Blackwater

Blackwater is the wastewater that comes from toilets, and consists of excreta (urine and faeces), flushwater and cleansing materials. Blackwater is a risk to public and environmental health, if not effectively treated. On the other hand, it contains nutrients, energy and water, which makes it valuable for resource recovery. Management and resource recovery options for blackwater rely on multiple scales of infrastructure, which are appropriate based on local drivers. Off-grid solutions entail treatment at the source, decentralised and semi-centralised onsite containment with transport to treatment, and centralised transport via a sewer to treatment.

Eawag is researching off-grid, decentralised and centralised approaches for treatment and resource recovery of wastewater streams, in order to increase the sustainability of globally relevant solutions. In the future, resource-recovery based approaches for city-wide inclusive sanitation (CWIS) will include a combination of parallel solutions, based on off-grid, decentralised, and centralised solutions.

Expensive centralised solutions

Centralised solutions that prevail in high-income economy countries are well established based on their effectiveness in protecting public health. However, centralised solutions are expensive, and resource and energy intensive, based on construction of required infrastructure, reliance on large volumes of water, and energy for transporting and treating the wastewater. Water is commonly used as an efficient way to transport excreta for treatment, but is not ideal as it results in the contamination of large volumes of drinking quality water. Off-grid and decentralised solutions reduce the volumes of water that need to be treated, as excreta is not mixed with greywater (see greywater factsheet [1]) and stormwater. In addition, separately collected greywater and rainwater can be used for toilet flushing or other non-potable uses, eliminating the resource intensive need for using treated drinking water. As existing centralised systems reach their capacity due to growing urban populations, off-grid and decentralised approaches could provide more sustainable ways to increase capacity and fill this gap.

Blackwater often ends up untreated

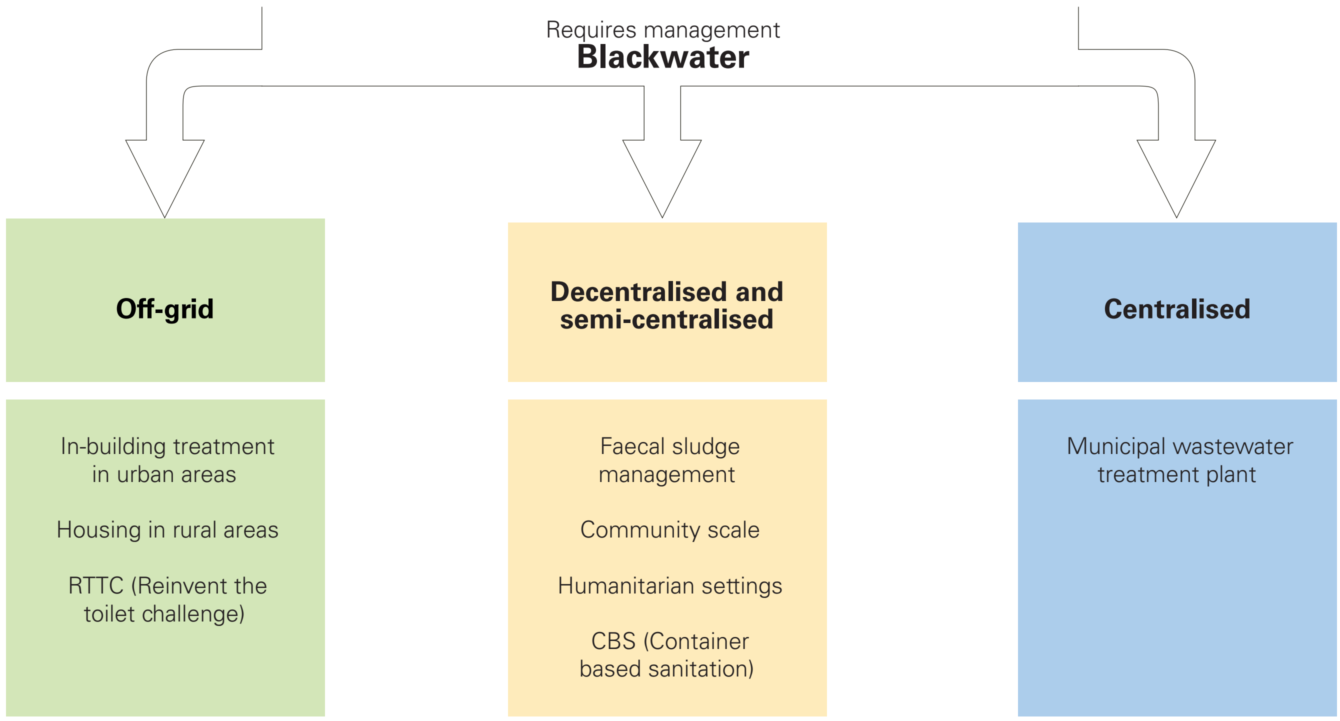
In many low- and middle-income economy countries, decentralised and semi-centralised treatment of blackwater prevails (faecal sludge management), for example with containment in pit latrines and septic tanks [2]. These solutions have the potential to provide adequate sanitation if the entire service chain is functioning. However in reality, the vast majority of blackwater in this context ends up untreated directly in the urban environment. Off-grid and decentralised solutions could help fill this gap, by eliminating the need for transport, and providing efficient, low-footprint technologies for dense, urban areas.

