduce demand for water by 2.5 billion m^3/year and increase supply by 2.5 billion m^3/year.

Treated wastewater reuse is a key focus of water and sanitation sector strategic and regulatory documents. It is positioned as an unconventional water resource to be developed in order to increase supply and thereby help rebalance supply and demand by 2030.

It is estimated that the **potential volume of reusable wastewater will be 550 million m^3 by 2030**, out of a potential volume of 1,100 million m^3 of treated wastewater.

Therefore, the PNAM anticipates reuse volumes of 325 million m^3 in 2030 and 573 million m^3 in 2040 for agriculture (46%), industry (5%), green spaces and golf courses (43%), and groundwater recharge (6%). 87 reuse projects are planned between now and 2027, the majority of which will focus on treated wastewater reuse in agriculture, with 22 projects focusing on reuse for watering golf courses.

Other national programmes include a component that seeks to regulate demand, particularly for agricultural irrigation. The vast majority of Morocco's water resources are used for agriculture, which accounts for nearly 85% of all water consumption. As a result, the 2015 national water plan (PNE), the future PNE (up to 2050) and Water Law 36-15 of August 2016 all include plans to develop more localised irrigation using recycled stormwater and wastewater.

Current uses are as follows:[2]

Uses of treated wastewater in Morocco	
Type of use	Description / Location
Golf course irrigation	23 golf courses in Rabat, Tangier, Tétouan, Agadir, Marrakech
Green spaces	Tangier, Tétouan, Oujda ecological park, Ouarzazate green belt
Industry (phosphate washing	Cities of Ben Guerir, Khouribga, Youssoufia
Forestry	Marrakech palm grove (FAO project)
Groundwater recharge	Reinjection at Biougra (near Agadir)
Agricultural irrigation (pilot projects)	Projects underway or being piloted in Ouarzazate, Ben Sergao, Drarga, Attaouia

The estimated potential irrigable area of between 65,000 and 130,000 hectares accounts for only a small proportion of the total irrigable area (1.4%); however, this potential should focus on areas where it would have the greatest benefit: semi-arid, arid, pre-Saharan and Saharan areas where there is low rainfall, mountainous areas (although implementation would be complicated by the topography and the fragmented layout of the farmland), as well as oases.

The Massire project has piloted small-scale treatment system options that include reuse in oasis areas. These systems were installed as close as possible to wastewater collection points and to treated wastewater points of use.

Sewage sludge reuse in Morocco: inclusion in strategies and situation assessments

Although the PNAM recommends including sludge management in sanitation project planning phases, sludge recovery is less of a key focus than treated wastewater reuse.

The expansion in the use of sewerage systems over recent decades has led to a proportional increase in the volume of sludge produced. At present, most of this sludge is sent for disposal at public landfill sites (60%). However, ambiguity around the status of sludge in the regulations is resulting in more and more local authorities responsible for landfill sites refusing this sludge, forcing treatment plant operators to store it on-site.

Studies and pilots are currently underway to develop sludge recovery. Prospective research conducted by the FAO on behalf of ONEE has identified a number of treatment processes and recovery options that are appropriate for the different types of area within Morocco:

Solar drying beds, following mechanical dewatering, is adapted to Morocco's climate conditions (and have been adopted for use in the Marrakech, Fes, Youssoufia, and Ben Guerir WWTP, and is being developed for Laâyoune).

Use in agriculture and for soil restoration (rehabilitating degraded soil, old quarries), as well as in cement manufacturing, both appear to be suited to the context in Morocco. As things stand, these two recovery options are relatively undeveloped.

The unfavourable water balance of solar drying makes it less relevant in areas of water stress, especially in rural areas. Thus, the research findings go as far as to recommend the land application of liquid sludge, after stabilisation treatment, ahead of uses to restore and amend arid soils on fruit tree, orchard and olive tree farms (pilot conducted in the rural village of Chouirij in the Marrakech-Safi region by the Ministry of the Interior, with support from GIZ).

In some agricultural areas, local farmers use the sludge from treatment plants on an informal basis (Al Attaouia, Skhirat).[2]

Faecal sludge reuse in Morocco: inclusion in strategies and situation assessments

There are few sewerage systems in the more remote douars, which are often too far away from the central douar WWTP to enable faecal sludge co-treatment. Local solutions therefore need to be put in place. This means considering all forms of sanitation, including on-site sanitation options. Sewerage systems, even those that use extensive treatment processes, are not necessarily the most appropriate solution in these areas. Sanitation product resource recovery and reuse, a practice that is already widespread for Morocco's urban WWTP and is becoming more common in small settlements with treatment plants, could also be introduced at these micro-levels.

This option has been explored by the Integrated Water Resources Management Support programme (AGIRE: Appui à la Gestion Intégrée des Ressources en eau) funded by GIZ in support of the Ministry of Energy, Mines, Water and the Environment's Water Department. The aim of the AGIRE programme's sanitation component was to develop a holistic view of sanitation, including the recovery of all its by-products, not just wastewater, focusing particularly on the options available at the household and small-scale sewer system levels. Solutions already in place in Morocco were examined as part of the programme. Other solutions were piloted, and guides

were produced to provide households and local and national policymakers with information on the various options and types of sanitation available, and on the technologies best suited to the Moroccan context. However, it is always necessary to examine each context separately in order to make tailored choices.

National regulations – Health risk management

Treated wastewater reuse

The regulations in Morocco are based on the following principles:

Approaches for treated wastewater reuse in Moroccan regulations [A]	
Conditions of use, quality of output products from the treatment plant **Required characteristics of treated wastewater**	**Category A** : Crops consumed raw, sports grounds, public gardens • Helminth eggs: absent (arithmetic mean per litre) • Faecal coliforms <1000 CFU / 100ml **Category B** : Cereal crops, industrial crops, feed crops, pastures, tree plantations • Helminth eggs: absent (arithmetic mean per litre) • Faecal coliforms: no specified limit **Category C** : Localised irrigation of B crops if the public and farm workers are at no risk of exposure
Restrictions on modes of use	• No irrigation of fruit trees in the 2 weeks prior to harvesting • No sprinkler irrigation • No picking up fallen fruit • Public health impact assessment required as part of the application
Restrictions on use	Morocco imposes no restrictions on crop irrigation with treated wastewater

A. - Water Law no. 36-15 (2016)

- Decree no. 2-04-553 of 24 December 2004 (on the quality of water for irrigation): sets quality standards for the agricultural reuse of treated wastewater

- Specific ruling on wastewater reuse for irrigation, no. 1276-01 of 10 Chaabane 1423 (17 October 2002), defining the quality standards for water intended for irrigation

- Environment Act (Law no. 11-03)

- A new ruling to define types of use is currently being drafted.

Sewage sludge reuse

The organic materials in sludge are a valuable resource that can be used to improve soils in Morocco, which are often poor in organic matter.

The Moroccan Water Law (law 36-15) and Waste Law (law 28-00) do not currently include adequate regulations for sludge as waste. In particular, the definition of sludge quality and its land application requirements are incomplete, which is hampering the development of agricultural reuse options. However, regulations prohibit the discharge of sludge into the environment without prior treatment, whereas the acceptance of sludge in landfills has prompted treatment plant operators to consider new options.

The Moroccan standards institute (IMANOR) has re-established Moroccan standard NM ISO 19698: 2023 (which is in line with the ISO 19698: 2020 international standard). This standard sets out the quality criteria that sewage sludge must meet before it can be used on farmland and for the rehabilitation of degraded sites. It categorises sewage sludge into two groups based on their level of treatment and their contaminant content, taking crop needs, contamination risk and water resource protection into account. This standard is still to be implemented through the publication of a decree, which should also cover faecal sludge from on-site sanitation systems.

Proposed operating and financing models

There is a comprehensive framework that sets out the division of roles and responsibilities among the various governmental, deconcentrated, decentralised and local authority stakeholders **for the different treated wastewater uses**. This covers the project implementation phase and operational phase of a sanitation chain that contains a resource recovery and reuse segment.

B. Various other government agencies are also involved:

- The national farm advisory board (ONCA: Office National de Conseil Agricole) provides support to farmers;
- The national office for food product safety (ONSSA: Office National de Sécurité Sanitaire des Produits Alimentaires) is responsible for monitoring agricultural inputs and the quality of agricultural products intended for human and animal consumption;
- Health and hygiene services carry out tasks including vaccination and epidemiological monitoring

Treated wastewater

Stakeholders involved in sanitation chain implementation and operation, including treated wastewater reuse, in Morocco			
Activity	Stakeholders	Role during the project (implementation) phase	Role during the operational phase
Régulation et contrôle de l'État[B]	**ABH** (Agences du Bassin Hydraulique: water basin agencies)	• Issue authorisations for reuse	• Monitor compliance with standards • Monitor compliance with conditions of reuse
	Ministry of Agriculture, Maritime Fisheries, Rural Development and Water and Forests (MAPMDREF)	• Can financially support projects • Can support development of the distribution network	• Monitors water quality compliance
	Regional / provincial councils	• Can provide financial and technical support to projects	• Can contribute to local management (not standardised)
Fonctions transport (réseaux) et traitement	**Local authority / local utility / ONEE-Water Dept - (ultimately the SRM) Users' Association**	• Project manager for infrastructure up to secondary treatment • Makes the necessary land available	• Ensures operation of the WWTP through to secondary treatment • Can manage additional treatment processes (depending on the agreement in place)
Transport et distribution des eaux usées traitées	**Predominantly municipal utilities or ONEE – Water Dept. (ultimately the SRM)** **AUEA** (Agricultural Water Users' Associations)		• Convey treated wastewater to the irrigation site • Manage agricultural irrigation systems • Can help with local maintenance
Utilisateurs finaux	**Farmers, private owners (golf courses, industries), local authorities (green spaces)**	• Responsible for installing private networks and irrigation systems	• Manage their private facilities • Expected to pay for treated wastewater to cover additional treatment costs (the price of treated wastewater is subsidised for agricultural use)
Acteurs émergents	**SRM** (Sociétés Régionales Multiservices)	• The SRM are gradually taking over the local authorities' managing role	• The SRM are gradually taking over the local authorities' operator (utility) role, as well as the ONEE's operating role where this has been delegated to ONEE

Stakeholder coordination

Given the number of different government, deconcentrated, decentralised and local authority stakeholders involved, a Public-Private Partnership agreement should be put in place to formalise roles and responsibilities for the implementation and operational phases. These agreements require the involvement of a host of institutional stakeholders, as well as their decentralised and deconcentrated agencies, such as the Wilayas, Regional and Provincial Councils, Water Basin Agencies (ABH), local authorities, the Department of Agriculture and its agencies (ONSSA, ONCA, etc.), public utilities or the ONEE water department, the Ministry of Health, users (AUEA), etc.

However, although defined in theory, the operational roles and responsibilities of these different stakeholders are not always sufficiently clear, particularly with regard to treated wastewater quality monitoring.

◄ Sewage sludge

It is possible to identify the stakeholders involved, but their roles and responsibilities are not clearly defined:

- Sludge-producing treatment plant operators - ONEE, public utilities, private concession contract holders and local authorities and, in the near future, the SRM.
- The Department of Agriculture and its deconcentrated agencies (Regional Agricultural Directorates (DRAs) and Provincial Agricultural Directorates (DPAs) will have a role to play in sludge land application plans.
- ONSSA, who is responsible for assessing the risks to human and animal health and monitoring the quality of agricultural inputs.[2]

FOR MORE INFORMATION:

- **Project TCP/SNE/3701: Unblocking the Potential of Treated Wastewater and Drainage Water Use for Agricultural Development in North Africa, led by the Food and Agriculture Organisation of the United Nations (FAO)** seeks to support the North African countries of Algeria, Libya, Morocco, Mauritania and Tunisia with knowledge on the safe use of treated wastewater in order to develop the agriculture sector:

[2] - Valorisation agricole des boues d'épuration dans les pays du Maghreb : potentialités et défis Gestion et valorisation agricole des boues d'épuration au Maroc ? Rapport national – Maroc, FAO, Soudi Brahim, El Khoumsi Wafae, 2024

[1] - Amélioration des connaissances sur l'utilisation saine et sécurisée des eaux usées traitées pour le développement du secteur agricole dans les pays du Maghreb-Déblocage du potentiel de la réutilisation des eaux usées traitées pour le développement agricole dans les pays du Maghreb - Rapport Maroc – Maroc, version provisoire, FAO, Brahim Soudi, 2020

(The figures mentioned are taken from these two reports)

- Gestion des boues générées par les STEP – ONEE - branche eau : mission 1 : diagnostic de la situation actuelle et ébauche d'une vision d'amélioration des performances- Rapport provisoire, FAO, Brahim Soudi, 2015

- **The Integrated Water Resources Management Support Programme (AGIRE: Appui à la Gestion Intégrée des Ressources en eau),** funded by GIZ, in support of the Ministry of Energy, Mines, Water and the Environment's Water Department examined rural sanitation in Morocco:
  - Guide d'assainissement durable en milieu rural marocain - catalogue des techniques et outils d'aide à la décision
  - Guide de traitement et de valorisation agricole - Boues issues des dispositifs d'épuration en milieu rural marocain
  - Guide de dimensionnement et de construction - Le réacteur anaérobie compartimenté et ses variantes (Maroc)
  - Guide de dimensionnement, de construction et d'utilisation des sous-produits - Digesteur à dôme fixe, Digesteur parallélépipédique
  - Guide de dimensionnement, de construction et de fonctionnement - Filtre planté horizontal de petite taille
  - Simplified versions in comic strip form were also produced in both french and arabic :
  - Mieux comprendre l'assainissement rural - choix des systèmes d'assainissement: french, arabic
  - Mieux comprendre l'assainissement rural- Le digesteur à dôme fixe: french, arabic
  - Mieux comprendre l'assainissement rural - le filtre planté: french, arabic
  - Mieux comprendre l'assainissement rural - Le digesteur parallélépipédique: french, arabic
  - Mieux comprendre l'assainissement rural - Réacteur anaérobie compartimenté: french, arabic
  - Mieux comprendre l'assainissement rural - toilettes de déshydratation à séparation d'urine: french, arabic

