Co-convened by

Lime treatment of faecal sludge for humanitarian contexts

Guidelines for onsite to centralised treatment

Table of Content

1. Introduction of basic concepts

1. 1. What is lime treatment for faecal sludge?

The purpose of these guidelines is to provide practical, hands' on guidance on lime treatment for faecal sludge in humanitarian contexts, based on the experiences of practitioners. Lime treatment is a batch-wise treatment method for faecal sludge and wastewater, primarily used to kill pathogens.

Faecal sludge is defined very broadly as "what accumulates in onsite sanitation systems and specifically is not transported through a sewer. It is composed of excreta, but also anything else that goes into a containment technology, such as flush water, cleansing materials and menstrual hygiene products, greywater, and solid waste. Hence, faecal sludge is highly variable, with a wide range of quantities (i.e. volumes) and qualities (i.e. characteristics)". (Velkushanova, et al., 2021).

Faecal sludge management (FSM) is the collection, transport, treatment, and enduse of faecal sludge from pit latrines, septic tanks or other onsite sanitation systems. The sanitation service chain describes the services required to manage faecal sludge from the point of generation to the point of ultimate disposal or reuse (**Figure 1**). The service chain should be customised based on the local conditions.

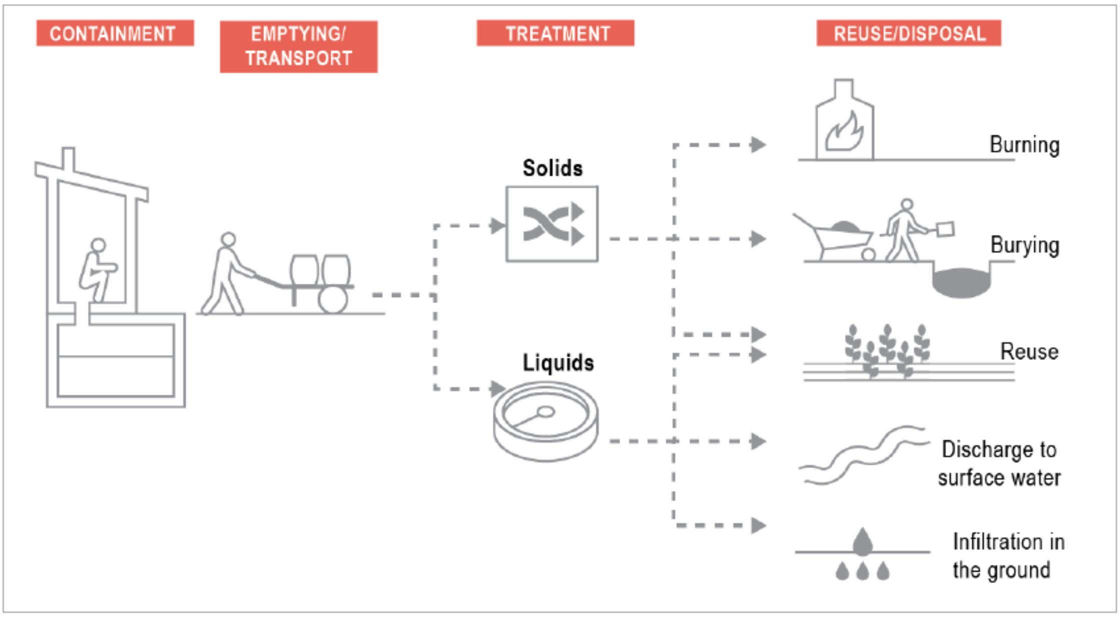


***Figure 1:** The sanitation service chain for humanitarian settings (Global WASH Cluster, 2021).*

Lime treatment (sometimes called "lime stabilisation") is the process of adding hydrated lime to faecal sludge so that a pH of >11 is attained and held for at least two hours[1]. This pH increase has the following impacts:

- Inactivates pathogenic bacteria and viruses;
- Improves solid-liquid separation;
- Minimises odour nuisances from faecal sludge;
- Prevents flies and other insect infestation (Greya, et al., 2016).

[1] Various retention times and pH ranges are reported in literature. USEPA recommends maintaining pH 12 for 2 hours (USEPA, 2000). Strande et al. (2014) recommend either pH >12 for 30 min, pH >11.5 for 60 min, or pH >11 for 120 min for use on faecal sludge. For humanitarian purposes, we recommend maintaining a pH >11 for 2 hours in this manual.

While lime treatment can inactivate bacterial and viral pathogens by 99% or more, hydrated lime does not inactivate helminth eggs[2] (Bina, et al., 2004). Besides, "it is important to consider that this process is only temporary and pathogen regrowth is likely when the pH drops below 11, for example during storage, transport or use of the treatment product". (Englund, et al., 2019). Figure 2 depicts the process in two phases: 1. A mixing phase where a lime slurry is mixed into the faecal sludge, and stored for two hours at pH>11, and 2. A settling phase of 16-24 hours to facilitate solid-liquid separation.

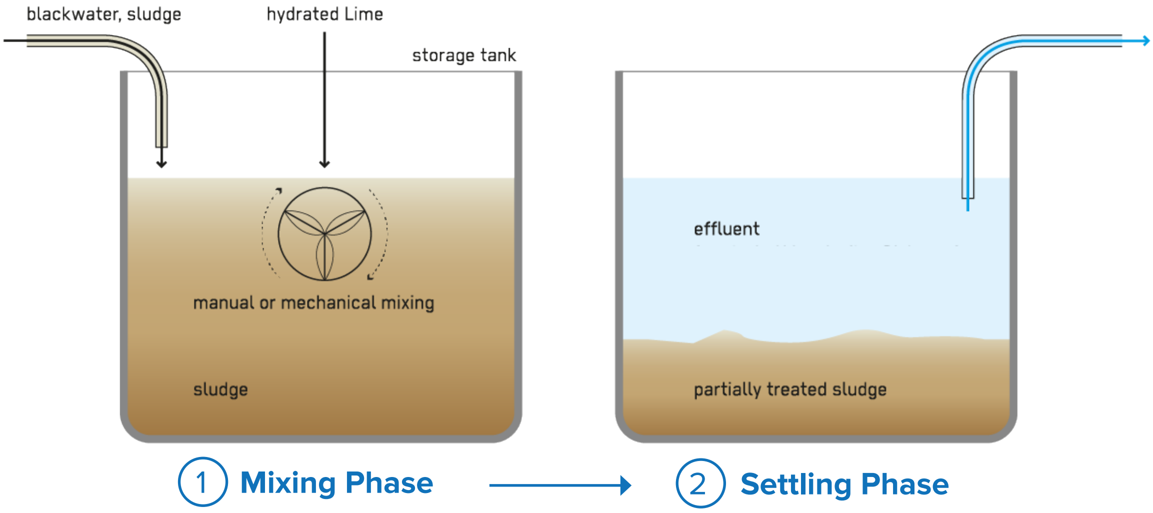


Figure 2: *A schematic representation of the lime treatment process, including a mixing phase and settling phase*

(adapted from Gensch et al., 2018)

What is lime?

