"Sanitation Innovations for Humanitarian Disasters in Urban Areas"

SPEEDY SANITITAZION and STABILIZATION

Final Report

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1 INTRODUCTION

1.1 SANITATION IN EMERGENCIES

Provision of adequate sanitation is one of the key measures to ensure low morbidity and mortality during emergency situations. Lack of proper disposal of faeces due to lack of sanitation facilities, poorly planned facilities or misuse of existing facilities (due to non-acceptance by users) is the main cause of diarrhoeal diseases (WHO, 2005). Diarrhoeal diseases such as cholera and dysentery have been reported to be the main causes of death of young children worldwide (Wagner and Lanoix, 1958; WHO, 2013). Also, child mortality has been linked to diarrhoeal diseases in emergencies (Connolly et al., 2004). Notwithstanding its importance, sanitation in emergencies has remained underfunded compared to water supply.

Disposal of excreta in difficult areas such as those with a high water table, unstable soils, rocky soils, inadequate space and land ownership issues, presents a challenge to humanitarian organisations (Chartier, 1995; Johannessen et al., 2012). In the immediate phase, that may lead to the practise of open defecation (which should be avoided if possible), use of trench latrines and use of raised latrines which make use of receptacles that require emptying (Chartier, 1995; Reed et al., 2013). Construction of raised latrines in emergencies may take long. Therefore, IFRC, WASTE and OXFAM compiled special kits for use in emergency which are easy to deploy and require minimal expertise to assemble. However, these latrines need to be desludged when they fill up (www.egmergencysanitationproject.org). The frequency of emptying may also be high due to a large number of users and limited size of receptacles. For instance, during the Haiti earthquake, 200 litre faecal matter receptacles had to be emptied every day (Johannessen, 2011).

After the pits and storage containers are emptied, faecal sludge is normally disposed off in to the environment. For instance, in the aftermath of Haiti earthquake, the tankers emptied the contents into the environment (Johannessen *et al.*, 2012). This is a health risk because of the likely contamination of ground and surface waters and spread of diseases by vectors such as rodents and flies (Harvey, 2007). Consequently, consumption of contaminated water and food can lead to faecal-oral diseases.

Indiscriminate disposal of untreated faecal matter is a health hazard. Untreated faecal matter is laden with pathogens which cause illnesses such as diarrhoea, cholera, and dysentery (Wisner and Adams, 2002). According to WHO (2013), diarrhoea is the second highest cause of death in children under five with an estimated 760,000 children dying annually. When faecal matter comes into contact with water sources, it pollutes the water, leading to water borne diseases. This occurs if the water is not adequately treated, which is often the case in emergencies. In addition, flies which breed on faecal matter may transfer pathogens to the food and if the flies are present in large densities, it may lead to break out of trachoma in children (Harvey, 2007).

The large concentration of the population in emergency situations, coupled with factors such as inadequate supply of clean water and lack of sanitation facilities lead to explosion of diarrhoeal diseases. Further, pollution of available water sources by faecal matter will exacerbate the situation resulting in death especially of children, if not controlled on time (Connolly et al., 2004).

To avoid disposal of untreated faecal matter into the environment, treatment options that can sanitize (kill pathogens) and stabilize faecal matter (reduce vector attraction), need to be employed in the immediate phase of emergencies. Several chemical and biological processes have been tested in the field for their efficacy in an emergency set-up. Studies carried out to establish efficacy of treatments in the context of an emergency concluded that treatment of faecal sludge using urea, lime and lactic acid fermentation can sanitize faecal sludge safely in between 3 and 15 days if certain conditions are provided (de Pooter, 2014; González Pérez, 2014; Malambo, 2014; Nobela, 2014). However, these studies did not investigate the stability of the end product. Further research is required to determine other treatment methods that can be employed to sanitize and stabilize faecal sludge.

On the other hand manufacturers of additives claim that their products increase the rate of decomposition. Earlier research on the use of additives to stabilize faecal matter gave mixed results; some state that biological additives work ((Jere et al., 1998; Taljaard *et al*., 2003) while others claim that they do not work (Bakare, 2011; Buckley et al., 2008; Foxon *et al*., 2008). The observed differences may be attributed to the difference in stabilizers, method of application and management issues (number of users, almost full pits, ownership of facility and whether the pit was or was not in use during the experimental period). Therefore, as part of the Emergency Sanitation Project, WASTE and its sanitation partners through funding from the Humanitarian Innovation Fund (HIF), initiated this research which was carried out to determine whether commercially available additives can stabilize and sanitize faecal sludge.

2 FIELD WORK OBJECTIVES AND SET UP

2.1 OBJECTIVES

The main objective was to identify select/develop and test effective bio/chemical additives that convert faecal matter into a harmless and non-smelling product.

In order to achieve the main objective the following specific objectives were followed:

- Determine a set of requirements that the additives to be selected need to fulfil.
- To obtain a comprehensive overview of existing bio-additives and select the most promising.
- To develop a protocol that can be used to assess the effectiveness of bio-additives.
- To test the selected bio-additives on real faecal matter.
- To assess whether the bio-additives tested are working satisfactorily and to decide whether it is worthwhile to develop prototypes.

2.2 ADDITIVE'S REQUIREMENTS

In order to determine the bio-additives' requirements, they have been grouped in five categories:

A. Contextual requirements

Since the main objective of bio-additives is to sanitise and stabilise faecal sludge in emergency situations, two contextual application situations are proposed:

A1. Application at household scale

Household scale is a bucket/bag toilet (*See Figure 1*) that can be emptied into vacant land every 5 days by an organised collection, transport and disposal system (an individual or group) as the poo is decontaminated.

Figure 1. Bucket/bag toilet for emergencies

A2. Application at communal scale

Communal scale is a faecal sludge container system where the human waste of 50 people is treated into a harmless, stabilised product. This container system is part of the raised latrine system developed by Oxfam GB and WASTE *(See Figure 2)*

Figure 2. Raised latrine and wheel bin collection tank

B. Application requirements

B1. Safe handling
Additives for use in FS treatment should adhere to environmental, safety and health standards. There should not be dangerous products/by-products formed.
B2. Robustness
The bio-additive is a robust product which can applied effectively under different types of excreta and climate conditions.
B3. Level of independency
The application of bio-additives do not require of external inputs such as power grid, water supply, etc.

C. Transportation

C1. Deployment
The bio-additive should be easily transported using standard air freight.
C2. Bulkiness and weight
The product should not be heavy nor with a large volume according to the following factor: 1 m^3 transport volume: 100 m^3 treated faecal sludge

D. Operation and maintenance

D1. Treatment capability The bio-additive has the ability to treat different types of sludge (liquid, solid, semi-solid). The type of sludge is related with the user interface, user's costumes and climate conditions.
D2. Treatment efficiency The bio-additive should be an effective solution to reduce pathogens (sanitisation) and organics (stabilisation) . The treated sludge should fulfil WHO criteria (treated sludge contain < 1000 CFU/g TS of *E. Coli* and < 1 *Helminth* ova/g TS)

D3. Treatment effectiveness The treated sludge do not require additional treatment and can be disposed in a landfill (or similar) or re-used.
D4. Treatment period The treatment process does not require more than 14 days.
D5. Vector breeding Access by vectors and vector breeding is minimized
D6. Odour release Limited smell (to allow the possibility to apply in facilities at household and communal level in human settlements)
D7. Accessibility The treated sludge is easy to empty using a desludging device (when a communal toilet is applied) or manually (when it is applied in bucket toilet at household level)
D8. Storage The bio-additive should be stored at ambient temperatures. In emergencies, some services i.e. power may be disrupted. Therefore, additives for treating sludge should be stored at ambient environmental conditions without need for refrigeration.