- **The MASSIRE project (2019-June 2024)** sought to build the capacities of stakeholders in the oasis and arid areas of North Africa to design and implement innovations to support the sustainable development of these areas.
  - L'assainissement et la réutilisation des eaux usées traitées dans le milieu oasien : un impératif et des solutions innovantes; MASSIRE, Ehssan El Meknassi et al., 2024

- **The Scientific and Technical Agricultural Water Committee (COSTEA: Comité Scientifique et Technique sur l'Eau Agricole)** piloted by Eau, Agricultures et Territoires (ex-AFEID) and supported by the French Agency for Development (AFD) brings together French and international irrigation expertise. COSTEA has produced a number of publications on treated wastewater reuse:
  - Chantier COSTEA Reuse - Réutilisation des eaux usées en agriculture - rapport de synthèse Maroc, COSTEA Eau, Agriculture et Territoires (ETA), Brahim Soudi & Khaoula Zahraoui, 2022

- **Other publications**
  - La réutilisation des eaux usées traitées : une réponse stratégique au stress hydrique ?, AFD, Mohamed Taha Laaouimri, Timothée Ourbak, 2024
  - Climate risk country profile – Morocco, World Bank, 2021
  - Revue de littérature sur le changement climatique au Maroc : observations, projections et impacts, AFD, Marie-Noëlle Woillez, 2020
  - Technologie de séchage solaire des boues des stations d'épuration des eaux usées et son impact sur la gestion des boues au Maroc, Revue Marocaine des Sciences Agronomiques et Vétérinaires, 2019

The resource recovery and reuse of sanitation products in Tunisia

Inclusion of resource recovery and reuse in national strategies

The sanitation sector in Tunisia

WWTP in Tunisia were developed in the 1990s through major sector investment programmes.

In 2019, the sanitation agency, ONAS (Office National de l'Assainissement) had 122 WWTP under its supervision, 113 in urban areas, 8 in rural areas and 1 industrial treatment plant. Plans are in place to accelerate access to rural sanitation as part of the Water 2050 strategy.

The majority of these WWTP were built between 15 and 30 years ago, with some being over 30 years old. Across Tunisia, non-compliance with pollution parameters such as Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) is very high, at around 80%. This is because the WWTP are overloaded and showing signs of disrepair. There a number of rehabilitation projects that are underway.

The WWTP mainly use activated sludge-type treatments, with some waste stabilisation ponds, and produce nearly 300 million cubic metres of treated wastewater per year. 25 WWTP have tertiary treatment to enable treated wastewater reuse.[4]

FOR MORE INFORMATION:

- For more information on the stakeholders involved in water and sanitation management in Tunisia, please see the pS-Eau country factsheet for Tunisia

Treated wastewater reuse in Tunisia: inclusion in strategies and situation assessments

Tunisia is a pioneer in treated wastewater reuse with the country first using treated wastewater for irrigation in 1965. As in Morocco, **treated wastewater reuse forms part of larger efforts to balance supply and demand in order to address the imbalances already being observed, and which are projected to become far worse**.

With increasingly frequent and prolonged droughts and reduced and irregular rainfall, climate change is leading to a reduction in conventional (predominantly groundwater) water resources, and causing mounting water stress in Tunisia. Conventional resources in the central and southern regions of the country are already depleted. Climate change could have a major impact on renewable water resources. The annual per capita share of renewable resources is expected to fall from its current figure of 450m^3 to 370m^3 by 2030.

Currently, the **300 million m^3 of treated wastewater produced equates to 6% of the country's total surface and groundwater resources in an average year, and up to 11% in a dry year**. Based on an estimated 640 million m^3 of wastewater treated per year, and taking the climate change-related drop in surface and groundwater resources into account, these figures could rise to 14% (average year) and 26% (dry year) by 2050.

Meeting the water needs of the agricultural sector is a key challenge, as they account for nearly 80% of total water consumption. This is due to population growth, climate change and the country's agricultural development strategies. Given this situation, resources other than groundwater and surface water could also be considered for tourism projects and golf courses, the number of which are set to grow.

Consequently, treated wastewater reuse is a key component of the recently developed Water 2050 strategy, and even has its own **specific strategy: REUT 2050**. Treated wastewater is considered a 'non-conventional' resource that can be used to increase 'supply'. To help achieve this aim, Tunisia is considering measures to restrict access to conventional water resources in instances where treated wastewater can be used as an economically and environmentally viable alternative.

At the same time, the Water Resources Development Strategy launched in 2010 is reinforcing the demand-driven management approach. For agricultural irrigation, this has led to localised irrigation using drip systems being recommended.

There are **66 wastewater treatment plants** from which all or part of the treated wastewater is reused (in 2020).

Some of these WWTP have **tertiary treatment** facilities, including **maturation ponds** at Djerba Aghir, **UV treatment** at Kairouan 2, and **sand filtration** at Médenine. However, the UV and sand filtration treatment processes are not operational.

Current uses are as follows:[5]

Uses of treated wastewater in Tunisia	
Type of use	Description / Location
Agricultural irrigation	31 agricultural areas irrigated with treated wastewater, equating to around 7,500 hectares
Watering golf courses	8 WWTP supply 10 golf courses 17 new golf courses to be irrigated with treated wastewater by 2050
Landscaped green spaces	At WWTP Tourist areas and hotels Green spaces around Tunis airport
Groundwater recharge	Korba (Nabeul), Boumerdès, Mahdia-Ksour Essef (Mahdia), El Hajeb - Sidi Abid - Agareb (Sfax), Oued Es-Smar (Médenine)
Industry (phosphates)	Projects underway at Gabès and Gafsa

The reuse of treated wastewater produced by small-scale WWTP (50 to 3,000 population equivalent) is not considered a national priority as the potential irrigable area is very small. The REUT 2050 strategy recommends assessing the benefits by weighing up the investment and operating costs of the additional treatment processes required and the opportunities for local use.

◄ Sewage sludge reuse in Tunisia: inclusion in strategies and situation assessments

In 2015, ONAS developed **regional sludge management master plans** for treatment plants in the North, Centre, South and Greater Tunis regions of the country. These plans include an assessment of sludge production up to 2035, the potential recovery options available, scenarios for each treatment plant, and an action and investment plan.

Demonstration projects are also being implemented for farmers to try out new sludge land application techniques and assess their viability. In the meantime, the sludge is being stored at and around the WWTP, under poor conditions, while awaiting completion of the drying and storage facilities initiated by ONAS.

Tunisia is also exploring the use of biogas to produce the electricity and heat required to run the treatment processes.

◄ Faecal sludge reuse in Tunisia: inclusion in strategies and situation assessments

There is little provision for on-site sanitation in the national strategy. Opportunities for reusing the output products from these types of system are not included in the strategy documents.

National regulations – Health risk management

Treated wastewater reuse

The regulations in Tunisia specifically cover agricultural uses and are based on the following principles:

Approaches for treated wastewater reuse in Tunisian regulations [C]	
Conditions of use, quality of output products from the treatment plant	21 authorised crops, broken down into 5 categories: • Industrial crops: cotton, tobacco, flax, jojoba, castor, safflower • Feed crops: barley, corn, sorghum, vetch • Fruit and forest trees: date palms, citrus fruits, vines • Forage shrubs: acacia, atriplex • Forest shrubs • Flowering plants: rose, iris, jasmine, marjoram, rosemary Helminth eggs: ≤1 (arithmetic mean per litre) Faecal coliforms: no specific limit
Restrictions on modes of use	• No irrigation 2 weeks prior to harvesting • No direct grazing • All animal feed must be stored before consumption • Fallen fruit must not be eaten or sold • Fruit trees must not be sprayed • Strict hygiene measures: awareness-raising, medical examinations, specific equipment, mandatory vaccination • Minimum distances from residential or busy areas and water resources
Restrictions on use	Market garden crops for food use Direct grazing

C. There is an extensive list of laws, decrees and rulings:

- Law no. 75-16 (31 March 1975) of the Water Law prohibits the use of raw wastewater and irrigation using treated wastewater of crops consumed raw.

- Standard NT 106.03, currently under revision, defines the water quality thresholds for agricultural reuse.

- The joint ruling of 29 December 2006 and decree no. 2007-13 govern the conditions of use of sludge from treatment plants in agriculture, and their management arrangements respectively.

- Decree no.89-1047, amended by decree no. 93-2447, sets out the required frequency of analyses for treated wastewater intended for agricultural use.

- A ruling in June 1994 defined the list of crops that can be irrigated using treated wastewater. The specifications approved in a joint ruling from the Ministries of Agriculture, the Environment, and of Health in September 1995 set out the conditions for modes of use.

Sewage sludge reuse

According to law no. 41-96 on waste and waste management, sewage sludge from treatment plants can be considered as waste.

The regulations in Tunisia are based on the following principles:

Approaches for sludge recovery in Tunisian regulations [D]	
Restrictions on use	**Permitted:** Agriculture (except vegetable crops consumed raw) Forestry Revegetation of degraded soils **Not permitted:** Vegetable crops consumed raw Direct grazing on sludge-treated areas
Sludge characteristics	• Agronomic value of sludge (organic matter, nitrogen, phosphorus, etc.) • Metal Trace Elements • Pathogens • Monitoring: every 2 years (intensive treatment systems), every 5 years (extensive treatment systems)
Treatments required	• Pretreatment is mandatory • Use of liquid and non-sanitised sludge is not permitted
Soil characteristics	• Initial soil characterisation –> suitability of soil for sludge application • Monitoring: every 2 years (intensive treatment systems), every 5 years (extensive treatment systems)
Modes of use	• Plot rotation, shallow slopes, environmentally sensitive areas (water catchments, etc.), pre-harvest interval • Not permitted during certain periods and on certain crops • Traceability, management of land application frequency and quantities

D. The regulatory framework for the use of sludge in agriculture is defined through a number of key texts. However, the wording relating to the practical management of sludge use in agriculture is broad in scope, leaving considerable room for interpretation when implementing these texts.

- Tunisian standard NT 106.20 of December 2002: "Fertilising materials – Sludge from urban wastewater treatment plants".

- The joint ruling of 29/12/2006 by the Ministry of Agriculture and Water Resources and the Ministry of the Environment and Sustainable Development approving the specifications defining the conditions of use of sewage sludge for agriculture and management arrangements for farmers.

- Decree no. 2007-13 of 3 January 2007, which establishes the conditions and modes of use of sludge from wastewater treatment plants for agriculture.

- The 2015 regional sewage sludge management master plans.

- The 2006 specifications and 2007 decree supplementing and expanding on the provisions contained in standard NT 106.20.

Proposed operating and financing models

There is a comprehensive framework that sets out the division of roles and responsibilities among the various governmental, deconcentrated, decentralised and local authority stakeholders for the project implementation and operational phases of a sanitation chain with a resource recovery and reuse segment. This framework is specifically defined for agricultural uses.

However, the range of stakeholders involved in operating the resource recovery and reuse segment is less clearly defined.

◄ Treated wastewater

The main stakeholders involved in the sanitation sector, and particularly in the reuse segment, are as follows:

Stakeholders involved in sanitation chain implementation and operation, including treated wastewater reuse, in Tunisia

Activity	Stakeholders	Role during the project (*implementation*) phase	Role during the *operational* phase
State regulation and monitoring [E]	**ANPE** (Environmental Protection Agency)	• Validates environmental impact studies (WWTP and surrounding areas) • Gives prior notice to MARHP for authorisation	• Conducts environmental monitoring (environments, farm products) • Can record environmental offences
	DHMPE (Hygiene and Environment Directorate – Ministry of Health)	• Consulted on health aspects during the project approval process	• Conducts health-related monitoring of treated wastewater • Monitors the quality of farm products
	MARHP (Ministry of Agriculture, Water Resources and Fisheries)	• Issues authorisation for agricultural use after validation by ANPE	• Oversees the CRDA and the national reuse strategy
Transport to the treatment plant **Treatment plant management**	**ONAS** (National Office of Sanitation)	• Installs (water + sludge) treatment facilities • Designs treatment processes based on intended use	• Undertakes WWTP operations and maintenance • Manages secondary and tertiary treatments
Treated wastewater transport and storage	**CRDA** (Regional Agricultural Development Commissions)	• Plan and implement irrigation schemes using treated wastewater • Create GDA under their supervision	• Manage treated wastewater distribution systems • In charge of water storage and pumping (depending on the season) • Monitors the quality of the water distributed

Activity	Stakeholders	Role during the project (*implementation*) phase	Role during the *operational* phase
Transport & stockage des eaux usées traitées	**GDA** (Agricultural Development Groups)	• Can be involved in project design	• Manage part of the secondary distribution network • Organise water rotas, theoretically collect fees Experience viability issues (as treated wastewater is often free)
Utilisateurs finaux	**Farmers, private owners (golf courses, industries), local authorities**	• Can participate in defining needs on certain projects	• Install and manage their private irrigation networks • Use treated wastewater for irrigation, cleaning, watering green spaces • Responsible for their own maintenance

E. A number of other government departments are also involved:

- The General Directorate of Water Resources (DGRE) is responsible for water resource knowledge and assessments, and for developing and coordinating sites where treated wastewater is used for groundwater recharge.
- The General Directorate for the Development and Conservation of Farmland (DGACTA) assesses and monitors the quality of the soil irrigated using treated wastewater.
- The General Directorate for the Protection and Quality Control of Agricultural Products (DGPCQPA) safeguards and monitors the quality of agricultural products irrigated with treated wastewater.
- The General Directorate of Agricultural Production (DGPA) oversees sludge recovery for agriculture, particularly through pilot projects, such as the agricultural recovery of residual sludge project, VBRDA (Valorisation des Boues Résiduaires Dans l'Agriculture).