Lime is a white, caustic, and alkaline powder produced by heating limestone. It is important to differentiate the two different products:

Hydrated lime (also called slaked lime) = calcium hydroxide ($Ca(OH)_2$)

Quicklime = calcium oxide (CaO)

Hydrated lime is commonly used in agriculture, construction (for mortars and plasters) or water/wastewater treatment. It can also be used for the rapid treatment of faecal sludge. In this manual, the use of hydrated lime over quicklime is recommended, as it is less caustic than quicklime and can be better stored. It is important to use hydrated lime ($Ca(OH)_2$) and NOT calcium carbonate ($CaCO_3$), as calcium carbonate will not increase the pH.

Lime should be handled with care and requires wearing proper protective equipment. The hazards of working with lime include severe chemical burns when it comes in contact with skin, eyes or lungs. In addition, during contact with faecal sludge, there are potentially harmful NH_3 emissions when inhaled. Appropriate safety protocols should always be followed when working with lime (see section 2.3).

[2] Helminth eggs are not inactivated based on pH increase from hydrated lime treatment alone, following the procedure described in this document. Only when pH increase is combined with a temperature increase using quicklime, such as described in Capizzi-Banas et al., 2004, can helminth egg inactivation be achieved. However, considering the hazards associated with quicklime, this is not recommended for application in emergencies.

1. 2. Why lime treatment for humanitarian settings?

Lime treatment is an internationally recognised, low-cost, proven treatment option, which is appropriate for rapid deployment in disaster or emergency settings. Lime treatment is specifically recommended if there is a need for rapid treatment (especially inactivating pathogens) during acute and/or stabilising response phases. It should be considered as a temporary solution, and ideally, in protracted crisis situations, the sanitation strategy should move to a more sustainable long-term solution. It is also only a viable solution if hydrated lime and water are available during the planned period of use at an affordable price.

It is NOT recommended to use lime treatment:

- If a constant supply of hydrated lime and/or water cannot be guaranteed, or if these are prohibitively expensive.
- If pH cannot be monitored and assured for the necessary time.
- If the faecal sludge is so thick that it cannot be mixed.
- If adequate Personal Protective Equipment (PPE) cannot be ensured. This includes both adequate PPE against pathogen transmission for working with faecal sludge, and protection against caustic burns for working with lime.
- If dry storage of lime cannot be ensured.
- If strict effluent standards regarding pH, nutrients, or organic matter must be met.
- If there is no viable option for the disposal of the alkaline sludge and effluent, carefully consider other treatment options first before resorting to lime treatment.

Table 1 provides an overview of the advantages and limitations of using lime.

Table 1: *Advantages and limitations of using lime for faecal sludge treatment.*

Advantages	Limitations
Effective reduction of bacteria and viruses	Does not inactivate helminth eggs
Rapid treatment, no start-up time required	Quality of hydrated lime affects treatment performance
Can improve solid-liquid separation	Requires reliable supply chain of lime
Produces non-odorous effluent	Could be expensive (depending on local cost/availability of lime)
	Pathogen regrowth possible
	Does not remove (dissolved) nutrients
	As mixing is required, energy supply or (significant) labour is required
	Limited options for resource recovery

1. 3. Options for lime treatment

Two types of best-practice applications are included in this manual[3]:

- **Barrel treatment (Figure 3)**: Faecal sludge is emptied from containments and directly transferred into barrels, where dissolved lime is then added. These barrels can then be transported to a treatment plant for further treatment and disposal of the faecal sludge. This method is particularly suitable when sludge is already being transported in barrels and when space constraints at the treatment plant do not allow for the installation of lime treatment tanks. Barrel treatment can also transition into treatment at the plant while the plant is still under construction.

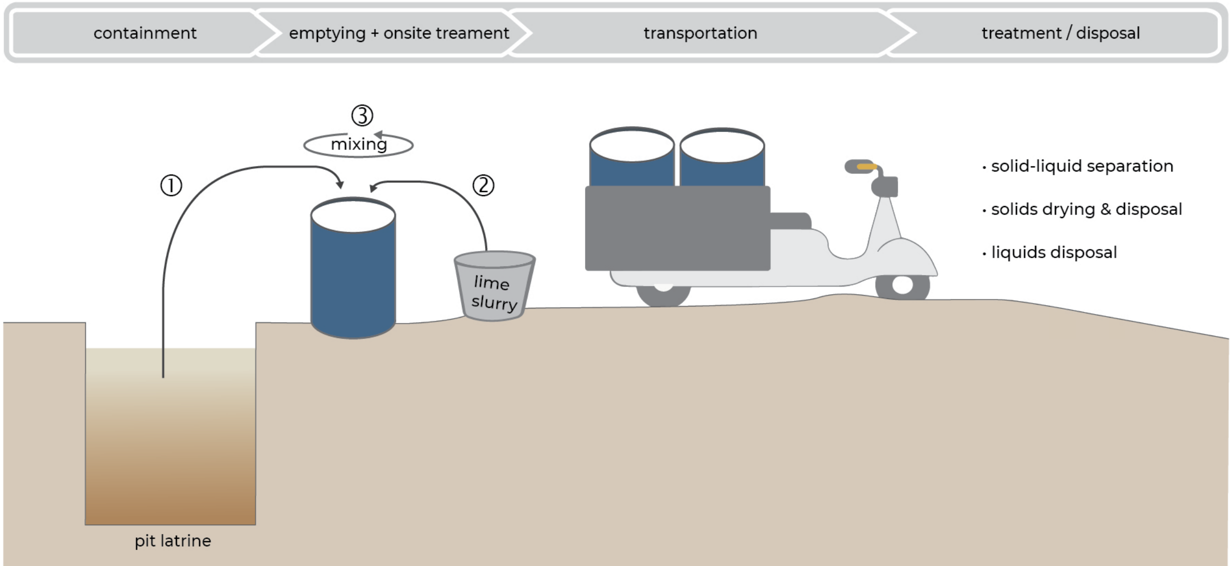


Figure 3: *The service chain for lime treatment in barrels.*

- **Offsite treatment at a faecal sludge treatment plant (Figure 4)**: The faecal sludge is emptied and transported to a centralised faecal sludge treatment plant, where batch-wise lime treatment is conducted in dedicated lime treatment tanks. Afterwards, the liquid fraction is infiltrated into the soil, and solids further dried and disposed of or reused. This is the most commonly deployed and best-case option, suitable for situations where centralised treatment is planned or already in place.