E. Cost

The cost of treatment with additives should be such that it warrants investment. The cost can be based on material cost, time for treatment and equipment required.

2.3 SELECTED AND TESTED ADDITIVES

Additives are products sold by manufacturers and distributor who market it citing that they enhance the performance (low fill up rates, no odour problems) of onsite sanitation systems (DOH, 2014). These products can be classified as biological or chemical.

Biological additives
Biological additives contain bacteria, enzymes and /or yeast. These contents may be mixed with nutrients and surfactants[3]. The products are marketed that they increase decomposition rates.

Chemical additives
These additives contain various products ranging from odour reducing chemicals i.e. formaldehyde, flocculants claimed to reduce suspended solids, inorganic compounds i.e. strong acids and alkalis, that unblock drains that are clogged and organic solvents (chlorinated compounds) sold as degreasers which removes fats and grease in the drains.

Manufacturers of additives claim that their products increase the rate of decomposition slowing rates of pit fill up. The studies available in literature have mixed results with some showing additives

[3] Source https://www.extension.purdue.edu/extmedia/HENV/HENV-13-W.pdf

increase rates of decomposition while others disapprove the claim. Moreover, advances in biotechnology could help isolate micro-organisms and enzymes that can help in improving decomposition in pits. To establish the efficacy of the additives, tests to establish stability and safety of end product for disposal were carried out. These tests included VS, TS, COD, *E. coli*, and *Enterococci* determination in the raw and treated faecal matter (Kemboi, 2015).

The additives tested were:

Table 1: Tested bio-additives description

No	**Additive name**	**Product description by producer**	**Category**
1	Biomax	A natural blend of thermophilic aerobic bacteria with optimal temperature of 70-80 ° and enzymes that break down the waste. The enzymes are keratinase, lipase and cellulase. In thermophilic processes dosed at 0.1% to FS.	Biological
2	Ikati	By-product of soda ash mining. Crystalline product. Used in village schools in Kenya to achieve volume reduction in pit latrines	Chemical
3	EM	A brown liquid readily flowing	Biological
4	Aquaclean	This is a proprietary formula of bacteria produced in the USA. It contains "vegetative bacteria representing aerobic, anaerobic, facultative, chemo-synthetic and photo-synthetic bacteria which make it versatile across many working conditions"	Biological
5	Soda	Lab grade Sodium Carbonate	Chemical
6	Saniloo	A microbial consortium of beneficial bacteria. 1mL of Saniloo contains more than 13 million bacterial cells (heterotrophic plate count).	Biological
7	Rid X	A formulation of bacteria and enzymes. The ingredients which are in percentages between 10 and 20% include "A-Amylase, bacteria, complex with amylase and proteinase, cellulose, subtilisin carlsburg and triacylglycerol lipase".	Biological
8	Terraktiv	Contains Effective Microorganisms (EM), molasses, water, sea salt, EM-Ceramic Powder, Green Gold, apple cider vinegar. It is used for domestic use as cleaner for the sewage treatment plant, as an accelerator and stabilizer for the pond, for stable manure or control of odour	Biological
9	Men xu ly be phot	Contains useful microorganisms that destroy viruses and worms. Ensures environmentally clean products	Biological
10	Magic Pit	Marketed for the treatment of septic tanks and pit latrines. Its contents are harmless bacteria which accelerate the degradation of human wastes, kill pathogens as well as eliminate odours. (Product package).	Biological
11	Safety Gel	White in appearance and is used to assist control infections by absorbing liquids in spillages, urinals, bedpans, vomit bowls etc	Chemical
12	Lime	Alkaline or Lime stabilization is a simple process which reduces odour, vector attraction and pathogen levels in wastewater and wastewater treatment sludges (also known as biosolids) (Williford, Chen, Shammas, &Wang, 2007) The process involves the application of an alkaline substance such as calcium hydroxide ($Ca(OH)_2$) to increase the pH and create a highly alkaline environment which is hostile to biological activity (Schwing Bioset, 2009).	Chemical
13	Urea	Urea Treatment is based on the sanitizing effect of uncharged ammonia (NH_3) which has been demonstrated to be a harmless chemical substance capable to efficiently inactivating bacteria (Vinneras, Nordin, Niwagaba, &Nyberg, 2008).	Chemical

2.4 FIELD TESTING PARAMETERS

The test parameters, reagents, apparatus and analytical method used for the analysis are shown in Table 2. The description of the methods is given in Appendix 3.

Table 2 Parameters measured

Parameter	Reagents/ Materials/Glassware	Apparatus	Method
Total COD	Digestion solution (Water, $K_2Cr_2O_7$, conc. H_2SO_4, H_2SO_4/Ag_2SO_4) Stock solution (Potassium hydrogen phthalate dissolved in water)	Digestion vessels Oven to operate at 150±2°C Spectrophotometer to operate at 600 nm	Standard method SM 5220D Closed reflux method
Total solids and Volatile solids		Oven, 105°C Analytical balance (10mg accuracy) Evaporating dish Muffle furnace	Standard method SM 5540G Gravimetric method
pH		WTW pH 340i field meter	
Temperature		Mercury Thermometer	
E. coli	Chromocult coliform agar (Merck Millipore) Distilled water Cotton wool Aluminium foil Peptone Sodium chloride	Autoclave Incubator, (37±2°C) Water bath controlled thermostatically at, 100°C pH meter Burner flame Petri dishes (90mm) Glass spreader	ISO 9308-1 Surface plate method
Enterococci	m Enterococcus agar (Difco) Distilled water Cotton wool Aluminium foil Peptone Sodium chloride	Autoclave Incubator, (35±2°C) pH meter Burner flame Petri dishes (90mm) Glass spreader	ISO 9308-1 Surface plate method

2.5 EXPERIMENTAL SET UP

The experimental set-up was done in two phases. The first phase was a laboratory scale experiment carried out at UNESCO-IHE, Delft Netherlands while the second phase was the field study in Blantyre Malawi, La Paz Bolivia and Kathmandu Nepal.

2.5.1 LAB SCALE EXPERIMENTAL UNITS

The lab scale set-up entailed use of 500 mL bottles, which were filled, with 300 mL of sample. The black water used for the tests was obtained from Landustrie Sneek BV. Landustrie is treating black water from the toilets in its office block and factory in Sneek, Friesland province in the north of Holland. 30 litres of the black water was collected in three 10L jerry cans and stored at UNESCO-IHE in the cold room at 4-6°C. Two trials were performed. The first trial was run for two weeks whereas the second trial was run for a week due to time constraints.

The set-up was composed of bottles with black water for five different additives i) Biomax, ii) Ikati, iii) EM, iv) Aquaclean and v) Soda, control and water reference, each designed as a triplicate, see Figure 3 below.