Stakeholder coordination

National and regional committees have been created to oversee the national and regional use of treated wastewater. All stakeholders are to be involved in coordination, not only those from the agricultural sector.

An agreement is put in place for each project to define commitments and responsibilities for the project implementation and operational phases.

User involvement

User consultation and participation mechanisms are put in place by the local Agricultural Extension Office, a branch of the CRDA responsible for supporting and informing farmers via centrally-planned activities or specific programmes. The Agricultural Extension and Training Agency (AVFA) and its regional representatives (Local Agricultural Extension agencies, CTV) are responsible for communicating best practice on reusing wastewater for irrigation, and for providing agricultural extension services to end users.

FOR MORE INFORMATION:

- **National Treated Wastewater Reuse Master Plan** – WATER REUSE 2050, Ministry of Agriculture, Water Resources and Fisheries, AFD:

[3] - Phase 1 : Diagnostic de la filière et élaboration des orientations de base, 2020

[6] - Phase 2 – Prospective de la filière à l'horizon 2050, 2022

- **Project TCP/SNE/3701: Unblocking the Potential of Treated Wastewater and Drainage Water Use for Agricultural Development in North Africa, led by the Food and Agriculture Organisation of the United Nations (FAO)** seeks to support the North African countries of Algeria, Libya, Morocco, Mauritania and Tunisia with knowledge on the safe use of treated wastewater in order to develop the agriculture sector:

[4] - Réutilisation des eaux usées traitées en agriculture, analyse de l'état des lieux et perspectives- cas de la Tunisie, FAO, 2021

- **The Scientific and Technical Agricultural Water Committee (COSTEA: Comité Scientifique et Technique sur l'Eau Agricole)** piloted by Eau, Agricultures et Territoires (ex-AFEID) and supported by the French Agency for Development (AFD) brings together French and international irrigation expertise. COSTEA has produced a number of publications on treated wastewater reuse:

[5] - Chantier COSTEA "REUSE - Réutilisation des eaux usées en agriculture" - rapport de synthèse Tunisie, COSTEA, 2022

- **Other resources**

  - Guide à la décision pour la mise en œuvre d'un projet REUT - Réutilisation d'Eaux Usées Traitées, BRL, 2022

  - Mission d'aide technique aux opérateurs de réutilisation des eaux usées traitées en Tunisie, IME, 2022

  - Accompagnement de projets pilotes tunisiens en réutilisation des eaux usées traitées, IME, ONA, 2020

  2022 National Water Sector Report, Republic of Tunisia, Ministry of Agriculture, Water Resources and Fisheries http://www.onagri.nat.tn/uploads/secteur-eau/revue-sectorielle-eau-2022.pdf

The resource recovery and reuse of sanitation products in Palestine

Inclusion of resource recovery and reuse in national strategies

The sanitation sector in Palestine

There are around twenty wastewater treatment plants in the West Bank and Gaza, which produce 48 million cubic metres of treated wastewater per year. Sewerage still needs to be further developed as only 54% of households are connected to a sewerage system and only 35% of wastewater is treated. Some water and sanitation service areas have sewerage systems but no treatment segment.

The majority of the WWTP in the West Bank are highly efficient at reducing BOD, COD and TSS (over 95%). However, in Gaza, energy supply issues and the under-sizing of facilities make similar performance levels difficult to achieve. Since the start of the war in October 2023, virtually all of Gaza's WWTP have been destroyed.

Recovering WWTP operating costs is a challenge for service managers, who are yet to introduce a sanitation service pricing system that is based on water service billing. A survey conducted in 2020 revealed that 34% of service managers covered all their costs, whereas 50% achieved only partial cost recovery (20-60%).[7]

FOR MORE INFORMATION:

- For more information on the stakeholders involved in water and sanitation management in Palestine, please see the pS-Eau country factsheet for Palestine

Treated wastewater reuse in Palestine: strategies and situation assessments

The 2013 National Water Strategy provided for a gradual increase in the reuse of treated wastewater for irrigation, from 4.2 million cubic metres in 2017 to 31.7 million in 2022, then up to 58.5 million in 2027, and finally to 93 million in 2032.[8]

Conserving and using wastewater inside the country – the West Bank

Transboundary wastewater is a key issue in Palestine. There are between six and seven wadis that border Israel. An estimated 15 million cubic metres[F] of Palestine's wastewater flows into these wadis each year, crossing the Green Line. This wastewater is usually treated in Israeli transboundary treatment plants, some of which have been specifically designed for this purpose. Although the treated wastewater is predominantly used by Israeli farmers, Israel bills the Palestinian National Authority for the operating, maintenance and investment costs incurred to treat this wastewater. This figure amounted to 34 million euros in 2023.[9]

F. Areas where development is constrained by occupation, see fiche pays Palestine, pS-Eau, 2020

Developing new 'unconventional' water resources

In the West Bank, the Israeli occupation restricts access to and the availability of water. The Oslo Accords include a provision for Israel and Palestine to share the abstraction rights of 3 aquifers in the West Bank. In addition, the quality of the shallow aquifer in Gaza is deteriorating at an alarming rate due to increasing seawater infiltration caused by aquifer depletion and to pollution from industry and agriculture (pesticides, fertiliser). The infiltration of partially treated wastewater is also contributing to this deterioration. The current war is also most definitely having an impact on groundwater quality; however, the extent of this will only become clear once the conflict is over.

Given this situation, Palestine's sector strategies consider treated wastewater to be an alternative to groundwater for irrigation. This makes it possible to reserve groundwater for domestic use.

Promote agricultural development, particularly in Area C [F]

Treated wastewater is also considered an additional resource that must be developed to meet the agricultural sector's current and future needs. Irrigated agriculture development strategies for Area C, which is based on treated wastewater reuse, form part of the broader struggle against the occupation.

Reusing treated wastewater is not part of a strategy to balance supply and demand as it is in Morocco and Tunisia. Instead, the aim is to proactively develop the use of this resource to ensure it remains in the West Bank. This is underpinned by a strategy to stimulate demand, including in areas that use traditional non-irrigated farming practices.

The WaDIS programme

Jointly supported by a community of European partners including the EU, KfW/BMZ (Germany), AFD (France), NRO (the Netherlands), ADA (Austria) and AECID (Spain), the Team Europe TEI has been designed to provide strong political, institutional and financial leverage to improve the WASH sector in the Gaza Strip and the West Bank. The WaDIS programme is the capacity-building and institutional strategies component of the TEI and specifically focuses on sanitation and treated wastewater reuse.

As part of this programme, the French Agency for Development has appointed the French consultancy firm Hydroconseil to carry out an audit of the sector, and define the support required by Palestine's centralised and decentralised institutions with a view to building their capacities, and revising and implementing regulations. One of the ultimate goals is to further expand wastewater reuse, ensuring this is safely managed and coordinated. This also includes sludge management. The audit is due for completion by mid-2025.

After collecting and assessing master plans, local project documents, regulations and national strategies, the next phase of the programme will involve conducting strategic studies, and reviewing and revising regulations to ensure they are properly adapted to the context (for instance, sludge management, quality standards for water intended for reuse, industrial wastewater management, etc.). The programme will ultimately guide the definition of a roadmap for implementing reuse projects in Palestine.

◄ Sludge reuse in Palestine: strategies and situation assessments

Palestine's sector strategies contain no provisions for sewage and faecal sludge reuse.

National regulations – Health risk management

Treated wastewater reuse

Approaches for treated wastewater reuse in Palestinian regulations [G]	
Conditions of use, quality of output products from the treatment plant	**Class A** : fruit trees, feed crops consumed raw (for example: alfalfa, fresh grass, fodder maize), green spaces open to the public • Helminth eggs: ≤1 (arithmetic mean per litre) • Faecal coliforms ≤200 CFU / 100ml (class A water) **Class B** : Cultures non consommées crues, arbres fruitiers, espaces verts non accessibles au public • Helminth eggs: ≤1 (arithmetic mean per litre) • Faecal coliforms ≤1,000 CFU / 100ml (other classes) **Class C** : Industrial crops, reforestation, feed crops consumed once dried • Helminth eggs: ≤1 (arithmetic mean per litre) • Faecal coliforms ≤10,000 CFU / 100ml (other classes) **Class D** : Few regulations
Restrictions on modes of use	• Irrigation: Localised irrigation preferred, spraying authorised ≥50m from housing • Harvesting: Feed crops must be dried before harvesting, no picking up fallen fruit, no irrigation for at least 1 week before harvesting • Hygiene measures: gloves must be worn, signage required for treated wastewater networks, mandatory vaccination of users
Restrictions on use	Not to be used on vegetable crops

G. The main regulations and standards are as follows:

- Standards set by the Palestinian Standards Institution (PSI): Standard PSI TR 34 (2012), Standard PSI 742 (2015)

- Guidelines for Using Reclaimed Wastewater in Agriculture (2010)

Sewage sludge reuse

The Palestinian Environment Quality Authority sets the standards for sewage sludge reuse, but to date, no specific strategy for managing sewage sludge has been defined.

There is, however, a regulatory framework for the agricultural reuse of this sludge.

The Palestinian Standards Institute's recommendation guides define the acceptable levels of heavy metals in sludge (standard 59/2015).

The land application of sewage sludge as a soil amendment is restricted to grain crops, which must be dried before consumption, and to fruit trees.

Proposed operating and financing models

There is a comprehensive framework that sets out the division of roles and responsibilities among the various governmental, deconcentrated, decentralised and local authority stakeholders for the different treated wastewater uses. This covers the project implementation phase and operational phase of a sanitation chain that contains a resource recovery and reuse segment.

Treated wastewater

Stakeholders involved in the implementation and operation of sanitation systems with treated wastewater reuse, in Palestine

Activity	Stakeholders	Role during the project (*implementation*) phase	Role during the *operational* phase
State regulation and monitoring [H]	**Palestinian Water Authority (PWA)**	• Approves the creation of Water Users' Associations (WUA) • Oversees the reuse sector strategy	• Monitors treatment facilities • Involved in treated wastewater quality monitoring
	Ministry of Agriculture	• Issues licences to new WUA • Approves crop varieties and irrigation areas	• Regulates the WUA • Involved in water quality monitoring
Transport (sewers) and treatment plant management	**Decentralised sanitation service operators**	• Implement tertiary treatments, although this role is under discussion in the sector strategy	• Operate WWTP, including tertiary treatment facilities
Treated wastewater transport and distribution	**WUA** (Water Users' Associations)	• Implement local irrigation networks	• Manage the treated wastewater distribution networks supplying water to farmland

Activity	Stakeholders	Role during the project (*implementation*) phase	Role during the *operational* phase
End users	**Farmers**	• Create WUA to access treated wastewater resources • Adapt their crops and techniques (e.g. feed crops) with institutional support	• Use the treated wastewater, maintain the private distribution network • Learn how to use new farming practices

H. A number of other government departments are also involved:
- Ministry of Health
- Environmental Quality Authority (EQA): conducts environmental monitoring of treatment facilities and the receiving environment

Official Development Assistance stakeholders (international donors, decentralised cooperation) can provide technical and financial support for reuse project implementation, as well as monitoring, capacity-building and maintenance support.

◄ Sewage sludge reuse

There is no strong incentive-based strategy for sewage and faecal sludge reuse. The network of stakeholders involved in resource recovery and reuse segment operations is not clearly defined.

FOR MORE INFORMATION:

• **The Scientific and Technical Agricultural Water Committee (COSTEA: Comité Scientifique et Technique sur l'Eau Agricole)** piloted by Eau, Agricultures et Territoires (ex-AFEID) and supported by the French Agency for Development (AFD) brings together French and international irrigation expertise. COSTEA has produced a number of publications on treated wastewater reuse:

[7] - Chantier COSTEA "REUSE" - Réutilisation des eaux usées en agriculture - rapport de synthèse Palestine, COSTEA, 2022

[8] - National Water and Wastewater Policy and Strategy for Palestine, Palestinian Water Authority, July 2013

• **Other publications**

- Quelle gouvernance des eaux pour quelle construction étatique dans les territoires palestiniens?, Thèse, Jeanne Perrier, 2020
- Palestinian water laws: Between centralization, decentralization, and rivalries, AFD, Jeanne Perrier, 2020
- Water reuse in the Middle East and North Africa, a sourcebook, Javier Mateo-Sagasta et al., IWMI, 2022
- WSRC website: https://www.wsrc.ps/portal/en

[9] - Compte rendu de la rencontre du réseau Palestine du pS-Eau, février 2022

The resource recovery and reuse of sanitation products in Lebanon

Inclusion of resource recovery and reuse in national strategies

The sanitation sector in Lebanon

With the support of international aid and the CDR (Council for Development and Reconstruction), a number of centralised treatment plants have been built over recent decades, mostly with activated sludge facilities.

However, few of these WWTP are operational, and many of the sewerage systems required to convey effluent to the treatment plants have never been installed.