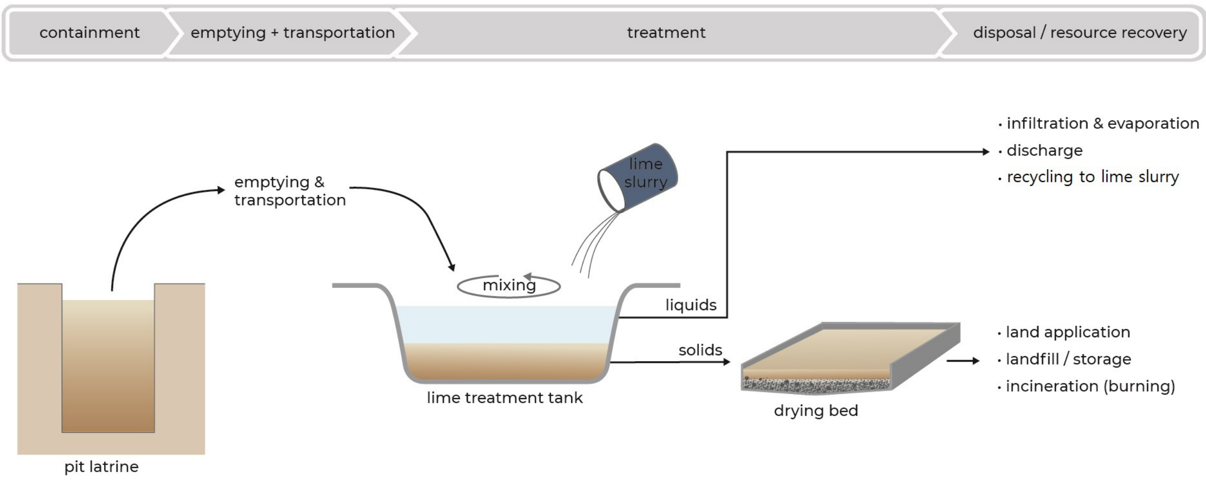


Figure 4: *The service chain for offsite lime treatment.*

[3] Treating the contents of pit latrines with lime in situ (in pit) before covering the pit is only suggested during an outbreak of infectious disease, where pathogens need to be inactivated before burying. This scenario is not explicitly included in this manual, but implementation would follow the steps described in sections 3.1-3.5

2. Preparation

2. 1. Requirements for setting up a lime treatment station

Barrel treatment

- The emptying method (manual or mechanical) will depend on availability of equipment and accessibility.
- For barrel treatment, a dedicated area for preparation and addition of the lime slurry should be identified either at the site of collection, at a central location nearby (e.g. transfer station), or at the destination treatment plant.
- The lids must be securely closed during treatment and transportation to prevent spillage.
- Clean up any spills immediately.
- The topography and layout of the camp will dictate what transportation mode is possible for the barrels. This can range from manual carrying with palanquins (which is not recommended unless absolutely necessary), to mechanical transportation with a motorised tricycle or pick-up truck.
- The volume of barrels can vary depending on availability and capacity to transport and lift. Recommended volumes are between 60-120 L. In Cox's Bazar, Bangladesh, 120 L barrels were used, but these were heavy and difficult to move (**Figure 5**). Smaller barrels are recommended.
- After lime treatment in barrels, the solid and liquid fractions need to be separated and further treated (as listed in **Figure 3**). For this, some form of offsite treatment infrastructure will be needed (see next section).

Figure 5: *Emptiers carry a barrel of lime-treated sludge with a palanquin to the treatment plant in Cox's Bazar, Bangladesh (source: Eawag).*

Offsite treatment at a faecal sludge treatment plant

The set-up of a faecal sludge treatment plant will depend on a variety of local factors (topography, availability of land and resources, regulations, etc.). For a detailed description on how to set up an emergency faecal sludge treatment plant, please refer to USAID (2015). General considerations include:

- The authorities and host community have to accept where the emergency faecal sludge treatment plant will be located.
- The site is level and not prone to flooding.
- The soil is at least 1.5 m deep before encountering groundwater or bedrock and the site is at least 30 m away from surface or groundwater sources (FSM TWiG standards, 2021). See **Annex 3** for information on determining the groundwater level.
- The site is accessible by vacuum trucks, if used.
- The site is large enough to accommodate the volume of sludge to be collected (including a buffer for potential scaling-up).
- An acceptable distance from residential areas (a minimum of 50 m recommended, if possible).
- The treatment area should be fenced, at a minimum with caution tape.
- Water for cleaning and for the preparation of lime slurry should be available.

A centralised lime treatment plant should at a minimum contain:

- A method for screening and handling solid waste (see **section 3.1**).
- A place for dry storage of lime (see **section 2.2**).
- A vessel for preparing the lime slurry. This could, for example, be a drum, barrel or polyethylene tank, depending on the amount of lime slurry required.
- Equipment for mixing the sludge and lime slurry (manual or mechanical) (see **section 3.4**).
- Lime treatment tanks/ponds: These can have a variety of forms and shapes (**Figure 6**). Optimal size of the lime treatment tanks will depend mostly on the mixing method (see **Table 2**) and available materials. Commonly used tanks/ponds are:
  - IBC (pallet) tanks. Suitable for manual or mechanical mixing.
  - Lined, earthen ponds of 0.5-0.6 m deep by 2 meters square. The liner should be impermeable, heavy duty PVC or a similar type of plastic that can withstand chemical wear. It should be suitable for manual or mechanical mixing.
  - 30 m^3 metal frame tanks with an impermeable, heavy duty EPDM (or similar material) liner. These are only suitable for larger-scale treatment plants where mechanical mixing is possible. Pump(s) to transfer sludge between treatment technologies.
- An option to dry the solids after solid-liquid separation (see **section 3.6**).
- An option for disposal of the dried solids (see **section 4.2**).
- An option for disposal of the liquid effluent (see **section 4.1**).
- An equipment washing station, including flowing water and soap.
- A staff washing station, including flowing water and soap, and an area to wash, dry and store working clothes and PPE.

Figure 6: *Different lime treatment tanks. Left: Metal frame tanks in Bentiu, South Sudan (source: IOM, 2023). Right: Treatment ponds constructed above-ground in Cox's Bazar, Bangladesh (source: Oxfam).*

2. 2. Lime quality and testing

Considerations for hydrated lime

- Use fresh hydrated lime. Its maximum shelf life is 6 months. Clumps or cakes (if the lime is no longer a free-flowing powder) indicate that the lime is past its shelf life (**Figure 7**), which could increase the required dosage to reach pH 11, or might fail to increase the pH at all.
- Quality: The quality of the lime is represented by the grade (% of $Ca(OH)_2$ by weight). It is recommended to use at least 80% $Ca(OH)_2$. There are different grades of hydrated lime available with typical concentrations of calcium hydroxide ($Ca(OH)_2$) between 80-99%, but some as low as 60%. Hydrated lime marked with a USP grade (the United States Pharmacopeia organization, which sets standards for potency and purity of chemicals) has a minimum assay content of 98% $Ca(OH)_2$. Good quality lime should have not more than 6% calcium carbonate ($CaCO_3$).


Figure 7: *Hydrated lime is a free-flowing white powder (left). Clumps or cakes would indicate old lime (right)*

(source: made-in-china.com).