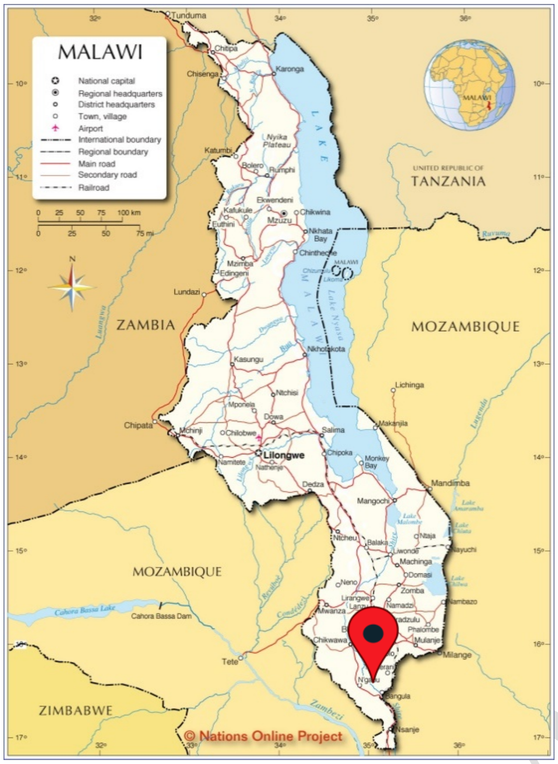
E. Coli was added to the sample used in trial 2 (1% which is approximately 10^7/mL of *E. Coli* ATCC 25922 obtained from the laboratory at UNESCO-IHE) because the *E. Coli* concentrations in the raw black water were low. The additive dosage was scaled down to the volume of the tested black water. The total volume of the additive and dilution water was expressed as a % of the black water volume. This yielded 1.7% v/v, which was adopted for all additives. For the powdered additives, 1.7% w/w was adopted.

Figure 3: Laboratory set up at UNESCO IHE

Based on the main findings at laboratory scale, three field trials were conducted in countries located at different continents with diverse climate conditions: Malawi, Bolivia and Nepal.

Figure 4: Field trials location

2.5.2 FIELD EXPERIMENT IN BLANTYRE MALAWI



Blantyre is Malawi's centre of finance and commerce, the second largest city with an estimated 1,068,681 inhabitants for 2015. It is sometimes referred to as the commercial capital of Malawi as opposed to the political capital, Lilongwe. It is the capital of the country's Southern Region as well as the Blantyre District.

The climate of Blantyre is classified by Köppen-Geiger climate classification system as a humid subtropical climate and is greatly influenced by its location in the tropical zone and altitude. The city experiences the tropical continental climate with two distinct seasons in the year. The rainy season is from November to April, with continuing light cold from end of May to July. The dry season is from May to October. The mean annual rainfall is 1,122 mm (44.17 in), of which about 80% falls within 3½ months between November and March. The city is generally cool with mean monthly temperatures ranging from 19 °C (66 °F) during the cool season (May to July) to 26 °C (79 °F) during the hot season (September to November).

Six additional additives were tested in Malawi: vi) Saniloo, vii) Rid X, viii) Terraktiv, ix) Men Be Phot, x) Magic Pit and xi) Safety Gel. Two trials with different type of faecal sludge were carried out in two types of setup. The first setup made in 2 L buckets was carried out for the first 8 additives, control and water reference (*See Figure 6*). For comparative purposes, the additive dosage adopted in the lab scale was used to test the effect of additives on faecal sludge. The additive dosage implemented was 1.7% v/v or w/v like the one in the lab scale. The second setup was carried out in 50 litre containers for three additives (Saniloo, RidX and Terraktiv) doubling the dosage from 1.7 to 3.4% v/v or w/v, control and water reference. The additives were weighed and added to the containers containing faecal sludge and mixed using a stick. Those that required dilution were mixed with the recommended volume of water.

Figure 6: Field experimental set-up in Malawi (2L and 50L containers)

2.5.3 FIELD EXPERIMENT IN EL ALTO – LA PAZ, BOLIVIA

El Alto (Spanish for The Heights) is the second largest city in the department of La Paz, Bolivia. Once merely a suburb of adjacent city of La Paz on the Altiplano highlands, El Alto is today one of Bolivia's largest and fastest-growing urban centres. The population in 2011 was 974,754. It is the highest major metropolis in the world, with an average elevation of 4,150 m.

Köppen-Geiger climate classification system classifies El Alto's climate as alpine, since all mean monthly temperatures are below 10 degrees. Among all cities in the world with Köppen-Geiger classifications of E, El Alto is the most populous.

The set up carried out in El Alto consisted in 10L plastic containers (*See Figure 8*), where 5L of faecal sludge collected from a public toilet were stored and 6 additives were added in 2 different dosages as indicated in Table 3.

Figure 7: El Alto location in Bolivia map

Table 3: Additives and dosages tested in El Alto, Bolivia

No	Additive	Dose	
1	Ikati	0.85% and 1.7%	Chemical additives
2	Caustic Soda	0.85% and 1.7%	
3	Safety Gel	0.85% and 1.7%	
4	Saniloo	2% and 5%	Biological additives
5	Terraktiv	2% and 5%	
6	Magic Pit	2% and 5%	

Figure 8: Experimental set up in El Alto, Bolivia

2.5.4 FIELD EXPERIMENT IN KATHMANDU, NEPAL

Figure 9: Kathmandu location in Nepal map

Kathmandu is the capital and largest municipality of Nepal. It also hosts the headquarters of the South Asian Association for Regional Cooperation (SAARC). It is the only city of Nepal with the administrative status of Mahanagar (Metropolitan City), as compared to Upa-Mahanagar (Sub-Metropolitan City) or Nagar (City). Kathmandu is the core of Nepal's largest urban agglomeration located in the Kathmandu Valley consisting of Lalitpur, Kirtipur, Madhyapur Thimi, Bhaktapur and a number of smaller communities. Kathmandu is also known informally as "KTM" or the "tri-city". According to the 2011 census, Kathmandu Metropolitan City has a population of 975,453 and measures 49.45 km2 (19.09 sq mi).

The city stands at an elevation of approximately 1,400 metres (4,600 ft) in the bowl-shaped Kathmandu Valley of central Nepal.

Five major climatic regions are found in Nepal. Of these, Kathmandu Valley is in the Warm Temperate Zone (elevation ranging from 1,200–2,300 metres (3,900–7,500 ft)), where the climate is fairly temperate, atypical for the region. This zone is followed by the Cool Temperate Zone with elevation varying between 2,100–3,300 metres (6,900–10,800 ft). Under Köppen's climate classification, portions of the city with lower elevations have a humid subtropical climate (Cwa), while portions of the city with higher elevations generally have a subtropical highland climate. In the Kathmandu Valley, which is representative of its valley's climate, the average summer temperature varies from 28–30 °C (82–86 °F). The average winter temperature is 10.1 °C (50.2 °F).

To perform the experiments in Nepal, fresh faecal sludge (3 days old) was collected from a mobile toilet. Approximately 1m^3 of sludge was collected and emptied in the experimental units (*See Figure 10*).

Figure 10: Faecal sludge collection from a mobile toilet

In order to simulate a multiple use household container system and a bucket toilet, two set-ups were implemented. The first setup was made in 10 L buckets and the second in 210 L plastic container (*See Figure 11*). Ten units of 10L bucket were implemented for five additives, testing two conditions: mix and no mix. The five units of 210 L have a mixing condition using a mixer manufactured locally (*See Figure 12*). Additionally an extra 210 L drum was used as control without any addition of additives.