As a result, it is estimated that less than 10% of wastewater is currently treated, and only 60% of users are connected to a sewerage system. A recent (not yet published) UNICEF-led study entitled Vulnerability assessment: evaluate the potential of solarization estimates that 1.5 million people discharge their wastewater into the environment without treatment, including 700,000 who discharge their untreated wastewater directly into a watercourse. There are also significant regional inequalities in this lack of access to sanitation services. While the sewerage connection rate in urban coastal areas stands at 90%, access rates in mountainous and rural areas are extremely low. Lebanon remains below the regional average for wastewater treatment, which is estimated to be 46% for the Middle East and North Africa.

Centralised wastewater treatment plant projects have been on standby for several years now. As a result, some local authorities have started to work with international donors and decentralised cooperation partners to explore decentralised solutions.

FOR MORE INFORMATION:

- For more information on the stakeholders involved in water and sanitation management in Lebanon, please see the pS-Eau country factsheet for Lebanon

Treated wastewater reuse in Lebanon: inclusion in strategies and situation assessments

Although Lebanon is one of the countries in the Middle East least affected by water scarcity, it does suffer from relatively high water stress, with this being set to increase in the coming years. The unbalanced distribution of available resources across the country, the current and projected impacts of climate change on water availability, and the lack of effective water supply systems make water resources management challenging. The country's hydrological balance (difference between needs and renewable resources) could reach a deficit of 1.7 billion m^3 year by 2040, compared with around 300 million m^3 today.

Agriculture places the main anthropogenic pressure on water resources, with an increase of more than 53% in annual demand projected for this sector by 2035. Thus the national water strategy published by the Ministry of Energy and Water (MoEW) in June 2024 prioritises treated wastewater as one of the main non-conventional resources that is to be developed, particularly for reuse in agricultural irrigation.[10]

In addition, it is important to note that informal wastewater reuse is already being practised throughout the country. Many WWTP are in agricultural areas suffering from water stress, and nearby farmers therefore use the treatment plant effluent for irrigation (particularly in the Bekaa valley).This wastewater is usually only partially treated, and there is little quality monitoring carried out, which poses health risks. These risks are even more significant when viewed in light of the cholera epidemic that struck Lebanon between November 2022 and February 2023.

The ReWater MENA project to expand and regulate safe treated wastewater reuse

Between 2018 and 2021, the International Water Management Institute (IWMI) embarked on a project funded by the Swedish International Cooperation Agency (SIDA) to assess the potential and barriers to treated wastewater reuse in the Middle East and North Africa.

Under this project, Lebanon's 'reuse potential' was estimated by cross-referencing the capacity of each current and planned WWTP against the estimated surface area of nearby irrigable agricultural land. The study revealed that 48 WWTP had good reuse potential (in 2020 when the study was conducted). Under a scenario in which the current WWTP are fully operational and running at full capacity, this figure could rise to 82 plants, which could be fitted with treatment systems to fulfil this potential. However, this scenario now appears optimistic given the financial crises and bombings that Lebanon has been experiencing since 2020.

Pre-feasibility surveys were conducted for Zahleh and Ablah WWTP to assess the feasibility of implementing (Zahleh) or recommissioning (Ablah) a treated wastewater reuse system. In addition to the technical aspects, these surveys revealed the importance of including a social component in treated wastewater reuse projects. The needs and dynamics of the various groups of potential users of the future system were carefully assessed, and participatory workshops were held to jointly examine different scenarios with the beneficiaries.

FOR MORE INFORMATION:

- For more information on wastewater reuse pilot projects in Lebanon, please see the factsheet on treated wastewater reuse in Lebanon produced by the LEbanese Water Actor Platform.

Sewage and faecal sludge reuse: inclusion in strategies and situation assessments

Sludge management appears as a key issue in the updated National Water Sector Strategy, and the use of sludge in agriculture is recommended. However, no details are provided on the operational arrangements to be considered.

There are currently no treatment plants that have a complete and effective sludge management component in place, i.e. that has treatment processes, sludge transport and an identified final destination, whether a landfill or recovery option. The sludge is discharged, uncontrolled, into the sea or the environment, which poses risks to both public health and the environment.

Pilot projects have recently been implemented or are underway to explore various sludge recovery options. However, none of these projects has so far resulted in the implementation of a sustainable recovery stream.

FOR MORE INFORMATION:

- For more information on sludge recovery pilot projects in Lebanon, please see the fact-sheet on sludge management in Lebanon produced by the LEbanese Water Actor Platform.

National regulations – Health risk management

Lebanese standard NL 819:2024, entitled Water Reuse in Irrigation, has been published by LIBNOR. The standard was developed in conjunction with a range of stakeholders, including public institutions, universities and experts from the private sector. The IWMI-led ReWater MENA project played a key role by providing scientific data and field tests to guide definition of the standard.

Approaches for treated wastewater reuse in Lebanese regulations	
Conditions of use, quality of output products from the treatment plant **Required treated wastewater characteristics**	**Class I** : Vegetables eaten raw, gardens and landscape areas with direct public exposure • Faecal coliforms: ≤100 CFU /100ml • Helminth eggs: ≤1 egg/L **Class II** : Processed food crops, fruit peeled before eating, fruit eaten without peeling (sprinkler irrigation is not permitted), tuber and root crops eaten co-oked, medicinal plants consumed raw, sun-dried or processed into spices, crops to feed milk- or meat-producing animals, gardens and landscaped areas with li-mited public exposure. • Faecal coliforms: ≤1,000 UFC/100ml • Helminth eggs: ≤1 egg/L **Class III** : industrial crops (cotton, flax), woodland, energy oil crops, grain crops not for human consumption • Faecal coliforms: ≤ 10,000 CFU/100ml • Helminth eggs: ≤ 1 egg/L
Restrictions on crops and irrigation methods	Irrigation of underground crops is not permitted with any class of effluent. Only vegetables whose edible part is produced above ground and is not in di-rect contact with reclaimed water may be irrigated with Class I effluent, and only using drip and sub-drip irrigation methods. Fruit eaten without peeling cannot be irrigated with sprinklers using Class II ef-fluent. For sprinkler systems, only low pressure, high discharge pop-up sprinklers at an angle of less than 11 degrees can be used. This applies to Classes I and II.
Multi-barrier approach	In addition, the standard provides recommendations based on the WHO multi-barrier approach on controls and requirements for health protection for farmers, operators and consumers. This approach is underlined by the need to adopt a health risk management plan for all water reuse projects.

Institutional set-up – Proposed operating and financing models

Although not widely developed, wastewater reuse for agricultural irrigation features prominently in sector strategies, providing an insight into the roles that the various governmental, deconcentrated and decentralised stakeholders could potentially play. However, this theoretical framework does not cover the reuse of sewage and faecal sludge.

As the authorities responsible for the management and operation (which can be delegated) of water and sanitation services, the Water Establishments would be in charge of any tertiary treatment systems required. Although treated wastewater reuse is not yet widespread, some treatment plants already have tertiary treatment facilities in place, but these are rarely operational.

Despite the difficulties encountered by the Water Establishments in managing domestic water and sanitation services, Lebanon's Water Law stipulates that they are also responsible for managing irrigation systems in areas where wastewater is reused for agricultural purposes.

The Water Law also recognises water users' associations (WUA). There are already some water users' associations in place, most of whom manage irrigation systems that distribute water from mountain springs in the Bekaa. Farmers pay the association's irrigation committee, who is in charge of maintaining the irrigation channels. In the Water Law, the official status of these WUA is defined through sophisticated organisational and operational arrangements, with formal governance that is adapted to the management of modern irrigation systems. Existing water users' associations have a simpler and more practical way of working; therefore, they may struggle to recognise and comply with these more formal requirements.

Direct management of an irrigation system by a local authority is much less common and is not covered by the regulations (there is just one case: Anjar in the Bekaa).

In other regions, where water for irrigation comes mostly from wells, informal arrangements are often made between farmers and the wells' owners.

The investment required for such an irrigation project, especially one aimed at preserving water resources, would be likely to attract funding from a range of different donors.

However, operations and maintenance also entail costs, for which a financial model would be required.

Given the current financial crisis, it may be difficult to ensure users' willingness and capacity to pay. The bill collection rate for water and sanitation services is already on the decline. This is exacerbating the financial situation of the Water Establishments, further hampering their ability to properly manage and restore users' confidence in the service.

If treated wastewater is to be provided free-of-charge to farmers, another financial resource must be found to ensure that the service operator has the revenue required to manage the service effectively.

FOR MORE INFORMATION:

- **Lebanese Standard 819 – Lebanese standard first edition 2024 – water reuse in irrigation, LIBNOR, 2024**

- **Project REWATER MENA, IWMI:**

[10] - Lebanon's national water strategy 2024 – 2035, Ministry of Energy and Water, juin 2024

- Analysis of Water Reuse Potential for Irrigation in Lebanon, IWMI, Karim Eid-Sabbagh et al., 2022

- Rehabilitation and Extension project for Ablah Water Reuse System, Bekaa Lebanon, ReWater MENA Output 2: Design of two local reuse models in Lebanon, IWMI, Marie-Helene Nassif et al., 2022

- Co-design of a water reuse project around Zahleh WWTP, Lebanon: Methodological learnings and implementation challenges, ReWater MENA Output 2: Design of two local reuse models in Lebanon, IWMI, Marie-Helene Nassif et al., 2022

- **"Water-Energy Nexus of Water and Wastewater Service in Lebanon", OXFAM, 2021**

- Volume I: Executive Summary

- Volume II: Social Network Analysis

- Volume III: Energy Audit of the Water and WasteWater Sectors

- Volume IV: Renewable Energy Potential and Market Assessment

- Volume V: Socio-Economic Assessment of the Water-Energy Nexus

- **Other resources**

- Lebanon Country Climate and Development Report (CCDR), World Bank, 2024

- Are Fresh Water and ReclaimedWater Safe for Vegetable Irrigation? Empirical Evidence from Lebanon, LARI, Marie Thérèse Abi Saab, 2022

- Treated municipal wastewater reuse for eggplant irrigation, LARI, Marie Thérèse Abi Saab, 2021

- Wastewater reuse and sludge valorisation and reuse proposition for Lebanon, FAO, 2010

- Energy from Wastewater Sewage Sludge in Lebanon; Transforming a Waste Disposal Problem into an Opportunity, Ministry of Eneregy and Water, UNDP, 2013

- Level of water stress: freshwater withdrawal as a proportion of available freshwater resources | Data (banquemondiale.org)

CHAPTER 4

Case studies

The following case studies examine how the challenges described in **chapter 2** have been incorporated into projects implemented under decentralised cooperation partnerships with French local authorities.

These projects involve different sanitation chain set-ups (wastewater treatment plants – WWTP, faecal sludge treatment plants – FSTP, intensive or extensive treatment processes) that enable treated wastewater reuse and/or sludge recovery.

Two of the case studies look at the types of sanitation and treatment segments frequently encountered in Mediterranean countries (intensive biological treatment and extensive waste stabilisation pond treatment).

The third examines the resource recovery and reuse options available for a segment that does not yet exist in Mediterranean countries: the treatment of faecal sludge, collected by vacuum truck, in a faecal sludge treatment plant (FSTP).

Case study 1
Reusing wastewater for the irrigation of green spaces in Tata, Morocco

Decentralised cooperation: Communauté d'Agglomération Hérault Méditerranée / Tata Province

A decentralised cooperation partnership was first established in 2009 between Tata province in Morocco and the city of Agde in France. Following a transfer of responsibilities, this cooperation has been continued by the Communauté d'Agglomération Hérault Méditerranée (CAHM) who took it on in 2017. The activities undertaken as part of this decentralised cooperation are currently being supported by the Rhône Méditerranée Corse Water Agency, Tata Provincial Council, Souss Massa Regional Council, the local authority of Tata and Morocco's Ministry of the Interior.

The decentralised cooperation project involves extending the sewerage system and developing reuse of the wastewater treated by the wastewater treatment plant (WWTP).

This has been designed as a pilot project, which could serve as inspiration for similar projects to reuse treated wastewater from other waste stabilisation ponds (WSP) in Tata province.

Tata Wastewater Treatment Plant, © pS-Eau, September 2024

1) 1) How is the sanitation chain set up and what facilities and treatment processes have been selected for the different segments of the chain? What are the sanitation products used for?

Tata's sewerage system was installed through a programme funded by the Islamic Development Bank. Commissioned in 2004, it collects effluent from Tata city centre and conveys it to a waste stabilisation pond treatment plant.

However, the programme did not include connecting the peri-urban douars to the sewerage system. Houses had latrines and pits of various types, often cesspools, which were covered over and abandoned once full. The blackwater went into the pit, the greywater was discharged into the street.

The decentralised cooperation project consists of extending the sanitation system to connect Tata's surrounding douars: Agadir Lhna, Tighremte, Sounhn, Agoujal, and Indfiane. This entails extending both the sewerage system and the treatment system. This work has been broken down into several phases spread over more than 10 years.

The first, completed phases consisted of extending the sewerage system. Several scenarios were considered for areas with challenging topography, with one of the key criteria being to minimise operating costs. With this in mind, a small-bore sewer system was chosen for three residential areas in order to remove the need for a lift station. As a result, there is only one pumping station on the entire sewerage system. This meant that the pipes had to be buried deep underground for certain sections of the network (up to 9m deep); however, it has helped reduce operating costs.

The last phase of the project, which is currently underway, involves extending the treatment plant. This extension work, which will increase the capacity of the plant from 13,204 to 25,155 PE, includes the installation of a primary pond, a secondary pond and an additional drying bed. The project also seeks to improve the quality of the treatment process to enable the wastewater to be reused in accordance with the Moroccan regulations for its intended use.

◄ Access/containment segment

Households within the sewerage system coverage area have flush toilets without urine diversion.

◄ Intermediate/transport segment

The raw wastewater from the flush toilets is discharged through the sewerage system to a WSP treatment plant.