Testing the quality of your lime

- Make sure you know the quality of the lime and test it to verify its quality, if needed. Testing is recommended at the arrival of each new batch of hydrated lime, if a new supplier is used, or if the quality of the lime is in doubt. Sometimes calcium carbonate is sold as hydrated lime.
- To test the reactivity of the hydrated lime, add a few spoons to a glass of water and measure if the pH is increasing to pH >11.This simple test is sufficient to check if the quality of the lime is sufficient for faecal sludge treatment.
- If a field laboratory is available, **Annex 1** provides a test method to test the available lime content (grade). Alternatively, the grade can also be tested in a local laboratory (ASTM Rapid Sugar Test).

Storage of hydrated lime

- Hydrated lime must be kept dry to remain effective, so dry, indoor storage conditions need to be ensured in all seasons (no leaking or flooding in the storage room, elevate stored lime on pallets, keep windows closed, prevent humidity as much as possible).
- Do not smoke in or around the storage area.
- The shelf-life is a maximum of six months.
- Depending on the reliability of the supply chain, aim to have enough lime to store for 14 days to three months, if it can be kept dry.

2. 3. Health and safety of workers

To address the myriad challenges faced by sanitation workers, conduct regular risk assessments in order to assess and mitigate the occupational risks inherent to all types of sanitation work. This involves establishing standard operating procedures, oversight of sanitation workers, and ensuring adequate training, technology, and personal protective equipment (World Bank, et al., 2019).

Staff

The number of staff required for lime treatment will depend on the treatment scenario, mode of mixing, and subsequent treatment steps. At least two to three staff members are needed for mixing, more if manual mixing is used. A manager has the final responsibility for the plant, with dedicated operators responsible for its operation. For in-barrel treatment, also consider the staff needed for transportation: two or more, depending on the mode of transportation.

All staff need to be trained on the health risks of faecal sludge, hydrated lime, the correct use of PPE, and required documentation. In addition, operational staff should be trained on treatment procedures. A designated (senior) person should be assigned to be responsible for training and monitoring.

Personal protective equipment

Faecal sludge should never be handled without the following Personal Protective Equipment (PPE) (**Figure 8**):

- Protective work suit or overalls
- Rubber or work boots
- Heavy duty gloves (ideally PVC)
- In addition, when handling hydrated lime, workers should wear:
- Respiratory mask (ideally FFP3, but any other type is better than no mask)
- Safety goggles

Ensure sufficient PPE for all workers. Consider that PPE needs to be washed and dried after a day of work. The availability of PPE needs to allow for this. Generally, PPE might need to be replaced every six months. In addition, sufficient water and detergent for cleaning equipment, washing and drying PPE, and removing spills needs to be available.

In addition, it is recommended that all staff members working with faecal sludge are vaccinated and have access to regular medical check-ups. The minimum recommended vaccinations are for Typhoid fever, and Hepatitis.

Figure 8: *The PPE required for lime treatment: protective overalls, safety goggles, rubber boots, respiratory mask and heavy duty gloves (source: Eawag).*

3. Lime treatment procedure

3. 1. Step 1: Removal of solid waste

Solid waste should be removed as much as possible before adding lime. For barrel treatment: remove as much solid waste from the latrine or barrel with a trash hook (**Figure 9**). For centralized treatment: use a trash screen and/or hook/rake to remove solid waste, while transferring the sludge to the lime treatment tank (**Figure 10**). The faecal contaminated solid waste needs to be handled and disposed of safely in a dedicated space:

- If a solid waste management chain exists, it can be disposed of at the existing infrastructure, but precautions should be made to avoid spreading pathogens. There should be a separate section for faecal contaminated waste, such as a designated sanitary landfill section, and workers should be trained on handling faecal contaminated waste and have access to appropriate PPE (see **section 2.3**).
- If no solid waste management exists, construct a designated pit or sanitary landfill for disposal of the faecal contaminated waste. Refer to the "Guidelines for the Safe Disposal of Solid Waste in Humanitarian Contexts" (GTH, 2024) for the design of a sanitary landfill in emergencies.
- Alternatively, dry the contaminated waste in a fenced location, and incinerate it afterwards (see **section 4.2** for information on incineration).

Figure 9: *A treatment plant operator removing solid waste with a trash hook (source: Eawag).*

Figure 10: *A treatment plant operator removing solid waste from a bar screen with a rake (source: Eawag).*

3. 2. Step 2: Determining lime dosage

The dosage depends on the characteristics of the sludge (solids and organic load), alkalinity of the sludge, and quality of the lime. It is recommended to do a quick test in a jar or beaker to determine lime dosage (as done in Anderson, et al., 2015):

- Add a known volume of faecal sludge to a jar or beaker (for example 200 mL).
- Measure and record the pH of the faecal sludge.
- Make a lime slurry according to step 3 in this manual, for example by adding 20 grams of hydrated lime to 60 mL water (ratio of 1 part (mass) lime to 3 parts (volume) water).
- Add the lime slurry to the faecal sludge incrementally and mix while measuring the pH. Keep doing this until the pH stays above 11.
- Record the amount of lime slurry that was added, and use that to calculate the amount of lime required for the volume of sludge to be treated

The dosage might vary between batches. Operators should monitor the amount of lime used, and adjust the amount of lime used in subsequent batches if needed. **Annex 2** provides examples of dosages used at various locations. However, the dosage should always be determined locally.

3. 3. Step 3: Preparing the lime slurry

It is best to first make a lime slurry with water before adding the lime to the faecal sludge. This minimises clumping, eases the mixing and is one way of maximising the efficiency of the hydrated lime.

Lime is a caustic material, and reacts violently with water, producing heat. Always start with water and slowly add the lime to the water to prevent dangerous situations. Do not add water to the lime!

Pay attention to the following points:

- Lime dust can cause harm to skin, lungs and eyes upon contact. Always wear appropriate PPE (see **section 2.3**).
- The recommended lime to water ratio for the lime slurry is 1 kg of lime for every 3 L of water (USAID, 2015). Based on the calculated required dose in step 2, start with the predetermined amount of water. Slowly add the lime, while mixing (**Table 2**). Mix well until the lime is completely suspended (no lumps) (**Figure 11**)
- Add the lime slurry to the faecal sludge directly after preparing the lime slurry, because settling happens quickly. If it settles, re-suspend before mixing with the faecal sludge. It is best to make the required amount of lime slurry directly before adding it to the faecal sludge.

Figure 11: *Two operators at the treatment plant in Cox's Bazar, Bangladesh, are making a lime slurry (source: UNHCR).*

A useful video on how to make a lime slurry from the Philippines can be found here[4]:

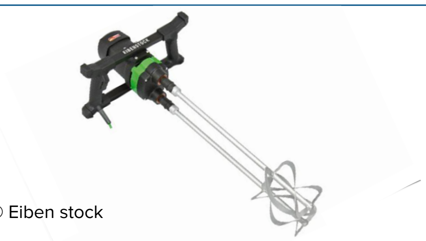
4 https://www.youtube.com/watch?v=3PZsxXK-il4

3. 4. Step 4: Mixing

The effectiveness of lime treatment depends on sufficient contact between the lime and the pathogens in the sludge. Sufficient contact is created through thorough, even mixing, and can require considerable effort with thicker faecal sludge. Overdosing does not compensate for poor mixing.