Complicated by high variabilities

Dewatering refers to the separation of the liquid and solid streams in blackwater, which can then be more efficiently treated. Adequate treatment of the resulting streams prior to resource recovery includes inactivation of pathogens, stabilisation, and nutrient management. However, off-grid and decentralised treatment is greatly complicated by the high variability in volume and composition of blackwater, as each toilet flush has widely varying characteristics, in contrast to centralised options where the blackwater is relatively more homogenised during transport in the sewer. Therefore, established technologies for the treatment of wastewater cannot be directly applied for the treatment of blackwater.

Filling local needs

Technology solutions for resource recovery need to be based on locally appropriate demands. Our goal is to develop multiple solutions for the off-grid and decentralised treatment of blackwater, that produce resource recovery based end-products in order to fill local needs and at the same time ensure public and environmental health.



Off-grid: Innovative off-grid solutions are being developed to treat blackwater directly at the source (treated onsite), eliminating the need for transport to an external treatment facility, and increasing the potential to maximise resource recovery.

Decentralised and semi-centralised: One third of the global population is served by non-sewered sanitation, where blackwater is contained and stored onsite and needs to be collected and transported for decentralised and semi-centralised treatment. In low- and middle-income countries, this is commonly referred to as faecal sludge management.

Centralised: 99 % of blackwater in Switzerland is transported together with greywater in a sewer system for centralised treatment, and can also include stormwater that drains to the sewer system. World-wide, 57% of households rely on centralised wastewater treatment, of which approximately two-thirds are safely treated [3].

Opportunities

Public and environmental health: Efficient management of blackwater minimises health risks and controls the spread of diseases by breaking faecal-oral transmission pathways. Additionally, indiscriminate disposal of blackwater results in pollution of the soil, surface water and groundwater. Hence, treatment of blackwater ensures the protection of public and environmental health.

Nutrient and organic matter: Recovered solids are rich in organic matter and phosphorus, and can be co-composted with other organic substrates, or pelletised for use as a soil amendment. Organic matter benefits the water holding capacity and diversity of soil microorganisms, and can be used in combination with fertilisers derived from separately collected urine (see urine factsheet [4]).

Energy: Dewatered blackwater can be used to produce pellets, char and briquettes as alternative dry combustion fuel sources. These endproducts have similar calorific values to wood-based products, and have been field-tested as fuel in industrial kilns in Senegal and Uganda [5]. Energy can also be produced through the production of biogas. Excreta from one person cannot entirely fulfill their heat and energy demands, but can provide a valuable offset for lighting, heating and cooking needs, or at a larger scale fed into the grid [6]. In addition, off-grid and decentralised solutions reduce the energy demand for the pumping and centralised treatment of drinking water.