Five additives were tested, four chemical and one biological. i) Caustic soda (sodium hydroxide); ii) Lime (calcium hydroxide); iii) urea; iv) phenol (traditionally used to clean toilet and reduce odour in pit latrines in Nepal); and v) EM (effective microorganism, produced locally)

a) b)

Figure 11: a) 1st setup 10L bucket b) 2nd setup 210L drum

In order to apply a dosage, two experiments were done to define the optimum dosage for lime and soda. For other additives the producers' recommended dosages were applied. In the

A faecal sludge mixer was designed and manufactured locally (*See Figure 12*). The main objective of it is to mix the faecal sludge not only at the time to add the additive, but also on daily basis. The mixing condition was recommended on previous research done in Malawi under Emergency Sanitation Project.

Figure 12: Mixer for 210L container

Table 4: Additives' dosages applied in Nepal

No	Additive	Dose	
1	Caustic Soda	2.7%	Chemical additives
2	Lime	1.4%	
3	Urea	2%	
4	Phenol	1%	
5	EM	1%	Biological additives

3 FAECAL SLUDGE CHARACTERIZATION

The characterization of the black water and the faecal sludge used in the laboratory and field experiments respectively are shown in the Table 5.

Table 5: Black water and faecal sludge characteristics

Location		Lab UNESCO IHE Delft, Netherlands	Blantyre - Malawi		La Paz – Bolivia	Kathmandu Nepal
Parameter	**Units**	**Black water**	**FS1**	**FS2**	**Public toilet**	**Mobile public toilet**
Total COD	mg O_2/L	17,000 – 27,000	18,000 ± 1000	140,000 ± 15,000	1,124 ± 128	13,781 ± 2,869
Total solids	%	0.71 – 1.85	1.35	16.97	1.06	0.98
Volatile solids	as % of TS	57 – 77	65.91	71.36	62.73	55.21
NH4-N	mg N/L	1000	1370 ± 500	4700±200	800 ± 130	2,864 ± 532
pH		6.96 – 7.05	6.95 - 7.52	6.81-7.25	8.09 - 8.72	7.4 – 7.6
Temperature	ºC	17 - 21	21	21	6,9 - 10,9	14 – 18
E. Coli	cfu/100mL	2,44E+06 - 2,77E+09	5.80E+07	4.03E+07	4.07E+06	3.25E+06

As is indicated in the *Table 5*, the characteristics of faecal sludge tested at laboratory, Nepal and in Bolivia are highly diluted and they can be compared with faecal sludge from septic tanks (Koné and Strauss, 2004). In Malawi two types of sludge were tested, both are fresh sludge from public dry toilet. The first type was diluted due to emptying process, consequently the total solids concentration is low (1.35%), but for the second trial in Malawi the sludge has been emptied with very low amount of water, consequently the TS concentration is very high (16.97%).

On the other hand the amount of organic matter is high in all samples as volatile solids (as % of TS) is always around 60% or more.

The temperature indicates the variation of different climate conditions, for example in Malawi the samples have a temperature of 21 °C and in Bolivia the temperature is between 6.9 to 10.9 °C.

In terms of pathogen concentration the concentration is very high, all samples collected in different countries have *E. Coli* higher than 1E+03 (which is the limit established by WHO)

4.1 STABILIZATION OF BLACK WATER / FAECAL SLUDGE

The parameter evaluated on this research to establish the stability of treated sludge/ black water was VS/TS ratio. A stable sludge has VS/TS less than 60% and has achieved a volatile solids reduction ≥ 38%. VS/TS of stable sludge was obtained using the equation below:

$$VS_{stable\ sludge} \leq 0.62\ VS_{influent}\ (Achieve > 38\%\ Volatile\ solids\ reduction)$$

4.1.1 BLACK WATER STABILIZATION AT UNESCO IHE LABORATORY DELFT, NETHERLANDS

As it is shown in *Figure 13*, in the laboratory trials a considerable reduction of biodegradable solids have been achieved with the application of Ikati and soda in black water, reducing the volatile solids below the VS (as % of TS) recommended to consider stable sludge. The use of Biomax increases the concentration of volatile solids, and other additives also reduce the VS concentration but they cannot be considered stable sludge.

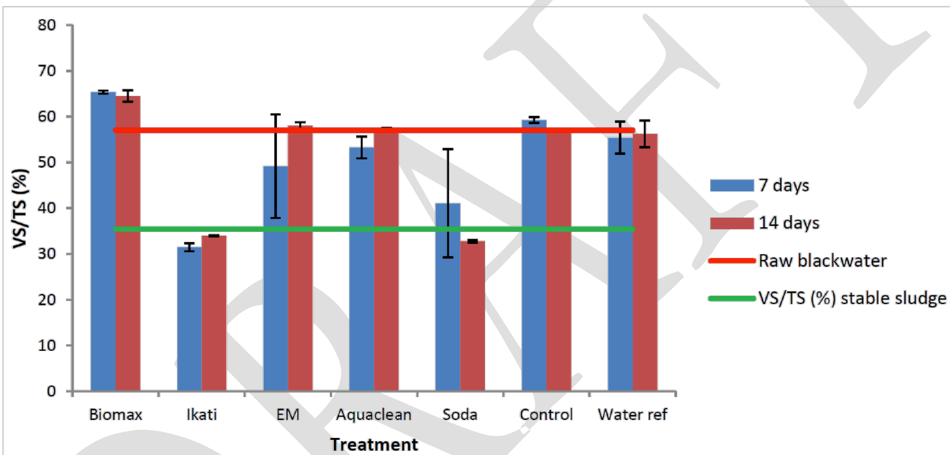


Figure 13: VS (as % of TS) of treated black water (Additive dosage 1.7% w/w or v/w)

4.1.2 FAECAL SLUDGE STABILIZATION IN BLANTYRE, MALAWI

Two trials have been tested in Malawi with different type of sludge (as described in faecal sludge characterisation), the first trial using the same dosage used in laboratory 1.7% but the second trial doubling the dosage to 3.4%. For each trial, two different experimental set-ups were implemented, using 2L and 50L containers respectively.

4.1.2.1 Trial 1: diluted Faecal sludge (TS = 1.35%). additive dosage 1.7%

The results for trial 1 in set-up of 2L containers are very similar to laboratory results, where Ikati and soda stabilized faecal sludge, other additives also reduce the biodegradable matter but not enough to consider stable sludge (*See Figure 14*).