After adding the lime slurry to the faecal sludge, mix the slurry through the faecal sludge manually or mechanically (**Table 2**) for at least five minutes, until you are sure that the lime slurry is fully mixed throughout the entire mass of sludge. **This is a crucial step, do not cut this short!**

Table 2: *Manual and mechanical options for mixing the lime slurry, and mixing the lime slurry through the faecal sludge. Generally, mechanical mixing is recommended over manual mixing, especially for larger ponds.*

Manual mixing	
Manual stirring with paddles	
 Source: USAID (2015)	• No electricity required. • Heavy, labour intensive work, especially with thick sludge and in larger treatment basins.
Mechanical mixing	
Agitator	
 © Eiben stock	• Best for mixing in drums or barrels. • Requires electricity.
Pump	
 Source: Eawag	• Best for inline mixing of liquid sludge or lime slurry. • For making lime slurry: while pumping water to the designated vessel for lime slurry, position the hose so that the water is moving around, then at the same time add hydrated lime powder. • For mixing faecal sludge with lime slurry: while pumping faecal sludge to the lime treatment tank, position the hose so that the faecal sludge is moving around the tank while adding the lime slurry. • A pump requires electricity or fuel (e.g. petrol or diesel). • Best for larger-scale lime treatment.
Cement mixer	
 © Amazon	• Best for preparing lime slurry only, not for mixing faecal sludge. • Useful for producing larger volumes of lime slurry, e.g. at a centralised treatment plant scale. • Requires electricity.

3. 5. Step 5: Monitoring pH

After mixing, check that the sludge is above pH 11 with a pH meter. Take a portion of the sludge in a small bucket or beaker (enough to submerse the probe tip). If using a large treatment tank, measure the sludge at several places to ensure that it is homogeneously >11 pH. If the pH is lower than 11, add more lime slurry, mix, and measure again after 15 minutes. From the time that the pH is above 11, monitor the pH every 30 minutes to ensure the pH stays above 11. The pH should stay above 11 for at least 2 hours to ensure proper treatment. If the pH decreases within the set time, add more lime slurry and mix again. Some literature sources state that the pH of the mixture should slowly decrease back towards neutral after 24 hours. However, in reality this often does not happen, and the high pH should be considered in the disposal plan.

Figure 12: *A common portable pH meter that can be used to monitor pH* *(source: Hanna Instruments, Inc.).*

Figure 13: *A staff member at the faecal sludge treatment plant in Cox's Bazar measures pH of the lime-treated sludge* *(source: UNHCR).*

Before storing the pH meter, ensure that the probe tip is clean: carefully rinse it with distilled water (or tap water if not available). Store the pH meter in a secure place with the cap covering the probe tip. Keep the probe tip moist, ideally in an electrode storage solution (4M Potassium Chloride solution (KCl)), or if that is not available, use pH 4 or 7 buffer solution. Maintain and calibrate the pH meter according to the manufacturer's instructions. Calibrate at least once a week with buffer solutions (if available), or as frequently as needed.

A useful video showing how to use a pH meter can be found here[5].

3. 6. Step 6: Subsequent treatment: Solid-liquid separation and drying of solids

Lime treatment can contribute to improved solid-liquid separation. After lime treatment, there are two possible pathways for solid-liquid separation:

- Leave the treated sludge to settle for 16-24 hours. Then, decant the liquid supernatant (effluent) by installing one or several decanting outlets at a suitable height in the lime treatment tank, or pump it to further disposal (e.g. infiltration). Pump the sludge to a further dewatering/drying treatment step (e.g. unplanted drying bed, as done in Bentiu, South Sudan. See textbox '**Example: Process flow in Bentiu, South Sudan**').
- Pump all lime-treated faecal sludge to the next solid-liquid separation technology (e.g. unplanted drying bed) to separate the liquids and the solids, and further treat the sludge and supernatant (as done at the Oxfam treatment plant in Cox's Bazar, see text box '**Example: Process flow in Cox's Bazar**').

5 https://www.youtube.com/watch?v=YwfWR2woWI4

Unplanted drying beds

After lime treatment, the solids fraction needs to be further dried before disposal. In an emergency setting, this is best done with unplanted drying beds. "An unplanted drying bed is made of layers of gravel and sand that support the sludge and allow the liquid to percolate (**Figure 14**)". (Gensch, et al., 2018). Sludge drying speeds will depend on climatic conditions, and generally range from 7-14 days. Ideally, drying beds should be covered by a roof to provide greater reliability during all seasons (**Figure 15**). Dried sludge can be harvested with a spade. The leachate (liquid effluent) that is collected in the underdrain will need to be disposed together with the liquid effluent from the lime treatment tank.

For the design and sizing of drying beds, refer to chapter 3.3 in Englund, et al., 2019 and chapter 7.2 in Tayler, 2018.

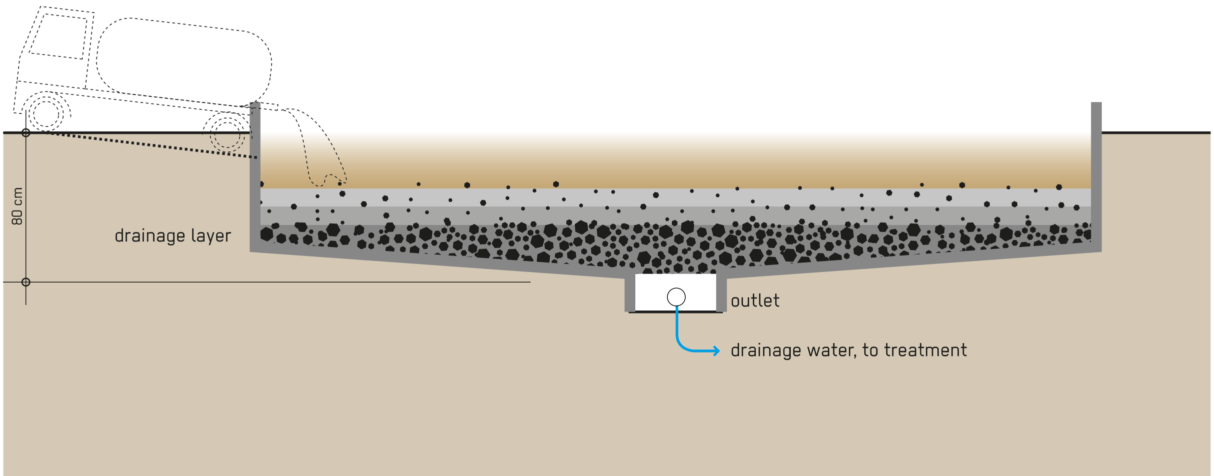


Figure 14: *A schematic depiction of an unplanted drying bed (Gensch, et al., 2018).*

Figure 15: *An unplanted drying bed loaded with faecal sludge in Cox's Bazar, Bangladesh (source: UNHCR).*

3. 7. Step 7: Cleaning

After use, all equipment and PPE need to be washed and cleaned:

It is ideal to have a designated cleaning station where equipment and clothing can be washed. At a cleaning station, sufficient water, soap and/or disinfectant, and space for drying need to be available. There should also be a bathing and handwashing space for the workers.