Biomass: Different treatment technologies can provide a food source for livestock or fish production. For example plants from wetlands and planted drying beds, and insect larvae as a protein source. Black soldier flies can rapidly consume the solids in blackwater, converting it into insect biomass.

Water: Treated liquid streams can be recovered and used for irrigation or toilet flushing. We plan to investigate the co-treatment of liquid streams resulting from the dewatering of blackwater together with greywater. Furthermore, water can be saved by using off-grid and decentralised blackwater treatment technologies.

Challenges

Dewatering: Even with reduced volumes of water, small amounts of excreta contaminate relatively large volumes of water. For example, blackwater is typically less than 1-5% solids by volume. Solid-liquid separation remains the missing link to many off-grid and decentralised resource-recovery technologies. Understanding of the fundamental mechanisms controlling dewatering of blackwater is therefore necessary to ensure adequate treatment of blackwater for resource recovery.

Development and uptake of treatment technologies: Although there is extensive knowledge on wastewater treatment from centralised systems, a direct transfer of knowledge from these systems is not possible due to the high variability in the volumes and characteristics of blackwater. We are working to transfer existing knowledge such as mechanical dewatering to the off-grid and decentralised context. Established treatment technologies for decentralised and semi-centralised solutions in low- and middle income economy countries include drying beds, co-composting, and settling-thickening tanks. Research is needed to develop lower-footprint solutions, and to upscale innovative solutions to the level of established.

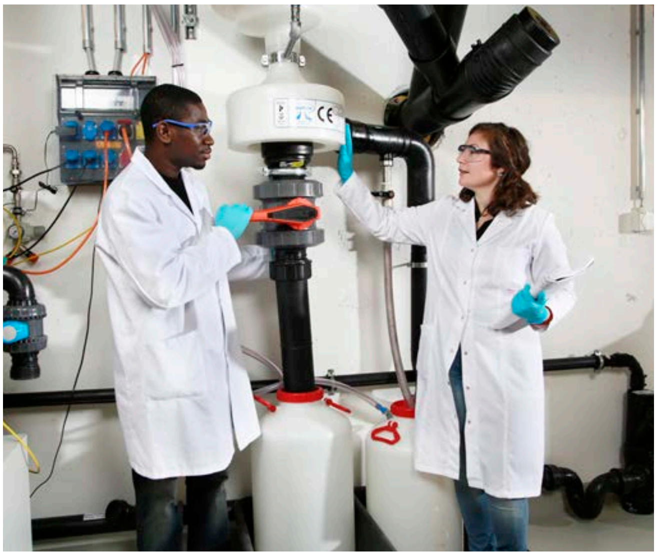
Inline monitoring: Dewatering of blackwater can be greatly enhanced if dosing of conditioners (e.g. flocculants for chemically enhanced dewatering) is based on the actual characteristics. For off-grid and decentralised treatment, this requires methods for rapid, real-time characterization. Eawag's recent research has shown that there is a potential to achieve this through inline monitoring of pH, electrical conductivity, texture or colour [7]. We are evaluating the use of sensors in blackwater, which is difficult due to fouling of the sensors and measurement disturbance by the complex composition of the water.

Acceptance of treatment products: The acceptance of resource-recovery end products from the treatment of blackwater can be improved through raising awareness of the actual risks. This can be achieved through a risk-based approach to ensure protection of public health. For example, recovery through combustion eliminates concern of pathogens, or using soil amendments with tree crops rather than on edible ground crops to maintain a physical distance.