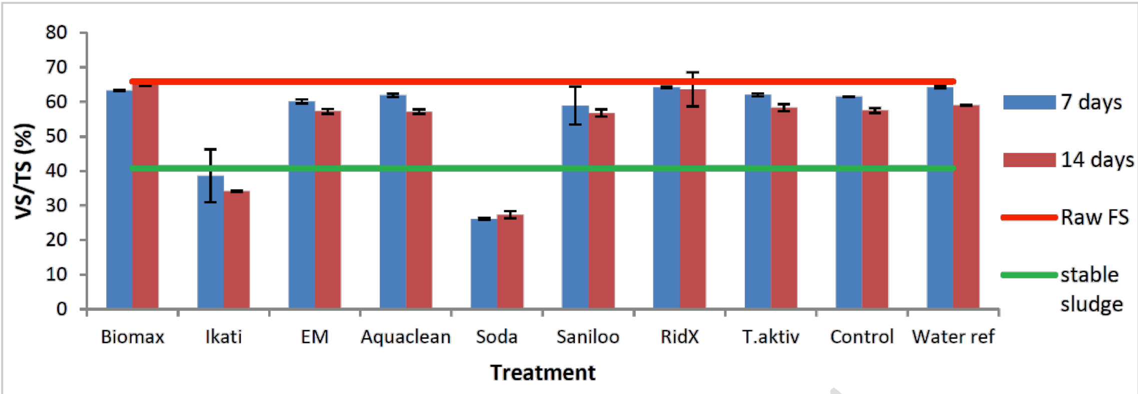


Figure 14: VS (as % of TS) of treated faecal sludge, trial 1(Additive dosage 1.7% w/w or v/w) 2L container

On the other hand, for set-up of 50L containers only three bio-additives were tested due to additives availability using 1.7% dose. O this set-up none of the additives achieved significant reduction to stabilize faecal sludge (*See Figure 15*)

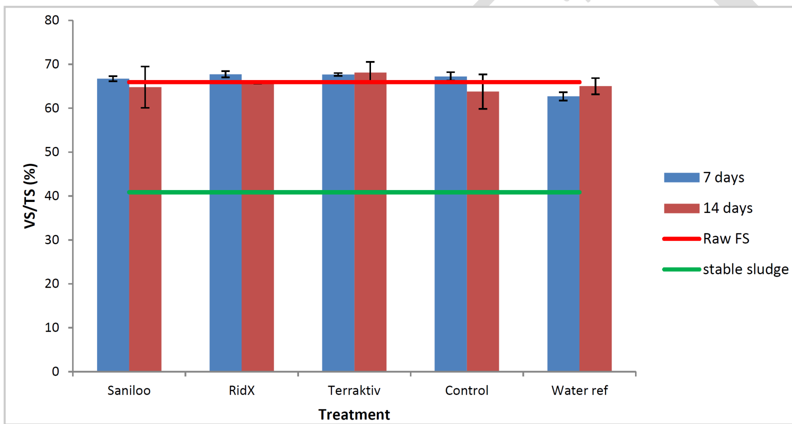


Figure 15: VS (as % of TS) of treated faecal sludge, trial 1(Additive dosage 1.7% w/w or v/w) 50L container

4.1.2.2 Trial 2: thick sludge (ts = 16.97%) in 50l containers. additive dosage 3.4%

The effectiveness of bio-additives to stabilize thick sludge (TS = 16.97%) is less than stabilizing black water or diluted faecal sludge. As it is shown in the *Figure 16* and *17* none of the additives applied in thick sludge were capable to stabilize it.

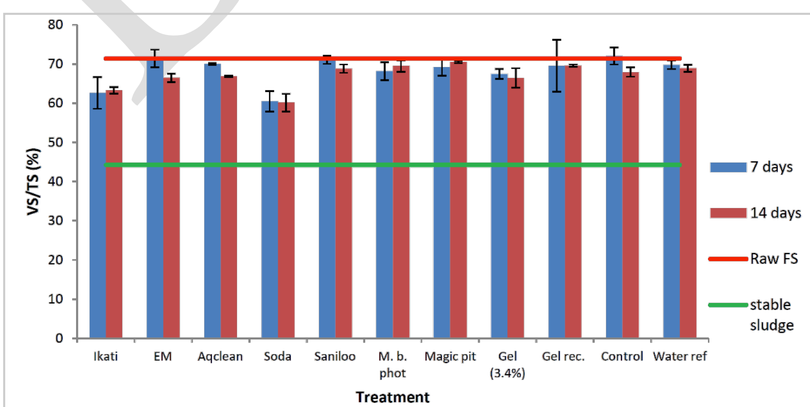


Figure 16: VS (as % of TS) of treated faecal sludge, trial 2(Additive dosage 3.4% w/w or v/w) 2L container

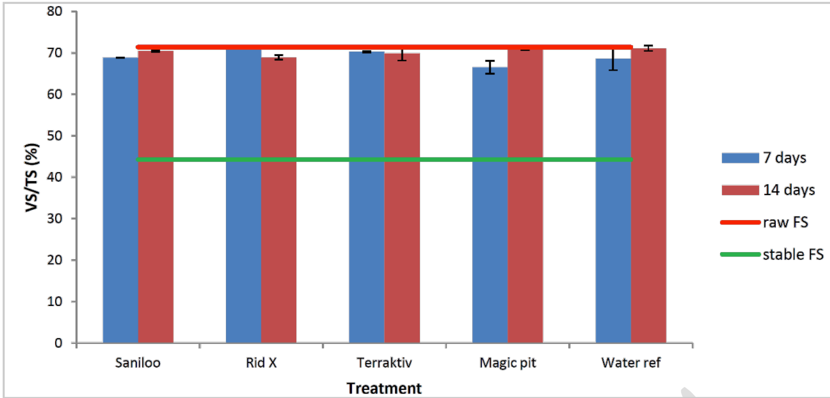


Figure 17: VS (as % of TS) of treated faecal sludge, trial 2(Additive dosage 3.4% w/w or v/w) 50L container

4.1.3 FAECAL SLUDGE STABILIZATION IN EL ALTO – LA PAZ, BOLIVIA

In the field testing in Bolivia, two dosages have been tested. For chemical additives (Soda, Ikati and Gel) low dose is 0.85% and high dose 3.4%. For biological additives (Magic Pit, Terraktiv and Saniloo) low and high dose are 2% and 5% respectively.

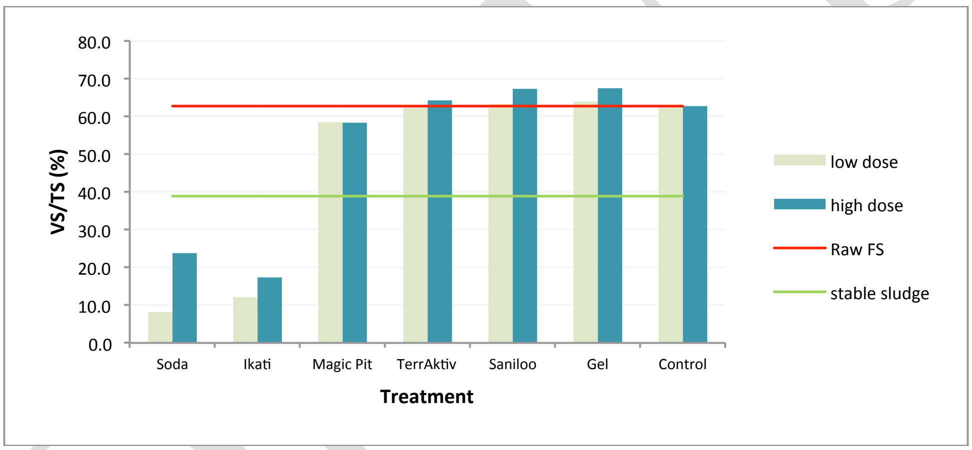


Figure 18: VS (as % of TS) of treated faecal sludge, 10L container

Like in the previous trials at IHE laboratory and Malawi, Soda and Ikati achieved a biodegradable matter reduction to VS (as% of TS) less than 38% (the limit to consider stable sludge), and other additives didn't present a considerable organic matter reduction to be considered stable.