All equipment (mixing equipment, barrels) needs to be rinsed with water after use, for example with a high-pressure device (**Figure 16**). Use 2% chlorine spray or similar disinfectant to clean equipment that has been in contact with untreated sludge.

Contaminated work suits and clothing need to be washed with detergent or disinfectant at the highest possible washing temperature.

Figure 16: *A staff member is cleaning a submersible pump with a high-pressure device at the faecal sludge treatment plant in Cox's Bazar, Bangladesh (source: Marij Zwart)*

4. Disposal / Resource recovery

4. 1. Liquid effluent

Liquid effluent is the liquid supernatant that is decanted after lime treatment and settling, plus the leachate from drying beds (if collected). Before final disposal/resource recovery, measure the pH of the liquid effluent to understand its potential impact on the environment. It will also still be high in organic matter and/or nutrients, which should be taken into account when deciding on final disposal/resource recovery. There are three options for disposal/resource recovery:

Reuse for treatment

A portion of the liquid effluent can be used to mix lime to create lime slurry (thereby, reducing lime and water consumption) or can be added to raw sludge to decrease thickness, if needed.

Infiltration / Evaporation

Infiltration into the soil is often the only viable option for liquid effluent. This can be done with infiltration basins or infiltration beds:

- Infiltration basins are shallow unlined ponds (1-2 m deep) (**Figure 17**).
- Infiltration beds are shallow beds lined with a permeable lining material, for example, cut-open sand bags (Figure 19) or geofabric. They commonly have a gravel base to improve infiltration (see textbox 'Example design for infiltration beds' below, or section 3.6 on unplanted drying beds), but can also be lined beds directly infiltrating into the soil.

Infiltration of the liquid effluent is ONLY possible if:

- The soil has enough infiltration capacity. Sandy, silty and loamy soils are ideal for infiltration (not clay soils). If not already known, see **Annex 3** on how to determine soil type and infiltration capacity.
- Infiltration bed and basins should be at least 30 meters away from water sources FSM TWiG, 2021.
- The bottom of the infiltration basin should have a distance of at least 1.5 m from the seasonally highest groundwater table FSM TWiG, 2021.

For the design and sizing of infiltration ponds or beds, refer to Reed, 2024.

If the supernatant still contains suspended solids (which is likely the case), these will collect at the bottom of the pond/bed and should periodically be removed to avoid clogging. Multiple infiltration ponds/beds should be constructed to allow for alternate use and maintenance.

A certain amount of natural evaporation will happen in infiltration basins and beds, especially in climates where the evaporation rate is higher than the precipitation rate. To stimulate evaporation, the walls of evaporation ponds should be as low as possible, while still maintaining adequate capacity, to increase wind effect.

A certain amount of natural evaporation will happen in infiltration basins and beds, especially in climates where the evaporation rate is higher than the precipitation rate. To stimulate evaporation, the walls of evaporation ponds should be as low as possible, while still maintaining adequate capacity, to increase wind effect

Example design for infiltration beds (Cox's Bazar, Bangladesh)

*The infiltration beds proposed by the Bangladesh Red Crescent & British Red Cross, 2023 are 3 m by 2 m with a depth of 70 cm. The beds are filled with 15 cm gravel at the bottom, which is covered by a permeable sandbag sheet, then a 10 cm layer of sand, and on top another layer of cut-open sand bags (**Figure 18**). Depending on the climate and the infiltration capacity of the soil, the treatment capacity and required number of beds needs to be assessed locally. On top of the infiltration bed, a cake layer will form. To enable this cake to dry and be scooped off easily, the infiltration bed should be left to dry without feeding new effluent until the cake can be removed with a spade.*

Figure 17: *An infiltration basin in Cox's Bazar, Bangladesh (source: Oxfam)*

Figure 18: *An infiltration bed lined with cut-open sand bags (source: Bangladesh Red Crescent & British Red Cross, 2023)*

Discharge

The pH of the receiving waters should be strictly monitored to avoid environmental impacts:

- The receiving body of water needs to be much larger in relation to the discharged volume to sufficiently dilute the discharged stream. The receiving water body should not be used as an immediate water source.
- Measure and record the pH of the final effluent before discharge into the receiving water body. Where possible, the pH of the discharge water should match the pH of the receiving water, but in any case the pH of the discharged effluent should always be below pH 9. Dilute if needed.
- Daily monitor the pH of the receiving waters (in several sampling locations) after discharge.
- If local regulations on pH limits for discharge exist always follow them. If regulations do not exist, discontinue discharge as soon as the pH of the receiving water bodies exceeds pH 8.

*The liquid effluent after lime treatment should ONLY be discharged into water bodies as an extreme emergency, short-term solution where there is no option for infiltration/evaporation or reuse (for example, see textbox **"Example: Process flow in Bentiu, South Sudan"**).*

4. 2. Dried solids

The solids after lime treatment are highly alkaline. Therefore, biological post-treatment is not realistic, as the microorganisms necessary for biological processes (such as co-composting) are inhibited. There are three options for resource recovery or disposal of the dried solids:

Land application

To use the solids for land application as a soil conditioner, the solids do not need to be fully dried. Incorporate them into the soil with a plough or spade to reduce exposure. Keep in mind:

- Transfer solids to the soil within a few days after treatment to prevent pathogen regrowth.
- Spread the treated solids over sufficient land. Excess application could result in a too high soil pH which can pose problems for plant growth, or leaching or runoff of excess nitrogen.
- If possible, record the rate of application.
- Restrict public access for 30 days after application, if possible.
- Before large-scale application, it is best to first test soil application on a small plot, and monitor its impact on yields.
- For detailed information on land application of faecal sludge, refer to WHO (2006).

Resource recovery as a soil conditioner should ONLY be considered if:

- The receiving soil is acidic, and if making the soil less acidic is desired.
- If there is no risk for helminth spreading: only use on crops that do not come into contact with the soil, for example, fruit trees or maize, fodder crops, or building material crops (such as reeds). Access to the area should be restricted.

If the soil is already alkaline (approximately pH >7.5), it is not advised to use the alkaline sludge as a soil conditioner.

Landfill / Storage

If a landfill exists, the dried solids can be used as landfill cover material. Alternatively, burying the dried solids at the landfill or storage in sand bags could also be an option.

Incineration (burning)

Lime-treated sludge has a high ash content, which could negatively impact the incineration process. However, incineration is an option if soil application or landfilling are not possible. Incineration can be done in an incinerator kiln (such as a De Montfort incinerator, for guidelines on design and construction, see IT Power India & WHO (2004)), or as open burning if absolutely necessary. If using an incinerator kiln (Figure 19), ensure that the chimney is at least higher than 2 m, and that it is away from residential areas in all wind directions.