Technology development at Eawag

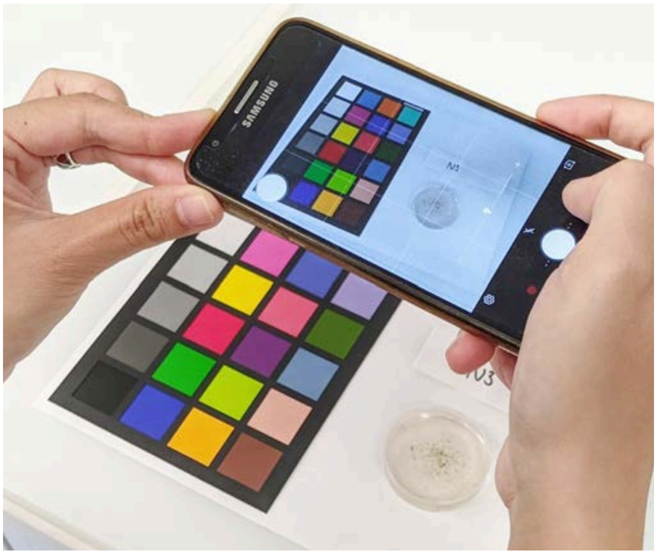
Water Hub: Eawag collaborates with industry to test their technologies and products in the Water Hub. The tests under realistic conditions are an important step to develop field-ready technologies. Current examples include mechanical dewatering, sensors, and conditioners (e.g. flocculants and coagulants).

Aldo Todaro, Eawag



Sludge Snap App: This app aims to predict characteristics of blackwater based on pictures taken with the smartphone. The app utilises a photo processing module that extrapolates colour and texture data of the blackwater. In addition to a photo, the user can input additional easy-to-measure data such as pH, conductivity and containment type. This data processed with a machine-learning module in order to predict characteristics based on an existing database [8].

Barbara J. Ward, Eawag



Volaser: The Volaser is a laser measuring device for measuring in situ volumes of onsite containments and volumes of blackwater (faecal sludge). It can be used to make predictions on the quantities of decentralised blackwater that need to be managed at the community- to city-level. The Volaser and Sludge Snap App are currently being field-tested internationally in eight different countries.

Joel Kinobe, Kizito Andrew

Automated dosing of conditioners: The under- or over-dosing of conditioners greatly impedes dewatering performance. Eawag is currently developing solutions for automated dosing of conditioners based on inline monitoring of physical and chemical properties, building on our previous research. This also includes identifying methods for the selection of optimal conditioners.

Michael Vogel, Eawag

eawag
aquatic research

Regulations

A DIN-standard (DIN 30762:2021-06) for *requirements for prefabricated sanitary systems without connection to water supply and sewage system is in development* [9]. The goal of this standard is to describe minimum specifications for the design and structural requirements of such systems so that a high level of quality, comfort and safety can be ensured.

Additional standards for the use of products of faeces and urine in horticulture can be found in the DIN-standard *Quality assurance of recycling products from dry toilets for use in horticulture* (DIN SPEC 91421:2020-12) [10].

In Europe, there are currently no regulations specifically for blackwater recycling. However, there are regulations for wastewater treatment in general:

CH: Since 2006, the direct use of sludge from municipal wastewater treatment plants as fertiliser in agriculture is not allowed. This sludge has to be dried and burned in incineration plants or cement works [11]. CH decided that starting on 1 January 2026, phosphorous needs to be recovered from municipal wastewater and other phosphorous rich waste streams [12].

DE: Wastewater treatment plants are encouraged to recover nutrients from wastewater. Sludge from wastewater treatment-plants can be incinerated or used as fertiliser in agriculture in compliance with the guidelines [13].

EU: Liquids: In 2020, the European Union has released the regulation "minimum requirements for water reuse". The purpose of this regulation is to create a framework for water reuse for the member states that want to practice water reuse from wastewater for irrigation [14].

Solids: Human faeces are not regulated in the EU regulations laying down rules on the making available on the market of EU fertilising products and amending regulations [15].

References

1 Morgenroth, E.; Doll, C.; Hess, A.; Hubaux, N.; Reynaert, E.; Hammes, F.; Julian, T.; Bryner, A.; Penicka, P. (2021) Fact sheet. *Grauwasser,* Eawag, Dübendorf, Switzerland https://www.eawag.ch/fileadmin/Domain1/Beratung/Beratung_Wissenstransfer/Publ_Praxis/Factsheets/fs_greywater_0221.pdf

2 Strande, L., M. Ronteltap, and D. Brdjanovic, *Faecal sludge management: Systems approach for implementation and operation.* (2014), London: IWA Publishing. https://www.dora.lib4ri.ch/eawag/islandora/object/eawag:10885