For three residential areas located below the nearest sewerage system, a local small-bore, gravity-fed sewer system has been put in place, which discharges the effluent into a semi-collective septic tank.

◄ Treatment segment - WWTP

The wastewater passes through a pretreatment facility (screening and grit removal).

Filière eau

- **Primary treatment:** primary treatment takes place in two (51 x 22m) 4m-deep ponds, which contain the conditions required for anaerobic biological treatment of the wastewater, and have a detention time of around 5 days.
- **Secondary treatment:** secondary WSP treatment takes place in two (175 x 60m) 'facultative' ponds that are 1.5m deep, enabling aerobic biological treatment, as well as photosynthesis. These ponds have a much longer detention time. The two primary and two secondary ponds work in parallel. They are fed and rested in turn, on a 5-day cycle, via a distribution system.
- **Tertiary treatment:** the project involves the addition of finishing or 'tertiary' treatment via two linked maturation ponds, one for microfiltration and the other for UV treatment.

Sludge from the waste stabilisation ponds

The sludge removed from the waste stabilisation ponds is treated in two drying beds.

Resource recovery and reuse segment

TERTIARY WASTEWATER → Tertiary treated wastewater

Uses

Farming activities (edible and non-edible crops) → **FARMING ACTIVITIES**

Irrigation of public green spaces (gardens, parks) → **PUBLIC GREEN SPACES**

The sanitation system currently produces 700m^3 of treated wastewater per day.

Under the project, this treated wastewater is to be used to irrigate three areas located near the treatment plant:

- A wooded area located on urban building land that is currently being developed on the outskirts of existing residential areas in the centre of Tata, and which has a surface area of 12 hectares;
- A 14 hectare 'green belt' that is to be created between the treatment plant and residential areas;
- An area of woodland that is to be created on the treatment plant site.

The reuse segment of the sanitation chain consists of the following components:

- A storage pond at the treatment plant outlet: although the planned uses are not seasonal, the decision was made to install a storage pond after the WWTP so that all the various pumping stations can be located in one place.
- A gravity-fed network to convey treated wastewater to the areas to be planted inside the treatment plant site and a drip irrigation system;
- A pumping and filtration station and a general discharge network;
- A pumping and filtration station and a network to convey treated wastewater to the green belt, as well as a drip irrigation system;
- A pumping and filtration station and a network to convey treated wastewater to the urban development area, as well as a drip irrigation system.

The filtration systems will help reduce total suspended solids (TSS), which could otherwise cause clogging in the drip irrigation systems.

DRIED PART-SAN SS Partially sanitised, dried sewage sludge

Uses

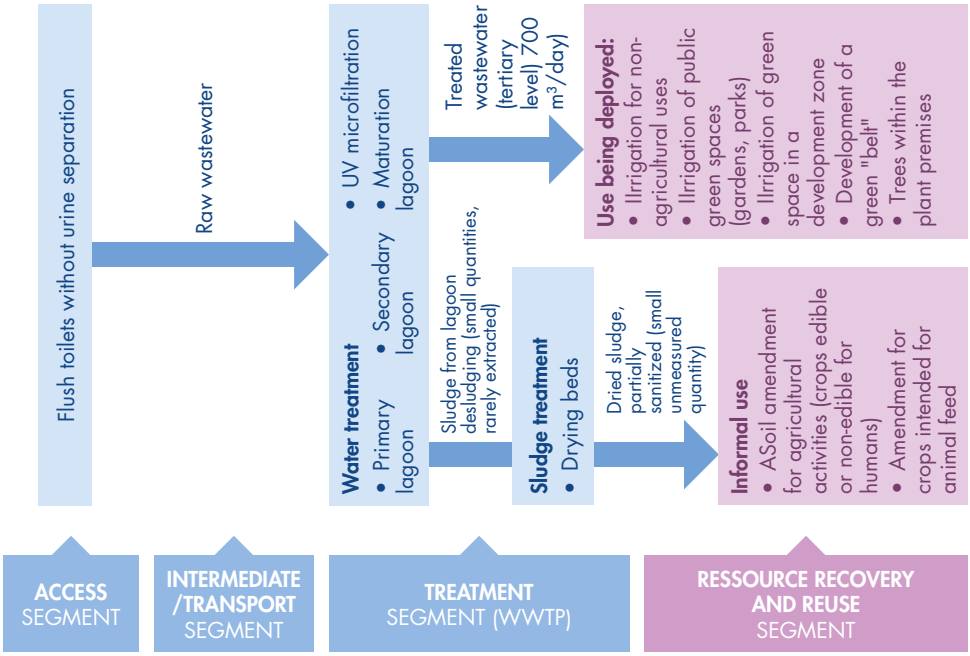
Farming activities (edible and non-edible crops) — FARMING ACTIVITIES

Livestock breeding (use of end-products for animal feed) — LIVESTOCK BREEDING

The drying beds produce around 760 m^3 of dried sludge per year.

The dried sludge produced by the treatment plant is taken to the Tata landfill site for disposal. The wastewater from the drying beds is returned to the wastewater network upstream of the pretreatment facility.

Informally, farmers collect dried sludge from the treatment plant's drying beds; a practice that is tolerated by the treatment plant operator. This sludge is then used as an amendment on crops grown for animal feed.

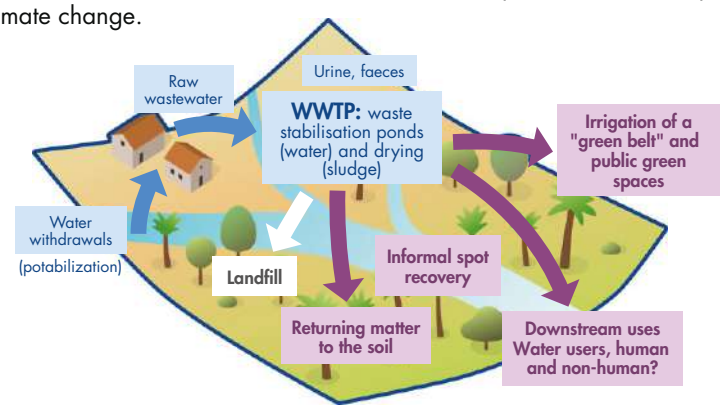


2) What are the environmental benefits of the project, and what impact assessments have been or will be carried out?

Returning materials to the soil

Development of a 'green belt' will help tackle desertification.

Irrigation of the woodland to be created in the urban development area will help ensure adaptation to climate change.

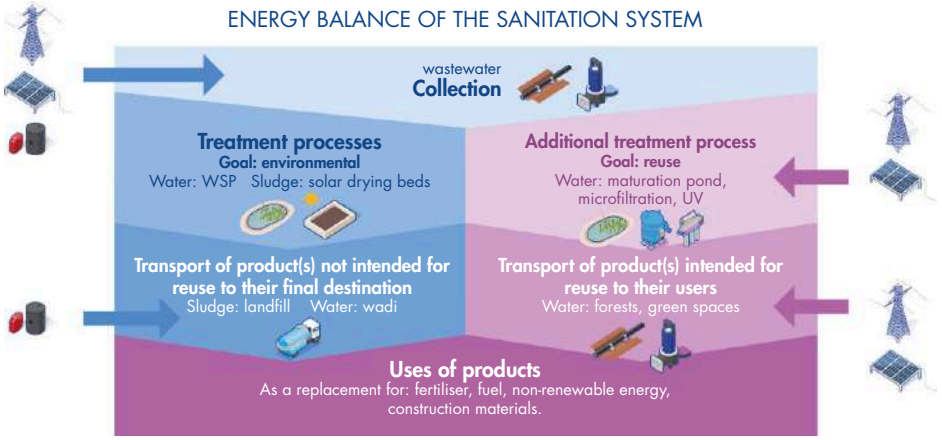


Environmental viability of the sanitation chain based on its energy audit

By opting for a gravity-fed sewerage system and extensive treatment process, the intermediate segment's sewerage system has only one lift station. The pumping system, which has a total head of 9.5m, requires 2 kW of power.

While there is no additional energy consumption required for the maturation ponds, the microfiltration and UV treatment processes do consume energy (for which no data is available).

The energy for the lift system required to transport the treated wastewater also needs to be taken into account. There are to be 3 lift stations installed for the resource recovery and reuse segment. Design studies are underway to estimate the total power output required.



3) What health risk management strategy has been adopted?

Health risk associated with the use of treated wastewater

Defining and monitoring quality standards for wastewater leaving the WWTP

Moroccan regulations on the use of wastewater from treatment plants are stringent and restrictive, which leaves little leeway for developing a tailored health risk management strategy.

Class C treated wastewater can be used to irrigate the planted areas to be installed in the green belt and on the WWTP site (using localised drip systems). However, the treated wastewater used to irrigate the woodland in the planned development area must be Class A. In Morrocco, using treated wastewater for irrigation is encouraged as using drinking water for this purpose is not permitted.

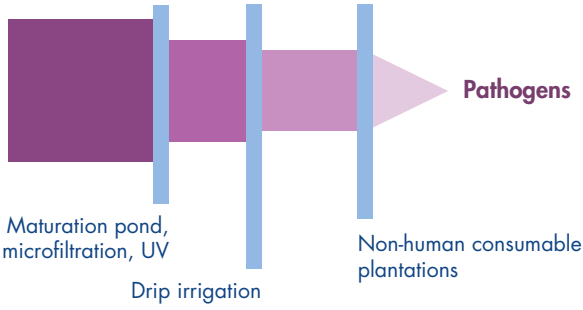
Effluent treated in the primary and secondary WSP will have undergone a significant reduction in the traditional physico-chemical parameters (especially BOD), as well as in certain pathogens (protozoan cysts and helminths); however, it will still contain some viruses and bacteria.

Maturation ponds are designed to substantially reduce pathogens: up to 6 log for bacteria, 4 log for viruses, and 2 log and 3 log, even up to 100%, for protozoa and helminth respectively (Sperling et al., 2006). Installing maturation ponds to supplement secondary treatment can help remove virtually all pathogens.

However, as Moroccan regulations require that Class A water be free of helminth eggs, additional sanitisation treatment using microfiltration and UV must also be applied.

The quality of the water leaving the treatment plant is monitored on a daily basis to check the pH, conductivity, and temperature, whereas COD, BOD, nitrogen and phosphorus levels are monitored every 3 months. Microbiological parameters, particularly helminth eggs will also be monitored on a regular basis (the frequency and monitoring mechanisms have not yet been defined).

Once the reuse system is up and running, it will be possible to bypass the irrigation network in residential areas should monitoring reveal a non-compliance that could pose a health risk.



Health risk associated with the use of dried sludge

The process of drying sludge on unplanted beds is not designed to reduce pathogens. The time required to increase the dry matter content and significantly reduce pathogens depends on both the sludge characteristics and local climate conditions. Bacteria undergo partial inactivation, usually less than 1 log, and can become active again if rehydrated. Viruses can be reduced by up to 2 log. According to WHO, a detention time of 3 to 6 months is required to achieve a 0.5 log inactivation of helminth eggs. Given the climate conditions in Tata, a long detention time in the drying beds will maximise pathogen reduction in the sludge.

Informal reuse by farmers is not regulated, but involves only a very small quantity of sludge (not measured), which is removed only rarely from the WSP (only once since the WWTP was commissioned). This sludge is reused by farmers after drying in the drying beds and so, theoretically, a significant amount of pathogens should have been removed.

Sludge quality is not monitored as there is no formal use and the sludge is taken to landfill for disposal.

4) What is the proposed organisational and financial model? What are the challenges for implementing this and ensuring its sustainability?

◄ Organisational model

The regulations designate the local authority as the authority responsible both for water and sanitation services (management and operation) and for the development and maintenance of green spaces. However, Moroccan legislation, and particularly the Public Procurement Act, includes numerous options for delegating management, such as to users' associations, deconcentrated services, agencies and national institutions. This delegation of responsibilities is particularly common for water and sanitation services, and is formalised through agreements that are binding on the stakeholders concerned. Therefore, all decentralised, deconcentrated and government agencies involved in a treated wastewater reuse project are encouraged to enter into a specific treated wastewater reuse agreement.

The 'transport' activity and the 'wastewater treatment' activity

Given the technical and financial capacities of the Tata local authority (low taxation and few government grants), under the direction of the governor, the stakeholders deemed it more appropriate to transfer management and operation of the various sewerage and treatment system components to deconcentrated institutions and national agencies.

As a result, the Tata local authority has delegated management of the sewerage system to Tata province. It is therefore Tata province who is in charge of managing the project to expand the sewerage system and install a treated wastewater reuse system.

The local authority has also transferred responsibility for water and sanitation service operations to the national water and electricity agency, ONEE (Office National de l'Eau et de l'Électricité). Prior to the sewerage system extension work, the local authority used to delegate water service management in the outlying douars to water management associations. With the new sewers being integrated into the sewerage system operated by ONEE, the local authority decided to also delegate water supply management to ONEE upon completion of the sewerage extension work to ensure consistency and efficiency.

It is therefore now ONEE who is responsible for operating all water and sanitation services on behalf of Tata province.

Due to its extensive technical and financial expertise, ONEE is able to integrate these new tertiary treatment infrastructures (maturation pond, microfiltration and UV treatment) into its current organisational model. To fulfil this responsibility, ONEE often outsources work to service providers under contracts known as 'gardiennage' contracts that are regulated by the Public Procurement Act. There are two operatives on-site at the treatment plant at all times, and there are several other operatives responsible for operating the sewerage system.