4.1.4 FAECAL SLUDGE STABILIZATION IN KATHMANDU NEPAL

Two set ups were implemented in Nepal, the first simulating a bucket toilet in 10L plastic container and the second in 210L drum simulating a raised latrine designed for emergencies.

4.1.4.1 First set up – 10L bucket toilet

In the 10L bucket set up two conditions were tested, mixed and no mixed. The mixed and no mixed condition has a significant influence to stabilize faecal sludge using Lime, Soda and Urea, however in Phenol and EM it does not affect (See *Figure 19*). From the five additives tested under mixed condition four have stabilized the faecal sludge (Soda, Lime, Urea and EM). Under no mixed condition only EM was capable to stabilize the faecal sludge. Under both conditions Phenol was not capable to stabilize faecal sludge.

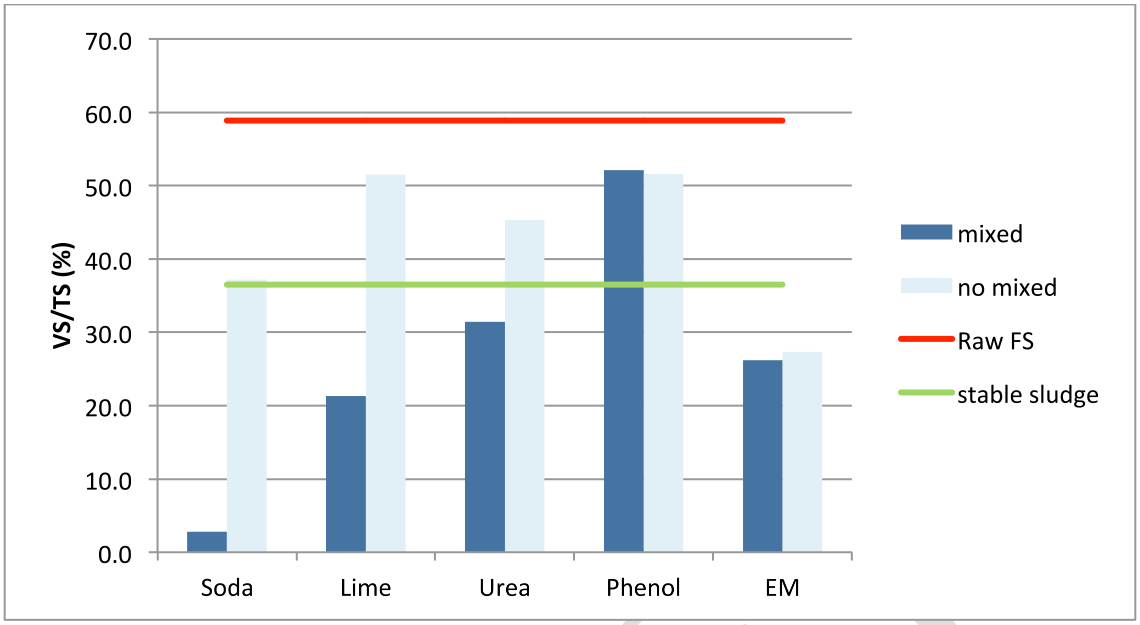


Figure 19: VS (as % of TS) of treated faecal sludge, 10L bucket toilet in Nepal

4.1.4.2 Second set up – 210L drum

In the second set up consisting on 210L drum (to simulate a raised toilet designed for emergencies) only Soda was capable to stabilize the faecal sludge. Although all the experimental units for the second set up were mixed, probably that the mixing condition was not enough to achieve the optimum efficiency regarding stabilization. (*See Figure 20*)

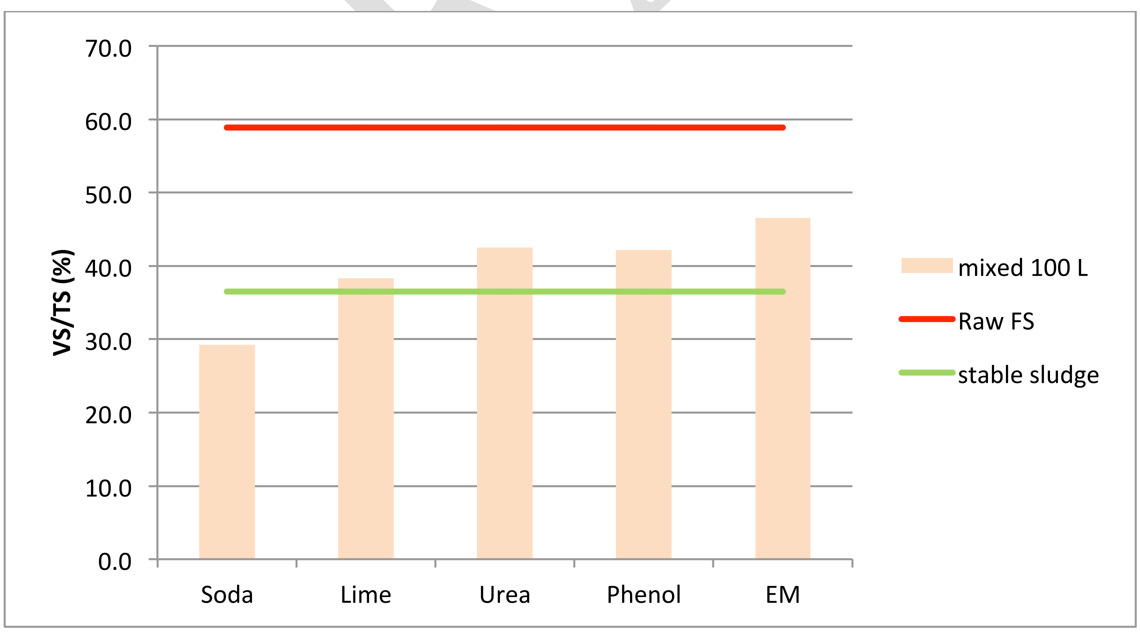


Figure 20: VS (as % of TS) of treated faecal sludge, 210 L drum in Nepal

4.2 SANITIZATION OF BLACK WATER / FAECAL SLUDGE

The concentrations of *E. coli* in treated black water was enumerated and compared to the WHO guideline value for restricted agriculture which is <1000 cfu faecal coliform/100ml (100g) of sample.

4.2.1 BLACK WATER SANITIZATION AT UNESCO IHE LABORATORY DELFT, NETHERLANDS

Better performance of Ikati and Soda is shown in *Figure 21*; it was attributed to the synergistic performance of higher pH and the concentration of carbonate. Other additives also reduce the *E. Coli* concentration, however they do not reach the limits established in WHO guidelines for re-use.