Figure 19: *An incinerator kiln in Cox's Bazar, Bangladesh (source: UNHCR).*

5. Possible risks, challenges and mitigation measures

Table 3 summarises the main risks and challenges that can occur during lime treatment and mitigation or troubleshooting measures.

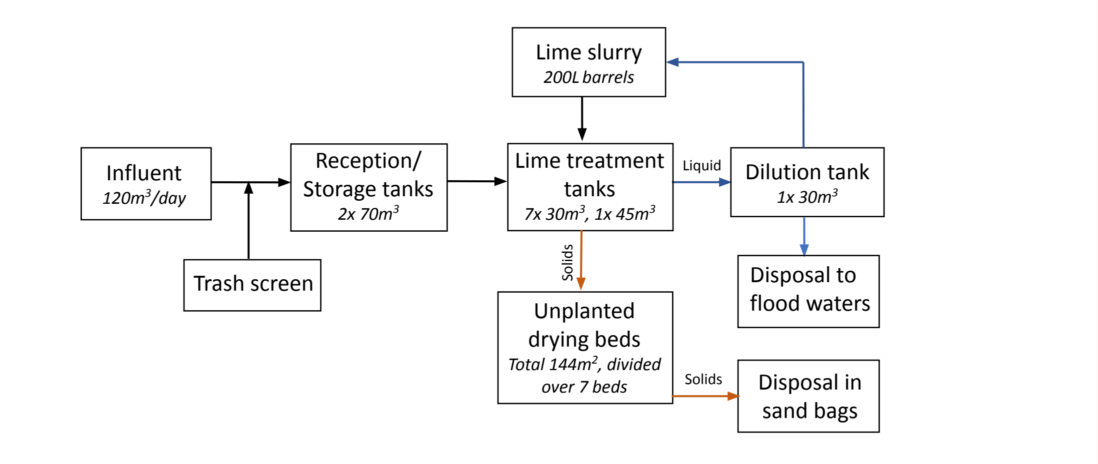
Table 3: *Potential risks and challenges, and mitigation measures to prevent or manage them.*

Challenge / Risk	Mitigation measures
Unable to achieve or maintain pH 11.	• Make sure that hydrated lime is being used, and verify the available $Ca(OH)_2$ content (in accordance with **section 2.2** or **Annex 1**). • Do not use hydrated lime older than six months. • If the pH does not reach 11, add more lime. Keep adding lime until the pH reaches 11.
High variability of influent faecal sludge.	• Doing a jar test to determine dosage as described in **section 3.2** will help to determine the correct dosage for each batch. If the characteristics of the sludge are rather constant, frequency can be reduced, but if the sludge is highly variable, this might need to be done before each batch.
Pathogen regrowth	• To avoid pathogen regrowth, reuse or dispose of the solids as soon as possible after treatment. Do not store the solids for extended periods of time as pathogen regrowth is a possibility.
Spillage of lime	• Sweep up as much of the dry powder as possible. • Wash the residuals away with copious amounts of water. • Always wear appropriate PPE when working with hydrated lime.
Spillage of faecal sludge	• Clean the spillage with water, and disinfect spillage of faecal sludge with a 2% chlorine solution or similar disinfectant. • Always wear appropriate PPE when working with faecal sludge.
Inhalation of lime dust	• Consult a medical doctor immediately. • If the victim is unconscious, put them in the recovery position.
Skin or eye contact	• For skin contact: wash immediately with water and soap. • For eye contact: rinse with water only for several minutes. Consult a medical doctor immediately.
Supply chain disruptions for hydrated lime	• Having a hydrated lime supply of up to three months in storage is recommended to prevent a supply chain issue from disrupting the treatment. • If hydrated lime is not available, quicklime can also be used to treat the sludge. However, extreme caution should be exerted both in the storage and use of quicklime as it is highly reactive! Quicklime reacts to form calcium hydroxide (hydrated lime) immediately when dissolved in water, and the strong exothermic reaction leads to a massive development of heat. Only do this if no other options are available. To reduce risks, wear appropriate PPE (**section 2.3**), make the lime slurry in a well-ventilated space (preferably outside), and only make lime slurry from quicklime in small quantities so that the reaction proceeds in a controlled manner.
There are bad odours during lime addition	• Some odours originate from the faecal sludge itself, although lime treatment should reduce odours from the faecal sludge during treatment. Practice good housekeeping. Move dried solids offsite as quickly as possible. Treatment sites should be located ideally at least 50 m away from residential areas. • Some odour comes from the production of ammonia (NH3) during the lime treatment, which will be unavoidable. Appropriate PPE, including respiratory masks to protect airways, should be worn, following the guidelines in **section 2.3**.
Clogging of the infiltration basin	• Dig a new infiltration basin, if the old one is clogged. • If space is available, having two alternating infiltration basins could be an option, so that the one not in use can dry and the bottom be scraped, if clogging occurs.

Example: Process flow in Bentiu, South Sudan (IOM, 2023)

Influent sludge was pumped from the desludging trucks to two 70 m³ reception/storage tanks ("Oxfam T70 tanks"). From there, a batch of 25 m³ of sludge was transferred to a lime treatment tank (30 m³ metal frame tank). The lime slurry was added to the lime treatment tank with a 3" centrifugal pump, and the contents were mixed while pumping and manually stirred. When pH reached 11.5, the sludge was left to settle for 16-24 hours (pH was monitored once after 30 min). Afterwards, supernatant was pumped to a dilution tank, where it was mixed with floodwater before discharge into the floodwaters. Settled sludge was pumped to the drying beds to a height of 0.1 m. Drying took 4-7 days, depending on weather conditions. All moisture evaporated. The dried sludge was mixed with sand and put into sand bags that were used to fortify the embankments.

For a full layout and dimensions of the Bentiu faecal sludge treatment plant, see www.sanihub.info (IOM, 2023).