This organisational setup could be revised to bring it into line with the changes currently being made to the water and sanitation sector framework. Law no. 83.21 of 12 July 2023, the implementation provisions of which are set out in decree no. 990.24 of 16 April 2024, provides for the creation of regional multiservice companies (SRM: Sociétés Régionales Multiservices), who would become the authorities responsible for water and sanitation service operations and management (as well as electricity distribution). The provincial council will remain a key Tata reuse project stakeholder, and the local authority will remain involved as both a beneficiary and member of the Souss Massa regional SRM management board.

The 'transporting treated wastewater to end users' activity

- For the green belt:

The regional directorate of the national water and forest agency (ANEF: Agence Nationale des Eaux et Forêts), which comes under the supervision of the Ministry of Agriculture, has signed a specific treated wastewater reuse agreement setting out its role for developing and managing the 'green belt' irrigation systems and plantations. The local authority is to enter into a bilateral agreement with the ANEF regional directorate under which the regional directorate will manage the green belt's irrigation systems and irrigated plantations for a period of 3 years.

The ANEF regional directorate oversees reforestation and woodland maintenance projects that focus on climate change adaptation and mitigation. Its scope also includes activities associated with this main role, particularly the management and operation of irrigation systems.

The ANEF regional directorate has the skills, human resources and funds required to fulfil this responsibility. It also has experience of creating and managing a green belt in Tata. Other regional directorates have experience of managing drip irrigation systems using treated wastewater, from the Bouarfa treatment plant in Figuig, for example. At the central level, ANEF has a range of experts available for deployment on projects implemented in the different regions, including an expert on drip irrigation systems.

The ANEF regional directorate has formally committed to managing the green belt irrigation system and plantations for a period of 3 years. However, all partners, including the ANEF regional directorate, remain commit-

ted to ensuring the smooth operation of the system, under the direction of the governor. The ANEF regional directorates are often required to take on this management role for many years, up to more than 10 years in some cases.

• For the planned woodland and irrigation system in the urban development area:

The local authority of Tata and the ANEF will be responsible for managing the irrigation system and the woodland.

• For the planned treatment plant site wooded areas and irrigation system

These will be incorporated into the facilities managed by ONEE (ultimately by the SRM).

Financial model

Due to its extensive technical and financial expertise, ONEE is able to integrate these new tertiary treatment infrastructures into its financial model (additional connections, installation of additional pipelines and a pumping station, new treatment ponds, particularly new tertiary treatment ponds). ONEE's overall financial stability is facilitated by an equalisation of income and expenditure at the national level. In addition, the water and sanitation pricing structure defined by Moroccan legislation for local authorities like Tata is affordable, and aligned to the relatively low depreciation and operating costs of an extensive waste stabilisation pond system. Ultimately, the SRM will be responsible for operating the wastewater treatment plant, thereby ensuring technical and financial equalization throughout of the Souss Massa region.

5) What co-construction initiatives have been put in place with stakeholders, particularly the users of the sanitation products intended for resource recovery and reuse?

◄ Co-constructing an organisational model

Under the specific treated wastewater reuse agreement, established in accordance with the regulations, the following stakeholders have committed to ensuring the success and sustainability of the project, under the governor's direction:

Tata Provincial Council, Souss Massa Regional Council, the local authority of Tata and Morocco's Ministry of the Interior

- Morocco's Ministry of the Interior
- The Wilaya of the Souss-Massa Region
- The Souss-Massa Regional Council
- The Tata province
- The Tata Provincial Council
- The local authority of Tata
- The Communauté d'Agglomération Hérault Méditerranée (CAHM)
- The Société Régionale Multi Service du Souss-Massa (SRM)
- The Deraa Oued Noun Basin Agency
- The National Agency for Water and Forests (ANEF)

However, the signatories to this agreement were not consulted on the subsequent division of responsibilities. Priority has been given to public project management, which is considered most effective as the governor is heavily involved in overseeing this project.

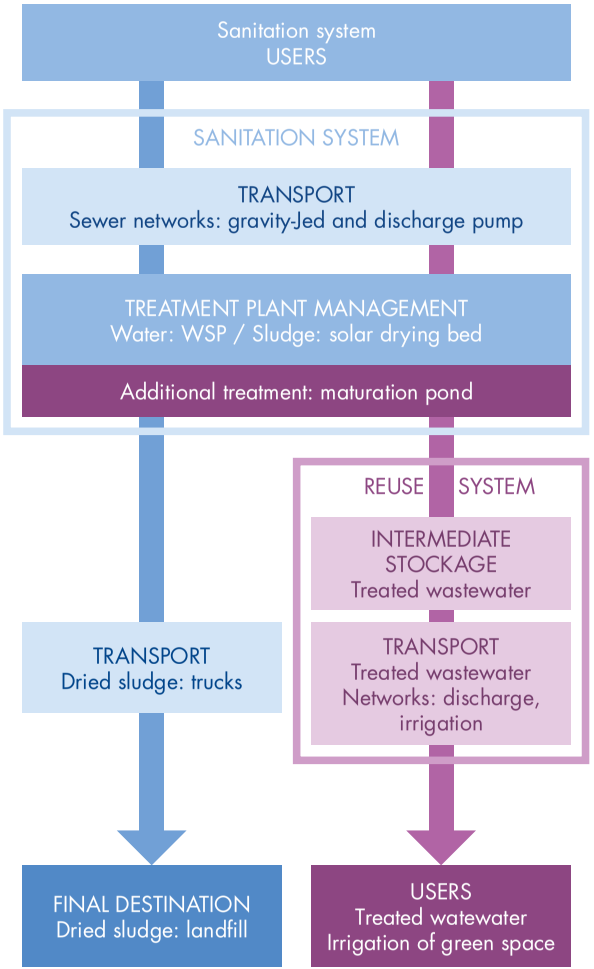
◄ Providing information on and raising awareness of the health risk

Local representatives need to be involved in providing information to users and gaining their consent. These representatives include: the military chief, the pasha and representatives of the different ethnic groups. These stakeholders are not signatories to the specific treated wastewater reuse agreement, but their involvement is essential for liaising with communities.

Moroccan legislation requires a public consultation be carried out. A public consultation notice, giving people the opportunity to submit comments and objections within a certain timeframe, is displayed at the provincial council offices, as they are the project manager. However, as in France, these public consultations are introduced at an advanced stage of the project design phase and few people are aware that they are taking place.

◄ Supporting changes in practice

ANEF is liaising with the users of the land affected by the future green belt project as part of the participatory approach set out in the 2020-2023 Forests Strategy. Therefore, ANEF facilitators will be responsible for informing and raising the awareness of shepherds whose animals graze on the land around Tata to ensure they use the future plantations responsibly. For instance, they will be prohibited from allowing their animals to graze on this land for the first few years to give the green belt time to bed in and grow. The Forest Strategy also contains provisions for a negotiation process that could result in compensation being provided. However, this process is designed more for the creation of woodland covering large expanses of land in rural areas.



Authority responsible: Tata local authority

- Management: Tata Province
- Operator: ONEE

Plantations in the future urban spaces:
Authority responsible: Tata local authority

- Project management: Tata Province
- Operations: Tata local authority, urban developer

Local residents

The 'green belt':
Authority responsible: Agence Nationale des Eaux et Forêts (ANEF)

- Manager : ANEF
- Operator : ANEF, Tata local authority, urban developer

2020-2023 Forests Strategy: participatory approach
ANEF facilitators

Shepherds whose animals graze around Tata

Case study 2
Optimising the Ramallah WWTP in Palestine to develop sludge reuse

Decentralised cooperation: Toulouse Métropole (with support from the NGO Hamap Humanitaire) / Ramallah Municipality

This project involves implementing additional treatment for the sludge produced by the Al Tireh WWTP in Ramallah in Palestine to enable sludge recovery, and to map out the resource recovery and reuse segment through a feasibility assessment. The treated wastewater produced by this WWTP is already being reused.

This project is being implemented under a decentralised cooperation partnership between Toulouse Métropole and Ramallah Municipality, the Adour-Garonne water agency, the International Office for Water (OiEau) and HAMAP Humanitaire. Toulouse Métropole and the Adour-Garonne water agency are funding the project under the Oudin-Santini Law.

Al Tireh WWTP, Palestine, © Hamap Humanitaire

1) How is the sanitation chain set up and what facilities and treatment processes have been selected for the different segments of the chain? What are the sanitation products used for?

Access/containment segment

The majority of households have flush toilets without urine diversion. However, there are many houses that are not yet connected to the sewerage system and which therefore have individual latrines.

Intermediate/transport segment

Wastewater is conveyed by the sewerage system to the Al Tireh WWTP.

Treatment segment

The wastewater treatment plant receives a large proportion of Ramallah's wastewater. It was commissioned in January 2014 and has a treatment capacity of 2,000m³ per day. It is currently being extended to increase its capacity to 6,500m³ per day from April 2025 onwards.

Wastewater:

- Primary treatment: thickening (not specified);
- Secondary treatment: membrane bioreactors;
- Tertiary treatment: chlorination.

Sludge:

Prior to the project, the sludge removed from the primary and secondary treatment facilities were transported by truck to a public landfill in Jenin about 50km away.

Under the project, a centrifuge has been installed to mechanically dewater the sludge to a dry matter content of 20%. This helps optimise sludge removal and transport as the sludge is reduced in volume.

Due to the occupation, travel restrictions in the West Bank have made it impossible to reach the landfill in Jenin. However, reducing the volume of sludge through dewatering means it can now be stored on-site at the WWTP.

As part of the project, a study was carried out to explore options for further treating the sludge to make it suitable for reuse.

Plans are now in place to introduce additional treatment using covered drying beds in order to reduce pathogens and enable agricultural reuse.

The existing mechanical dewatering process will help optimise the volume of sludge to be spread over the beds, meaning a smaller footprint will be required.

The land on which these drying beds are to be installed has already been identified. A feasibility assessment has determined the various context-specific parameters to be taken into account when defining the size of these drying beds, as well as the sludge detention time. Now that the centrifuges are in operation, the actual characteristics of the sludge must be included as input data. In addition, fluctuations in sunlight throughout the year may mean that underfloor heating will be re-

quired, powered either by a gas boiler, a pump using heat from wastewater, or by solar panels.

The target dry matter content of the sludge dried in these beds is 75%.

The dried sludge removed from the beds can then be pressed into granules. These dried sludge granules will be stored on-site to respond to the seasonal requirements of farmers.

Maillon réutilisation/valorisation

TERTIARY WASTEWATER — Tertiary treated wastewater

Uses

Farming activities (edible and non-edible crops) → **FARMING ACTIVITIES**

Irrigation of public green spaces (gardens, parks) → **PUBLIC GREEN SPACES**

The chlorination-treated wastewater is reused for a range of purposes: the irrigation of public green spaces, such as Ramallah park, the irrigation of roadside verges in the Al Tireh region, and for watering private gardens. Treated wastewater is also provided to contractors carrying out roadworks to water the roads (reduce dust) and to compact backfill.

DRIED PART-SAN SS — Partially sanitised, dried sewage sludge

Uses

Farming activities (edible and non-edible crops) → **FARMING ACTIVITIES**

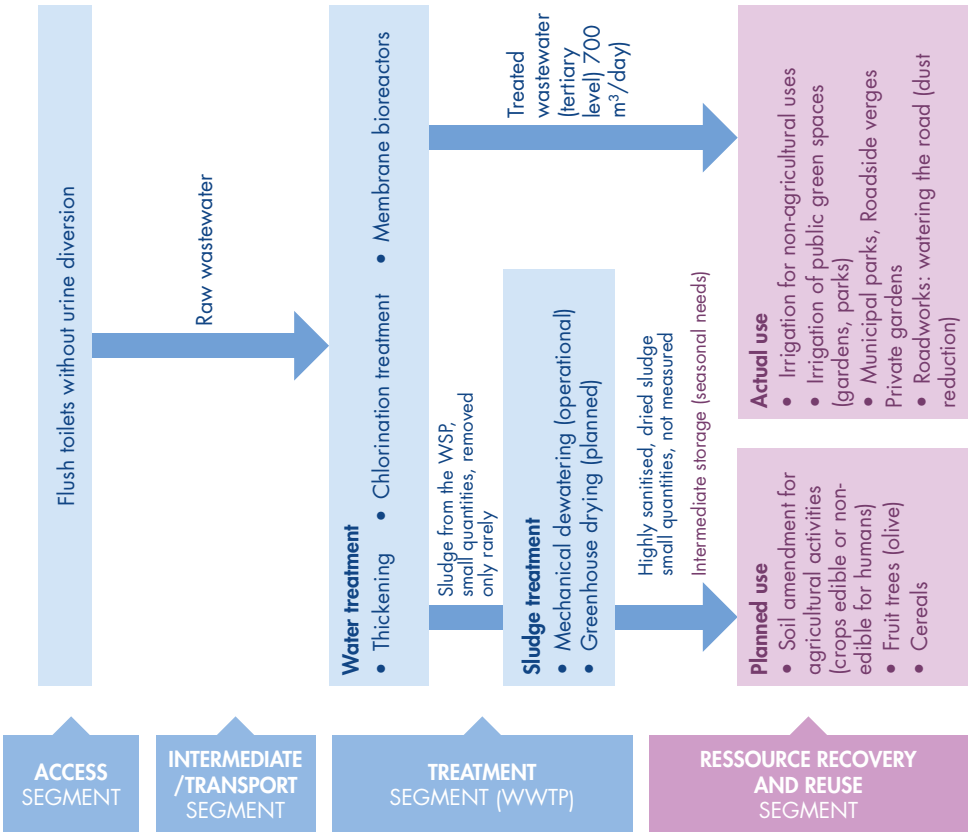
The dried sludge produced is in the form of granules.