3 UN Habitat and WHO, 2021. *Progress on wastewater treatment – Global status and acceleration needs for SDG* indicator 6.3.1. United Nations Human https://www.unwater.org/publications/progress-on-wastewater-treatment-631-2021-update/

4 Udert, K.; Doll, C.; Bryner, A.; Penicka, P.; Etter, B. (2019) Fact sheet. Urinseparierung, Eawag, Dübendorf, Switzerland. https://www.eawag.ch/fileadmin/Domain1/Abteilungen/eng/projekte/nest/factsheet_urine_march19_de.pdf

5 Gold, Moritz, et al. *"Faecal sludge as a solid industrial fuel: a pilot-scale study."* Journal of Water, Sanitation and Hygiene for Development 7.2 (2017): 243-251. https://www.dora.lib4ri.ch/eawag/islandora/object/eawag%3A15049/

6 Andriessen, N.; Ward, B.J.; Strande, L. *"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 9.2 (2019): 210-224. https://www.dora.lib4ri.ch/eawag/islandora/object/eawag:18906

7 Ward, B. J.; Andriessen, N.; Tembo, J. M.; Kabika, J.; Grau, M.; Scheidegger, A.; Morgenroth, E.; Strande, L. (2021) *Predictive models using "cheap and easy" field measurements: can they fill a gap in planning, monitoring, and implementing fecal sludge management solutions?,* Water Research, 196, 116997 (12 pp.). https://www.dora.lib4ri.ch/eawag/islandora/object/eawag:22336

8 Ward, B. J., Allen, J., Escamilla, A., Sivick, D., Sun, B., Yu, K., Strande, L. (2021). *Sludge snap: a machine learning approach to fecal sludge characterization in the field* (p. 1234 (2 pp.). Presented at the 42nd WEDC international conference. Equitable and sustainable WASH services: future challenges in a rapidly changing world. https://www.dora.lib4ri.ch/eawag/islandora/object/eawag:24096

9 DIN 30762:2021-06, *Prefabricated sanitation systems without connection to water supply and sewage system - Requirements and product features;* Draft (2021). https://www.beuth.de/en/draft-standard/din-30762/338299741

10 DIN SPEC 91421:2020-12 (2020); *Quality assurance of recycling products from dry toilets for use in horticulture.* https://www.beuth.de/de/technische-regel/dinspec-91421/330937272

11 Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK, (2003) *Verordnung über umweltgefährdende Stoffe* (Stoffverordnung, StoV), https://www.admin.ch/gov/de/start/dokumentation/medienmitteilungen.msg-id-1673.html

12 Der Schweizerische Bundesrat, (2015), *Verordnung über die Vermeidung und die Entsorgung von Abfällen* Art. 1 and Art. 51, https://fedlex.data.admin.ch/eli/cc/2015/891

13 Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (2017) *Verordnung zur Neuordnung der Klärschlammverwertung,* https://www.bmu.de/gesetz/verordnung-zur-neuordnung-der-klaerschlammverwertung/

14 The European Parliament and the Council of the European Union (2020), R*egulation (EU) 2020/741 of 25 May 2020 on minimum requirements for water reuse,* http://data.europa.eu/eli/reg/2020/741/oj

15 The European Parliament and the Council of the European Union (2019), *Regulation (EU) 2019/1009 of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC),* http://data.europa.eu/eli/reg/2019/1009/oj

Further information: www.eawag.ch/waterhub , www.autarky.ch, www.sandec.ch/mews

Contact: Eawag, Dr. Linda Strande, Department Sandec, +41 58 765 5553 linda.strande@eawag.ch

Factsheet contribution: Carina Doll (Process Engineering); Linda Strande, Michael Vogel, Stanley Sam, Barbara J. Ward (Sanitation, Water and Solid Waste for Development); Andri Bryner, Peter Penicka (Communication)

Adress: Eawag, Überlandstrasse 133, CH-8600 Dübendorf, Schweiz, +41 58 765 5511, info@eawag.ch, eawag.ch

eawag
aquatic research