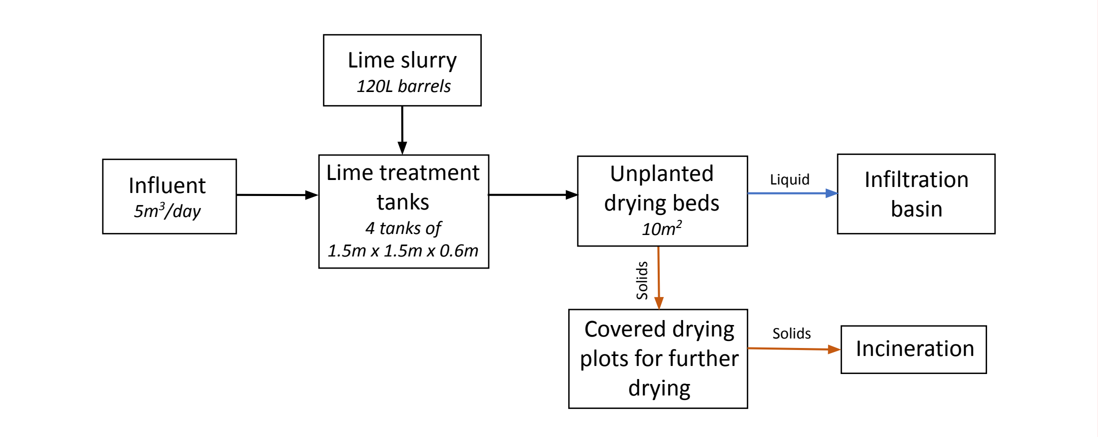
Lessons learned

- *Lime treatment was quick and easy to set-up (two days to get the plant up and running), and worked well in emergency cases, but was too expensive for long-term operation. It should be considered as a temporary option. In this specific case study, costs were extremely high because there was no road access and the lime had to be delivered by air. However, the temporary high costs were justified since there was no other option to prevent exposure and protect the health of the 102,000 people in the camp.*
- *It is necessary to have capacity to train staff quickly.*
- *Effluent receiving flood waters were monitored every day, but no effect of the discharge was observed.*

Photo: *The lime treatment facility in Bentiu, South Sudan*

Example: Process flow in Cox's Bazar, Bangladesh

Influent faecal sludge is pumped directly to the lime treatment tanks (total of 9 m², divided into four tanks). There, it is mixed manually with lime slurry, and monitored to stay at pH 12 for two hours. Optimal depth of lime treatment tanks for manual stirring is 0.5-0.6 m. After two hours, the contents of the lime treatment tanks flow by gravity to an unplanted drying bed (10 m² x 0.5 m depth) for solid-liquid separation. From the drying beds, the supernatant flows to an infiltration basin, where it infiltrates into the soil or evaporates. The dewatered solids are left on the drying beds for five to seven days, depending on weather conditions, and are then removed and put on a designated drying area (flat surface covered with a roof) to dry further. Once they are dry enough to be incinerated, they are removed.



Lessons learned

- *Lime treatment was effective for rapid, first response treatment. It was also particularly useful for medical faecal waste and during disease outbreaks. There was quick installation of the plant with local materials, and no complex civil structures were needed. Initial investment was low. However, persistent use of lime in the long term can be costly.*
- *Mechanical mixing is advisable over manual mixing, when possible. It is helpful to have shallow (0.5-0.6 m deep) lime treatment tanks to facilitate easy mixing.*

Photo: *Unplanted drying bed.*

Photo: *Covered drying plots.*

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ANNEX 1 - Testing for carbonation

When lime is stored exposed to the atmosphere, carbon dioxide reacts with the calcium hydroxide $Ca(OH)_2$, and converts it back to calcium carbonate ($CaCO_3$), which is not reactive and has no treatment effect. This process is called carbonation. If you notice that the hydrated lime is not working as desired, or performance changes over time, the problem could be carbonation. The following procedure could be used to test for the amount of carbonation (amount of $CaCO_3$):

> "Where the lime has become carbonated, there may be no immediately obvious change in appearance. What tends to happen is the lime is no longer fine, light and soft but bags of lime become harder and the lime lumpy. Good quality lime should have not more than 6% calcium carbonate ($CaCO_3$). A simple test is to see if there is a reaction with dilute hydrochloric acid. There should be no obvious effect if some dilute, 10%, hydrochloric acid is dropped onto a little of the lime in a watch glass or saucer, apart from some dissolution of the lime. If there is 'fizzing' and bubbles of carbon dioxide, then it suggests that the quality of the lime has deteriorated due to exposure, possibly in inadequate storage conditions over a period of time". (Practical Action, 1997)

ANNEX 2 - Example lime dosages

The table below shows dosages of hydrated lime that were used at various locations. This table is meant as an example, and should not be considered as a recommendation. The wide range of dosages used in practice highlights the need to determine dosage locally, following the procedure described in **section 3.2**.

Location	Dosage (g lime/L faecal sludge)	Reference
Cox's Bazar, Bangladesh	15 g/L for pH 12	Oxfam
	9.8 g/L for pH 11, and 21.3 g/L for pH=12	Bina, et al. (2004)
Sittwe, Myanmar	40 g/L for pH 12	Krähenbühl (unpublished)
San Fernando, Philippines	10 g/L for pH 11 (septic tank sludge)	Strande, et al. (2014)
Bentiu, South Sudan	24 g/L for pH 11.5	IOM (2023)
	10-17 g/L for pH 12	Gensch, et al. (2018)
	20 g/L for pH 11	Bangladesh Red Crescent & British Red Cross (2023)

ANNEX 3 - Soil tests and groundwater table

When designing faecal sludge treatment with infiltration, it is important to know the groundwater level, soil type, and infiltration capacity of the soil at the designated treatment site.

Groundwater level

Local authorities might have information on the groundwater level. However, if this information is not accessible or existing, it will be necessary to check with the engineers and construction crews of sanitation facilities, if groundwater is encountered when pit latrines are constructed.

Soil type: Soil ribbon test

Sandy, silty and loamy soils are ideal for infiltration, whereas clay soils are unsuitable. A quick soil ribbon test could help determine if the soil is suitable for infiltration. Dig a test hole that is approximately 30 cm deep. Take a sample of soil from the hole in the palm of your hand, mix it with water until pliable, and form the soil into a ribbon between your dumb and middle/index fingers. Generally, if you can make a ribbon longer than 2 cm, it probably has too much clay for infiltration (USAID, 2015). See NSW gov[6] for a detailed description with illustrations.

Infiltration capacity: Percolation test

To test the infiltration capacity of the soil, you can do a percolation test at the site where the treatment plant or infiltration ponds/beds are planned:

1. Dig a test hole of 30 x 30 cm wide, and 30 cm deep.
2. Fill the bottom of the hole with 5cm of gravel to avoid clogging.
3. Place a ruler or measuring tape in the test hole (along the depth axis).
4. Fill the hole with water, and let it soak away overnight to saturate the soil. You might need to repeat filling the hole until the water soaks away as slow as possible.
5. Fill the hole with water again (30 cm deep), and use a stopwatch to measure how many minutes it takes for the water level to decrease by 1 cm. This is the soil percolation rate (min/cm).

Table 4 translates the soil percolation rate to possible infiltration (application) rate for liquid effluent. For more information on conducting a percolation test for sanitation systems, refer to Gensch, et al., 2018.

Table 4: *Soil percolation rate and application rate for infiltration of liquid effluent*

(Morel & Diener, 2006; adapted from Crited and Tchobanogious, 1998)

Soil texture	***Percolation rate*** min/cm	***Application rate*** l/m²/d
Gravel, coarse sand	< 0.4	Not suitable
Coarse to medium sand	0.4–2	50
Fine sand, loamy sand	2–6	30
Sand loam, loam	6–12	25
Loam, porous silt loam	12–25	20
Silty clay loam, clay loam	25–50	8
Clays, colloidal clays	> 50	Not suitable

6 https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/164615/determining_soil_texture_using_-ribboning_technique.pdf

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