The plan is to bag these granules so that they can be packaged in a similar way to the dried manure already used by farmers.

The main crops on which this sludge can be used are olive trees and, more broadly, all fruit trees, provided that their branches are high enough off the ground. Reuse for some grain crops is also being considered. These crops require amendment in autumn and spring, which means that the dried sludge will need to be stored at the WWTP to respond to these seasonal requirements.

In order to ensure the reuse of all the sludge produced by the WWTP (an estimated 350 tonnes), 80 hectares (800 dunums) of land has been identified, which is used by an estimated 50 farmers due to the fragmented layout of the surrounding farmland.

Some of the farmers in the nearby village of Ein Qinya have already manifested an interest in using the sludge.



2) What are the environmental benefits of the project, and what impact assessments have been or will be carried out?

◄ Returning materials to the soil

The using the treated sludge will improve the quality of the soil, and provide the soil with organic matter and fertilising nutrients (nitrogen, phosphorus, potassium). This means that farmers will need fewer chemical fertilisers, thereby reducing their costs.

The addition of organic matter rich in nitrogen (N), phosphorus (P) and potassium (K) will improve the structure and fertility of the soil, as well as its water retention capacity. In order to ensure that the application of dried sludge helps improve both soil and crops, the annual quantities of sludge incorporated into the soil will be monitored: three tonnes of dry matter per hectare per year, i.e. 400kg of dried sludge with a dry matter content of around 75%. This will ensure that the amount of fertilising inputs is adapted to both the retention capacities of the soil and the crop requirements in order to increase crop yields while minimising the risk of heavy metal accumulation.

Sludge use, sludge quality and soil quality will all be strictly monitored in a laboratory in accordance with the guidelines issued by the Palestinian government (mandatory technical instruction no. 59/2015).

Environmental viability of the sanitation chain based on its energy audit

The project will reduce energy consumption related to sludge transport. Although sludge transport is currently suspended (see above), sludge from the WWTP is usually taken to a landfill nearly 50km away. The combination of the sludge treatment process already installed (centrifuge) and planned additional treatment (drying beds) will reduce the volumes of sludge produced. In addition, the resource recovery and reuse option selected will involve transporting bags of sludge granules to nearby farmland around the WWTP.

However, energy consumption of the WWTP will increase as a result of introducing the centrifuges required to dewater the sludge before it is dried in the covered beds.

3) What health risk management strategy has been adopted?

Defining and monitoring quality standards for wastewater leaving the WWTP

The additional treatment described above will significantly reduce pathogens in the sludge.

The health risk management strategy also includes measures to monitor the quality of the sludge at different stages:

- Sludge in the covered solar drying beds will be analysed every three months. Traceability of the sludge will be ensured by attaching a reference number linked to the analysis results to each bag of sludge granules.
- It is recommended that analyses are carried out on the soil that is to receive the sludge.
- Traceability is to be ensured by monitoring the plots of land treated with the sludge, and recording the results of these analyses, as well as the sludge application history.

It is recommended that the results of these types of sludge and soil analyses are correlated prior to confirming the feasibility of applying a batch of sludge to a particular plot of farmland.

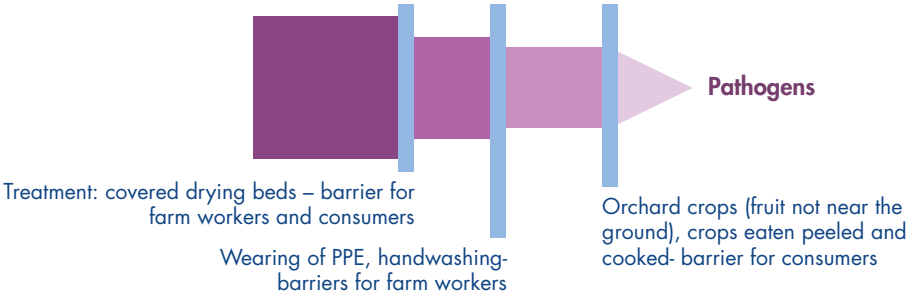
Taking post-treatment barriers into account: sanitation output products modes of use

The project will promote:

- The use of personal protection equipment (PPE) by people coming into contact with the sludge (protective clothing and footwear), the use of gloves when handling sludge for land application and when handling the bags of sludge granules.
- Handwashing with soap after contact with sludge.

Restricting uses and modes of use

Use is restricted to specific crops (grains and orchards), whose fruit does not grow near the ground receiving the sludge and/or is eaten peeled and cooked.



4)What is the proposed organisational and financial model? What are the challenges for implementing this and ensuring its sustainability?

Organisational model

Ramallah Municipality manages most sanitation chain activities.

Its technical departments manage the sewerage systems and the WWTP. The additional water (chlorination) and sludge (future dewatering and drying beds) processes also fall under its responsibility.

The decentralised cooperation partners (Ramallah Municipality, Métropole de Toulouse, Hamap Humanitaire) organised training sessions to provide the WWTP operatives with the technical skills required to operate the centrifuge system. This training was delivered by a French organisation, the International Office for Water (OiEau).

Ramallah Municipality will also be responsible for preparing (packaging) and transporting the sludge to users (delivering it to farmers).

Sludge quality and soil suitability will be jointly monitored by Ramallah Municipality and the Ministry of Agriculture.

Financial model

The operating costs of the treatment systems to be introduced for sludge recovery (particularly the analysis and centrifuge energy costs) will make it challenging for Ramallah Municipality to ensure the financial stability of its sanitation service, especially as sludge recovery cannot be relied upon to provide this financial stability in the short-term.

Ramallah Municipality and its decentralised cooperation partners have recognised that the only way to ensure that the resource recovery and reuse segment is a success is through a gradual implementation and demonstration-based approach that fosters acceptance among the target users, i.e. local farmers.

Therefore, bags of dried sludge will initially be provided free-of-charge to a group of farmers who have already volunteered to test this sludge on their land. In addition, demonstration plots will be created in partnership with the University of Al Birzeit to study the effectiveness and safety of sludge on different types of crops and to communicate the study results. The strategy therefore involves gaining the trust and gradual acceptance of other farmers.

Farmers will be asked to pay a contribution at a later stage.

Farmers currently use chemical fertilisers and manure collected free-of-charge from livestock farmers and so pay only transport costs. After the launch phase, during which sludge will be delivered free-of-charge to farmers, it may be difficult to convince farmers to pay for this sludge once its effectiveness and safety has been confirmed, as they will have become accustomed to free delivery. Furthermore, this sludge will not be able to compete with manure and chemical fertilisers, as these are used on high value crops, mainly fruit and vegetables, for which sludge application is not permitted.

Consequently, introducing a pricing structure for dried sludge will require consultation, and the modes of use and cost of other fertilisers will also need to be taken into account.

5) What co-construction initiatives have been put in place with stakeholders, particularly the users of the sanitation products intended for resource recovery and reuse?

➨ Co-constructing an organisational model and health risk management strategy

The stakeholders came together as part of the decentralised cooperation project to discuss their various expectations, perceptions, priorities and reservations.

The Ministry of Health and the Palestinian Water Authority are primarily concerned about the health risk. The Ministry of the Environment and the Palestinian Water Authority deems preserving the quality of surface water and groundwater to be a priority. The Ministry of Agriculture considers that the agronomic value of the sludge is a key factor in demonstrating the benefits of the project.

The nature park manager and farmers are concerned both about the health risks of using sludge, particularly the potential presence of heavy metals and microplastics, and about the cost-effectiveness of using sludge to improve crop yields compared to chemical fertilisers. They would be more inclined to use this new product if it was packaged in a familiar format, similar to the bags of fertiliser that they have been using up to now. Training will be required to support the changes in practice required to comply with the sludge handling protection measures (PPE, handwashing). Some stakeholders are concerned about the odours that could be generated by land application of the sludge.

➨ Providing information on and raising awareness of the health risk

In order to improve confidence and acceptance of the resource recovery and reuse segment, priority will be given to communication: distributing communication materials to farmers and local residents, publishing articles and reports in local media.

➨ Démontrer l'intérêt de l'usage du produit

Demonstration plots, both with and without the application of sludge on various crops, are to be put in place. These will be overseen by agricultural technicians who will be able to revise recommendations for use and demonstrate, especially to farmers, the effectiveness of the sludge on crop production. Comparative tests will demonstrate to farmers the benefits and advantages of using dried sludge as a soil amendment.

Case study 3
Valorisation des boues de vidange à Fianarantsoa, Madagascar

Sludge recovery in Fianarantsoa, Madagascar
Decentralised cooperation: Grand Lyon / Haute Matsiatra Region, Fianarantsoa Urban Municipality

Métropole de Lyon and the Haute Matsiatra Region have been working under a decentralised cooperation partnership since 2006.

The 3F project implemented under this decentralised cooperation partnership between 2018 and 2021 involved developing a sanitation chain for the city of Fianarantsoa (210,000 inhabitants). In addition to financing from the decentralised cooperation partners, the project was jointly funded by the Rhône Méditerranée Corse water agency and SIAAP. It was implemented by Fianarantsoa municipality with technical support from the SIA/Practica consortium.

Fianarantsoa Fecal Sludge Treatment Plant, Madagascar, © Practica Foundation

1) How is the sanitation chain set up and what facilities and treatment processes have been selected for the different segments of the chain?
What are the sanitation products used for?

◄ Access/containment segment

The project supported households to install on-site latrines through pro-poor subsidies, and also involved rehabilitating and constructing public and school latrines.

◄ Intermediate/transport segment

Faecal sludge is transported to a faecal sludge treatment plant (FSTP).

◄ Treatment segment

The FSTP can treat up to 11m^3 of sludge per day. It has 49 unplanted covered drying beds.

The sludge has a detention time in the beds of 90 days.

The capacity of the drying beds is 1500 m^3/year. Following prolonged drying, the complete treatment process is capable of producing 250 m^3 of sanitised dried sludge per year.

Once removed from the drying beds, the sludge is stored in a 'sanitisation area' in heaps that are regularly turned over. It is therefore left to dry for a period of 8 months to ensure it is safe and ready for use as a high quality organic soil amendment.

Wastewater

The water from the drying beds is treated in WSP then infiltrated into trenches planted with trees.

◄ Recovery segment

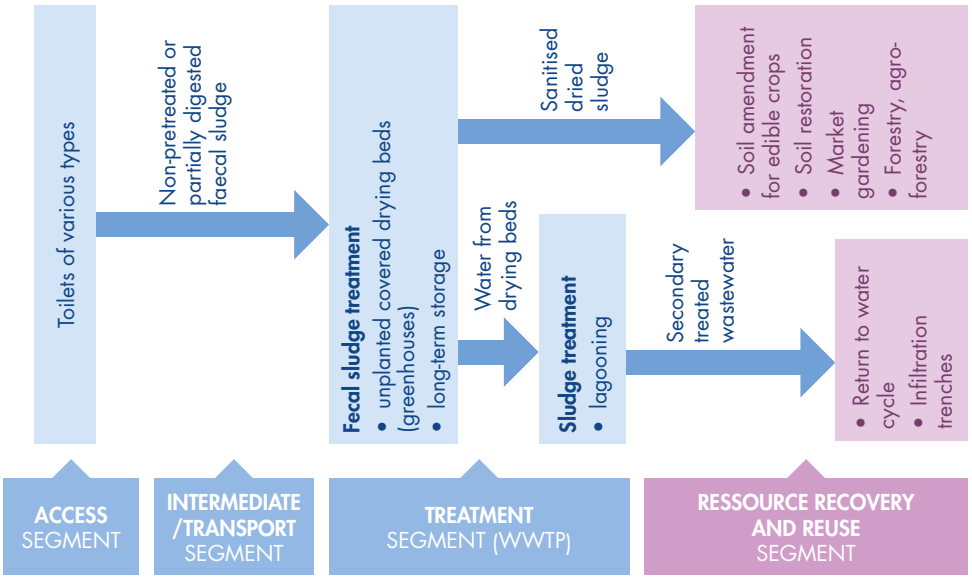
DRIED SAN FS/SS Sanitised dried sludge

Uses

Farming activities (edible and non-edible crops) → **FARMING ACTIVITIES**

Rehabilitation of mining or industrial areas, restoration of soil damaged by intensive farming → **RESTORATION OF SOIL**

This sanitised dried sludge was initially to be used for forestry and agro-forestry. However, its potential as a soil amendment has attracted growing interest from local farmers and market gardeners. Agricultural demand now exceeds the production capacity of the FSTP.



2) What are the environmental benefits of the project, and what impact assessments have been or will be carried out?

Returning materials to the soil

Returning the organic matter and nutrients contained in the sanitised dried sludge has environmental benefits for the forest areas in the water catchment. Sludge recovery will help restore the soil to enable reforestation of the Haute Matsiatra region catchment areas while supporting agro-ecological practices.

This is aligned with another project implemented under the decentralised cooperation partnership to restore catchment areas in the Haute Matsiatra region. This second project consists of developing an IRWM approach (planning, resource protection, etc.) and of building forestry and agricultural management capacities in order to promote the sustainable and circular management of local ressources.

3) What health risk management strategy has been adopted?

The sanitation sector in Madagascar is regulated by the 1999 Water Act and its implementing decrees (2003, 2007), which govern the organisation of public water and sanitation services. The National Sanitation Policy and Strategy (2008) and WASH Sector Programme (2019-2023) supplement this framework by defining waste management guidelines. There are no national regulations in place for the sanitation product resource recovery and reuse sector.

In the absence of a national framework, municipal regulations have been developed under the decentralised cooperation partnership, which are based on WHO recommendations and French standard NFU 44-051.