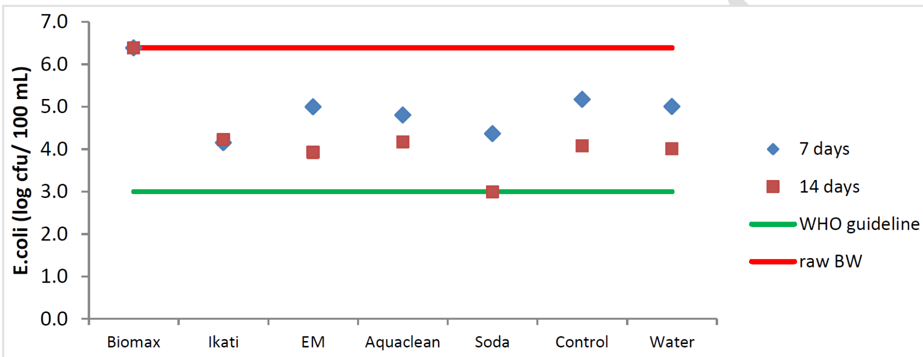


Figure 21: CFU of E. Coli in treated sludge at IHE laboratory

4.2.2 FAECAL SLUDGE SANITIZATION IN BLANTYRE, MALAWI

4.2.2.1 Trial 1: diluted Faecal sludge (TS = 1.35%). additive dosage 1.7%

In the set-up of 2L containers on general was observed that all additives achieved reduction in *E. Coli* concentrations between the two weeks of treatment for additives applied at 1.7% v/w or w/w. Due to few colonies observed after 1 week of treatment, the enumeration of colonies for Ikati and Soda in the second week is on an undiluted sample. Ikati, Soda and Saniloo recorded values under the detection limit as well as below the WHO standard for re-use in agriculture after 2 weeks.

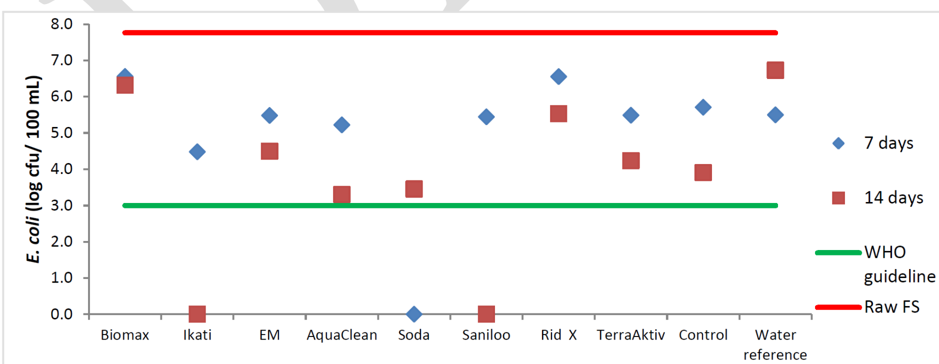


Figure 22: CFU of E. Coli in treated sludge, (additive dose 1.7%) 2 L containers

The additives tested in the second set-up using 50L containers also present *E. Coli* concentration reduction; however none of them are below the WHO guideline recommended limits for re-use in agriculture (*See Figure 23*).

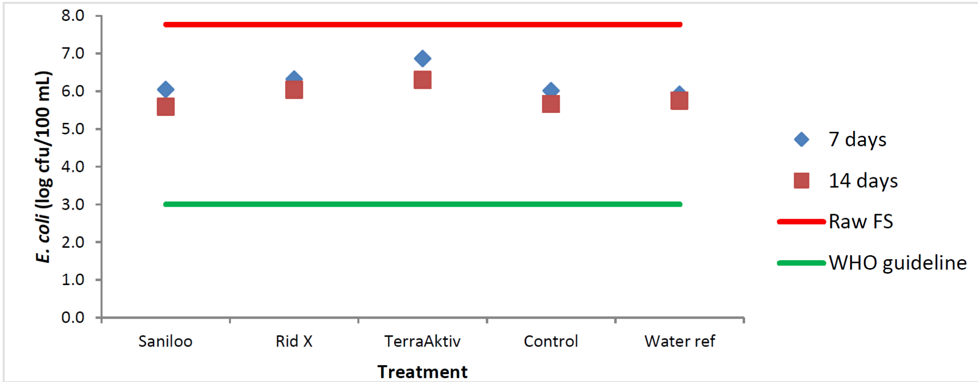


Figure 23: CFU of E. Coli in treated sludge, (additive dose 1.7%) 50 L containers

4.2.3 TRIAL 2: THICK FAECAL SLUDGE (TS = 16.97%). ADDITIVE DOSAGE 3.4%

The results of second trial applying additives on thick sludge (shown in *Figure 24*) indicate that Ikati and Soda have high efficiency to reduce the *E. Coli* concentration; other additives also are capable to reduce it, however not below the WHO guidelines recommendation.

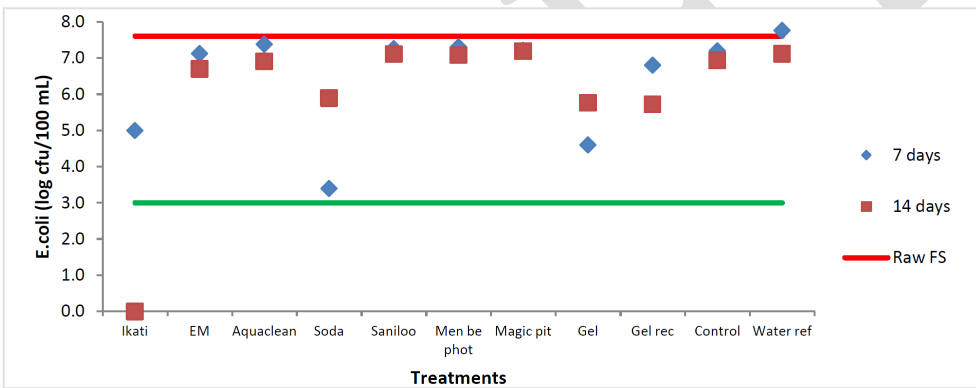


Figure 24: CFU of E. Coli in treated sludge, (additive dose 3.4%) 2 L containers

4.2.4 FAECAL SLUDGE SANITIZATION IN EL ALTO – LA PAZ, BOLIVIA

In 2 weeks treatment Soda and Ikati show a high potential to reduce the *E. Coli* concentration in faecal sludge below the limits recommended by WHO guidelines (*See Figure 25*). Although other additives also contribute to reduce the *E. Coli* concentration, they are not capable to reduce below the limits recommended by WHO.

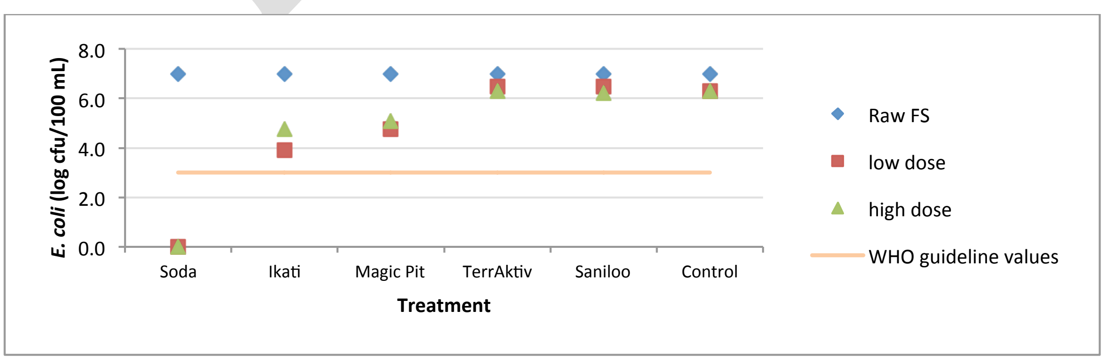


Figure 25: CFU of *E. Coli* in treated sludge, 10 L containers

4.2.5 FAECAL SLUDGE SANITIZATION IN KATHMANDU NEPAL

4.2.5.1 First set up – 10L bucket toilet

As it was mentioned before, mixed and no mixed conditions were tested in the 10L bucket toilet set up. From the five additives tested three were capable to reduce the pathogen concentration below the WHO guideline recommendation (Soda, Lime and Phenol). In the case of Soda and Phenol there is no difference between mixed and no mixed condition, however Lime is less effective when it is applied in no mixed condition. Although Urea and EM did not reduce the pathogen concentration below WHO recommendation both presented a significant reduction. (*See Figure 26*)