FOR MORE INFORMATION:

- Pour en savoir plus, consultez la Fiche Pays Madagascar du pS-Eau

◄ Defining and monitoring quality standards of the sanitation product leaving the FSTP

The strategy for managing the health risk associated with the use of sanitised dried sludge is based on the application of an advanced sanitisation treatment. When combined with the covered drying beds (greenhouses), which already provide significant sanitisation, the subsequent 8-month drying period further reduces pathogens in order to produce dried sludge that can be considered totally sanitised.

During the sanitation chain implementation phase of the 3F project, analyses were conducted in France by SIAAP, a laboratory in Rennes (Labocéa), and by a laboratory in the UK (Ridgeway Research). However, given the lack of local sludge analysis capacities, it may not be enough to base the health risk management strategy for the operations phase on sludge quality monitoring measures alone.

◄ Taking post-treatment barriers into account: sanitation output products modes of use

When it comes to hygiene measures, the health risk management strategy focuses more on the access and intermediate segments than on the resource recovery and reuse segment. The hygiene awareness-raising and household latrine promotion approaches adopted by the 3F project are being continued by the municipality through 'Sanitation and Hygiene Teams'.

4) What is the proposed organisational and financial model? What are the challenges for implementing this and ensuring its sustainability?

◄ Organisational model

As the authority responsible for the sanitation service, Fianarantsoa municipality is responsible for both sludge transport and sludge treatment at the FSTP.

The local authority has entrusted the management of the collection and processing of faecal sludge to several local companies under Public Service Delegation contracts. One contract covers the management of toilet blocks (renewable contracts of 1 to 4 years). Another contract, held by Ecodio, covers emptying and treatment at the FSTP, including the preparation of dried sludge for sale (10-year contract).

The users of the sanitised dried sludge come to the FSTP to collect the sludge as required. There are also points of sale, which Ecodio supplies.

Financial model

The financial stability of the sanitation chain is based on the revenue received from users of the sanitation service and the users of public and private latrines. Households with private latrines pay for pit emptying. Meanwhile, users also pay to use the public latrines. It is this revenue that covers all sanitation chain operating costs.

Although successful, the sale of sanitised dried sludge is not considered a main source of sanitation chain funding. The income received from the sale of this sanitised dried sludge is used to cover recovery-related costs, such as screening, packaging and marketing, but does not provide a sufficient source of revenue to ensure the long-term viability of the service.

It was never the intention to base the financial model on the opportunity to generate additional revenue through the sale of sanitised dried sludge. However, given that the use of this product has met with such success, this is now a possibility. The sanitised dried sludge is sold to winegrowers, farmers (quinine production, cereal growers, coffee growers), market gardeners, and foresters.

Fianarantsoa municipality is the owner of the public latrines, the faecal sludge treatment plant (FSTP) and the emptying equipment. The municipality defines the pricing structure for use of the public toilets, emptying services and the sale of sanitised dried sludge. This enables the municipality to adjust these prices to ensure financial stability while continuing to support development of the resource recovery and reuse segment.

At the beginning, a low sale price was set for sanitised dried sludge. This has since been gradually increased while remaining lower than the price of competitor products.

One competitor product is chemical fertiliser, use of which should ideally be phased out due to the environmental impact of its production method. However, chemical fertilisers are not widely used in Fianarantsoa or its surrounding areas. There is also very little manure available.

There is one composting facility in Fianarantsoa. Compost is also a competitor product of sanitised dried sludge from the FSTP as it has a sustainable recovery application. However, compost is also derived from the recovery of organic matter. Consequently, there is no environmental benefit to be had from positioning sanitised dried sludge in competition to, or even as a replacement for, compost. The two products are complementary as they have specific advantages for different uses. Compost is particularly good for improving the structure of soil, whereas sanitised dried sludge has better fertilising properties. This is why sanitised dried sludge is generating so much interest among local farmers.

It is to be noted that the option of further sanitising sludge from drying beds at the composting facility rather than on a long-term storage site was rejected. The compost facility was deemed to be too far from the FSTP. In addition, this set up would have been more complex to coordinate as it would have involved the private delegated operators of both the FSTP and composting facility, which are not the same.

5) What co-construction initiatives have been put in place with stakeholders, particularly the users of the sanitation products intended for resource recovery and reuse?

◄ Providing information on and raising awareness of the health risk and demonstrating the benefits of using the product

The Hautes Terres region of Madagascar does not have a history of using faecal sludge in farming and this could give rise to reservations. To address this, tests were carried out with farmers as part of the decentralised cooperation project to assess the agronomic value of the product. These tests were carried out for market gardening, reforestation and plant nurseries and returned very positive results for both yields and effectiveness.

By directly involving users in the test phase, the project helped build progressive ownership of the sludge recovery activity. It is the feedback from the farmers themselves that led to this change in perception: the product, which was initially viewed with suspicion, is now in high demand due to its agronomic qualities and low cost.

This positive feedback was relayed to farmers by a network of extension workers known as 'master farmers' who were trained to share their experience and persuade other farmers of the benefits of the product. Demand now outstrips the FSTP's production capacities, which shows that this demonstration and participatory approach has led to a huge shift in the initial mindset.

◄ Co-constructing an organisational model

The project was managed in close consultation with all stakeholders: the local authority, health authorities, the Ministry's technical departments, local operators, hygiene committees and user representatives. This consultation ensured all viewpoints were included, and also helped to anticipate constraints and adapt the technical choices to the local situation.

Technical, organisational and financial scenarios were jointly developed, particularly with local authority involvement, to refine and validate the decisions made. The management bodies (technical committee, steering committee) played a fundamental role by prioritising shared governance and local, regional and national level coordination.

The use of public service delegation contracts, co-signed by the local authority and Ministry, reveals a willingness to consolidate clear accountability frameworks, while at the same time encouraging stringent management practices (short contracts, regular evaluations).

This continuous dialogue has helped not only ensure the viability of the project, but also build collective momentum, where each stakeholder has legitimacy and is committed to the success of the scheme.

Supporting changes in practice

The technical support provided by Practica under the decentralised cooperation project was instrumental in structuring the resource recovery and reuse segment. In addition to technical aspects, this support also helped build the capacities of local stakeholders to work together, develop appropriate services and make commitments for the long-term.

The company Ecodio, created through the project by building on the network of local associations, received support over several years and is now a professional operator responsible for sludge collection and treatment across the city. This development took place in stages, and was closely aligned to the needs on the ground and the capacities of local teams.

At the same time, craft workers received latrine building and maintenance training, and the 'master farmers' encouraged local farmers to get involved in the project.

The aim of all of these actions was progressive skills transfer, with added technical support to ensure resource recovery and reuse segment operations remain sustainable over the long-term.

General conclusion

This guide provides an overview of the sanitation product resource recovery and reuse options available, focusing not only on the most common types of sanitation chain or uses.

These reuse and recovery options apply to both public sewerage systems and on-site sanitation systems, including those that have household resource recovery and reuse facilities. For sewerage systems, these options cover all types of treatment processes, whether intensive or extensive.

Decisions on the type of sanitation, scale and treatment processes to be adopted must be based on an analysis of the context. Designing the sanitation chain to include output product reuse and recovery adds new meaning to some of the selection criteria, and introduces further criteria specific to the resource recovery and reuse segment.

This guide covers the key challenges that developers of a sanitation project that includes a resource recovery and reuse segment need to address.

Environmental benefits: opportunities to be fully assessed.

Although the environmental benefits of recovery are often highlighted – replacing the use of natural resources, return to the soil, energy recovery – they still need to be carefully examined for each context. This entails assessing the impacts for the catchment area, comparing treated wastewater uses to baseline practices, taking the energy consumption of additional treatment processes and of transporting sanitation products to end users into account, and ensuring these sanitation products are environmentally compatible with the receiving environments.

Health risk: a balance between ensuring safe use and developing opportunities

The health risk applies not only to end consumers in the case of agricultural use, but to all the people exposed throughout the sanitation chain, up to and including the resource recovery and reuse segment. This risk can be managed using several levers, which can be employed in combination: additional dewatering/sanitisation treatments; modes of use that reduce pathogens and stakeholder exposure in order to supplement treatment processes; restricting uses to control exposure to risk. Deployment of these levers must be aligned to the regulatory framework where this exists (or to international standards such as those defined by WHO), as well as to the technical and financial capacities and practices of the stakeholders involved throughout the sanitation chain, including the intended end users.

Organisational and financial models: a condition for viability

The introduction of a resource recovery and reuse segment will entail new activities and additional financial costs, which must be adapted to the technical and financial capacities of the different stakeholders involved in the sanitation chain. It is often unrealistic to base the financial viability of the sector on the opportunity to develop new revenue streams. User demand for the sanitation product will depend on whether or not there is competition from a resource that fulfils a similar function: a free water resource or water stress, the availability and cost of fertilisers and manure.

Sociological aspects: a cross-cutting challenge

Involving the stakeholders responsible for managing the various activities, as well as the targeted end users of the sanitation products, is necessary for gaining an insight into their perceptions of health risks and the benefits of the product, and will also highlight any reluctance to change their practices to incorporate resource recovery and reuse. The use of jointly developed scenarios involving different treatment technologies, product uses, health risk management strategies, and organisational and financial models can help strike the right balance between information, awareness-raising and even marketing initiatives to convince and support stakeholders to change their practices and perceptions. This approach can also help rule out any scenarios that prove to be unsuited to the context.

These challenges were addressed in the context of selected Mediterranean countries (Morocco, Tunisia, Palestine and Lebanon).

Given the **pressure on water resources** being experienced in Mediterranean countries, **treated wastewater** provides an opportunity to develop an additional and so-called **non-conventional water resource** that could help balance supply and demand for a range of uses. However, the real environmental benefit of this use is dependent on it being part of an integrated water resources management approach that takes into account the overall catchment area water balance, as well as the different uses and users, both human and non-human.

Due to the **high demand for water in the agricultural sector**, treated wastewater reuse in agriculture is a key priority. Overall, Mediterranean countries have adopted **cautious regulations** to protect consumers from health risks. These can limit opportunities for the agricultural use of treated wastewater and instead encourage uses such as the **irrigation of green spaces**. In these situations, opportunities for project developers to expand the reuse of treated wastewater is largely determined by these regulations. However, there is still scope for experimentation, particularly for extensive treatment processes in rural sanitation chains, as well as for on-site facilities.

Government, deconcentrated or decentralised sanitation and agriculture sector stakeholders must be involved in these projects. They therefore need to be identified and are usually encouraged to enter into specific treated wastewater reuse agreements. These agreements help clearly define the operational roles of each stakeholder, and ensure participatory approaches are adopted from the outset of the project, specifically involving the wastewater target users.

Although **sludge recovery** is neither widely developed or regulated in Mediterranean countries, the environmental impact of sludge production can be huge, particularly for extensive treatment processes that generate large volumes of sludge. Rather than disposing of this sludge in landfills – an approach that is ineffective as the status of sludge is not clearly defined – sludge recovery can help reduce the environmental impact of the sanitation chain. In addition, the sludge's **structuring and fertilising properties** can be used to improve soil. This opportunity, of particular value in Mediterranean countries where soils are often dry and poor in organic matter, can be applied to the **agricultural sector**, as well as to other uses such as the **restoration of degraded land**, or forestry. While there is also a health risk associated with this, there are few regulations in place. Furthermore, the stakeholders to be involved in this activity are not clearly defined. As a result, a project developer wishing to develop these uses has the leeway to propose, in conjunction with the relevant authorities, a tailored health risk management strategy and management and financial model.

Alongside these official practices, which are already well-established for treated wastewater reuse and are being trialled and set up for sludge recovery, there is also a wide range

of **informal wastewater reuse and sludge recovery practices** in place. These practices must be identified and the stakeholders employing them should be involved in project activities, such as analysing the context and developing scenarios.

Although not yet widespread in Mediterranean countries, there are **other recovery options** that could be developed. **Using the energy potential of sludge**, which can be combined with the use of digestate, can help optimise energy use in the sanitation chain. However, the viability of this option needs to be weighed against the technical and financial capacities of the stakeholder operating the digesters. Other more niche uses with less environmental impact could also be introduced, such as using plants from planted drying beds or ponds in the crafts sector, using duckweed from WSP for animal feed, or using biochar from pyrolysis as a construction material. It is to be noted that there are few to no health risks associated with these uses.

In conclusion, the reuse and recovery of sanitation products provides a major opportunity for improving resource circularity in areas affected by pressure on natural resources, growing demand for water and organic inputs, and the need to reduce the environmental impact of sanitation systems.

This guide sets out the key challenges of this paradigm shift for sanitation, and defines the key points to be considered to aid decision-making, as well as resources for further information.

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TOOLS & METHODS

Opportunities and Challenges for Resource Recovery and Reuse in the Sanitation Chain

Focus on southern Mediterranean countries

Thinking about sanitation in terms of circularity of flows and materials involves a paradigm shift, as it adds a new dimension to the traditional goals of health and environmental protection. This guide focuses on the challenges of integrating a 'resource recovery and reuse' segment into the sanitation chain, taking both its technological and socio-economic aspects into account.

The aim of this guide is to provide keys to understanding and resources to identify and take into account:

- Opportunities for resource recovery and reuse in the sanitation chain, adopting a comprehensive approach that covers all types of sanitation and treatment processes, as well as all output products and their potential uses;
- The main challenges involved in integrating the recovery and reuse of these products, and which need to be taken into account when designing a sanitation project that includes resource recovery and reuse.

This guide addresses these opportunities and challenges in the context of southern Mediterranean countries, specifically Morocco, Tunisia, Palestine and Lebanon. It also provides key insights into the options available for adopting resource recovery and reuse approaches within the sanitation chain in all countries.

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