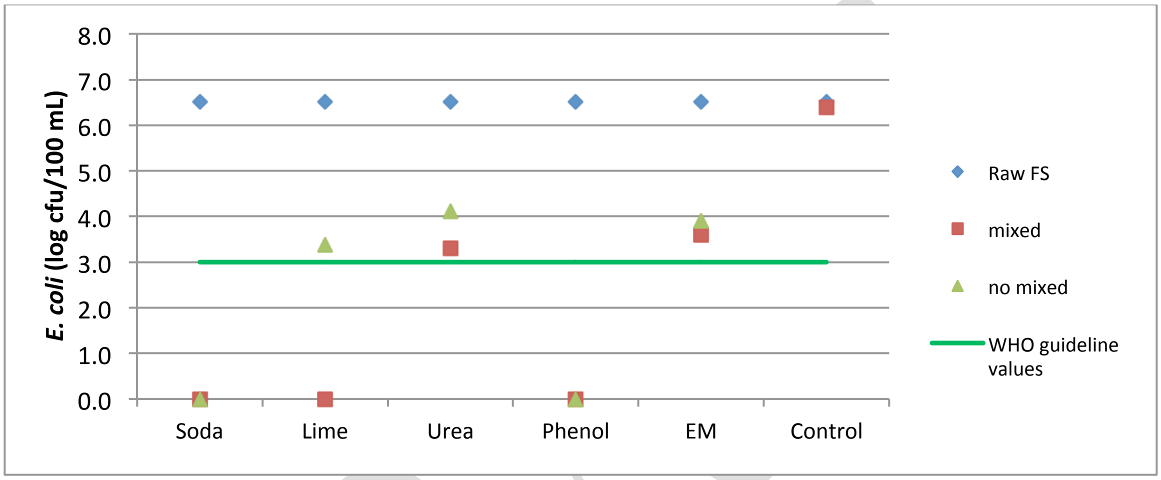
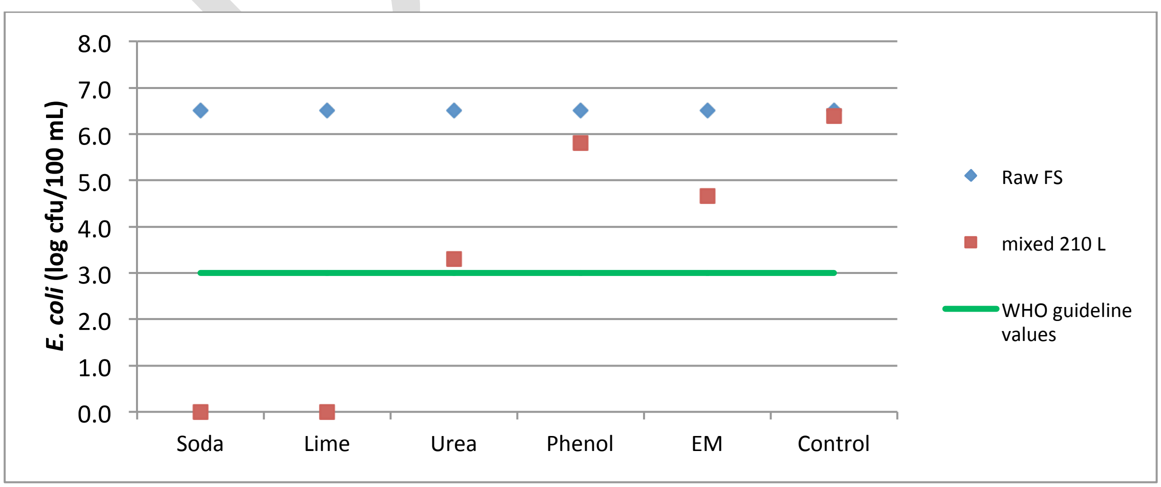


Figure 26: CFU of E. Coli in treated sludge, 10 L containers in Nepal

4.2.5.2 Second set up – 210L drum

In the second set up, from the five additives tested two (Lime and Soda) reduced the pathogen concentration below the detection limits, Urea has reduced significantly but not below the WHO recommendation limits. Phenol and EM also reduced the pathogen concentration but not below the WHO recommendation limits.



5 CONCLUSIONS

This study characterized black water and faecal sludge from four countries; Netherlands, Malawi, Bolivia and Nepal, and determined the efficacy of 5 additives at lab scale and 13 additives in the field to rapidly stabilize and sanitize faecal sludge with the aim of applying it in emergencies. 3 field trials were run in Malawi, Bolivia and Nepal applying different dosages. The stability was evaluated against attaining volatile solids reduction (VSR) whereas the sanitization was evaluated against WHO guideline value for restricted irrigation.

From this study, the following conclusions can be drawn:

a. Rapid stabilization and sanitization of faecal sludge is most likely to be achieved using chemical additives as indicated by Ikati, Soda, Urea and Lime.
b. Bio-additives did not increase the rate of stabilisation and sanitisation for the treatment period studied as was found by previous studies with other additives (Buckley et al., 2008; Foxon et al., 2008), however a locally produced EM (effective microorganism) in Nepal was capable to stabilize the faecal sludge between two weeks, additionally the mixing or no mixing condition does not have an effect on its performance.
c. Significant reduction in concentrations of E. coli was observed in FS treated with additives of chemical origin - Ikati, Soda, Lime and Urea.
d. There is no significant difference in faecal sludge treated with Ikati, Soda, Lime and Urea with the rest of the additives and controls in terms of pathogen reduction. The choice between them should be based on other factors such as treatment period and costs.
e. The die-off of faecal coliform in black water/ faecal sludge treated using Ikati and Soda was likely caused by the carbonate ion. The dosages should be increased if a shorter treatment time is desired (Arthurs et al., 2001; Diez-Gonzalez et al., 2000; Jarvis et al., 2001; Park and Diez-Gonzalez, 2003).
f. From the biological additives tested only EM locally produced in Nepal performed successfully stabilizing the faecal sludge and reducing significantly the pathogen concentration (although not below the WHO recommended limit). It indicates that biological additives may be effective when they are working under the climate conditions where they are produced. For emergencies biological additives may not be very effective unless they are produced in the place where the emergency happened.
g. As it was already identified in previous studies done by WASTE the mixing condition using chemical additives like Lime, Soda and Urea has a significant influence in the performance. Especially when applying the additives at large volumes of faecal sludge (>100L) it is very important to mix properly to assure the effect of sanitization and stabilization of faecal matter.
h. At small scale (simulating bucket toilet) the mixing also is very important, however to mix low volume of faecal sludge is easier than large volumes.
i. In order to continue with the second phase of this research, it is recommended to design a device to mix and add the recommended dosages of effective additives, putting more attention in the mixing conditions for large volumes of faecal sludge.

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