IFA-Tulln

Institute for Environmental Biotechnology

MicrobialSludgeQuality - Project

Report: Field trail in Blantyre, Malawi

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1. Aim of the field trail

The aim of the field trial was to test the prototype of the field lab, developed in the first part of the project, under conditions as close to those found in urban emergency settings. The testing should include on one side the monitoring of different faecal sludge or wastewater treatment plants and on the other side an assessment of the operational state of the prototype.

The involvement of Waste in the project allowed the field trial to take place in Blantyre, Malawi in Waste, Malawi's office. Blantyre was deemed to be a good location for the field trial. Due to several recent and ongoing sanitation projects, Waste, Malawi is very well connected to the Blantyre City council and its faecal sludge and wastewater treatment plants. While Malawi is considered a safe country, with Blantyre boasting good infrastructure, some water and power shortages are common, simulating some of the conditions of emergency settings.

Austrian Red Cross and Waste connected the project to the Polytechnic, University of Malawi. During the planning of the field trial, the inclusion of a reference lab was deemed to be important to counter check the field labs results. Due to several technical and organisational problems, the reference lab only could analyse few samples during the field trial.

2. Lab set up & operation

The prototype was handed over to the logistics department of the Austrian Red Cross. Transport to the office of Waste, Malawi in Blantyre was organised before the field trail. The prototype safely arrived in Malawi approximately two weeks ahead of the team. Due to the cost – effect ratio of different transporting dangerous goods (e.g. butane gas bottles, technical alcohol), some parts of the field lab were bought in Blantyre.

Before even the prototype arrived in Malawi, the field lab space was prepared by Waste (Figure 1). The lab was set into the garage of the office building. To prepare the space, the earthen floor was concreted, electrical outlets and a water tab were installed. The lab space also included a storage room.

The entrance to the lab was marked with signs to indicated "restricted accesses", "lab space" and "possible biohazard". The main lab space, the garage of the Waste office, was split in a "dirty" and a "clean" side (Figure 1). The "clean" side was used as office for the lab. All lab work was conducted in the "dirty" side to reduce the risk of contamination of personal equipment and street clothing. All contaminated waste streams were either when possible autoclaved (temperature restrictions of plastics), rubbed or sprayed with alcohol or chlorine and afterwards safely disposed.

During the field trial in August, winter in Malawi, due to the dry weather power and water cuts were common. As these situations are also common in emergency situations, equipment was included into the field lab to cope with them.

Combined with water shortages also the tab water quality was problematic. While chlorination is a standard water treatment technology, it cannot be used for the lab. Residual chlorine in the water could disturb bacteriological analysis. Therefore, an ultrafiltration membrane treatment system was included in the field lab. To counter the water shortages several foldable water canisters always kept filled. The water quality was regularly checked by the lab.

In Malawi black outs are quite common, especially during the dryer winter weather. Most of electricity in Malawi is generated by hydroelectric dams. Some parts of the field lab, e.g. incubators, need constant power supply. Two car batteries were used as uninterruptable power sources. To recharge both batteries a solar panel combined with a wind turbine were used. The solar panel was first used alone on the ground until both systems were installed on the roof of the office (Figure 2).

Figure 1: Impressions from the field lab, a) Empty lab space, b) Clean & dirty side of the lab

Figure 2: Recharge of batteries a) solar panel on the ground; b) solar panel and wind turbine installed on the roof of the Waste office building

3. Training of lab staff

While the MSQ-project only focuses on the development of hardware, early on in the project the importance of estimating the training need for field lab operators was discussed. The field trail in Malawi offered a good chance get first-hand knowledge on the actual training requirements. During the field trial, two people were trained to operate the field lab.

For the Austrian Red Cross a member of the WASH Emergency Response Unit joint the lab in Blantyre. He had just finished his master internship in the lab of a well-regarded European university in the area of environmental science. His previous experience in academic lab work and operation of water field labs, allowed for a short training period, only needing to touch up on some changed and new analytical methods. The practical training amounted to setting up the field lab and about one week in the lab. After this time, he was qualified to manage the whole lab and supervise lab techs.

At the end of the second week, a lab tech was hired by Waste, Malawi to support the team (Boku & AutRC) and to continue the work after the end of the field trail. He had received a bachelor's degree in environmental science from the Polytechnic, University of Malawi.

While, he had acquired some lab experience during his academic education and another internships, the breadth and scope of the field lab required additional training during the field trail. The remaining two weeks of the field trail were spent to administer practical training and to refine the analytical methods.

This intensive hands-on approach allowed the lab tech to operate the lab under supervision. However, placing the responsibility of managing the whole lab on a lab tech with such a short training period can be considered impractical.

Training both members of the field trial team, was a great experience and proved the high importance of qualified personal and efficient training for the operation of such a field lab. While the operation of the lab can be taught in a hands-on approach, if needed even directly in the field, managing the lab requires extensive beforehand training or professional experience.

4. Treatment plants

The field lab was originally intended to operate as public health and process monitoring attached to a single faecal sludge treatment plant. However, during the field trail in Blantyre the lab was used to assess the efficiency of several different treatment plants in the vicinity of the city. This arrangement offered the possibility to sample different sample matrixes (e.g. faecal sludge, wastewater).

During the field trail, five different plants were sampled. Focus in sampling was set on characterizing influent and effluents of these plants to estimate the treatment efficiency. In Blantyre, two wastewater treatment plants and an official dumpsite are operated by the city council. All three plants were sampled at least twice. Waste, Malawi was involved in the construction and start-up of two other faecal sludge treatment plant in Malawi. While, these two plants were located outside of Blantyre, due to them treating faecal sludge instead of wastewater they were of high interest.

For the field trail equipment for all parameters used

During the start of the field trial, faecal sludge and wastewater samples were analysed for helminths. In general, no Ascaris eggs were found in the samples. Further inquires, with the Waste, Malawi and the University of Malawi indicated that in Malawi regularly successful deworming campaigns are performed. Thus, the number of helminth eggs analyses were reduced and the results are not displayed.

4.1. Limbe dumpsite

The Limbe dumpsite is part of a larger lagoon-style plant (Figure 3), which is not operational due to technical problems. The dumpsite only uses the first anaerobic lagoon. Normally a lagoon plant uses three different lagoon types (Figure 4). Faecal sludge is dumped over the bank from the roadside into the lagoon (Figure 5 – a)), the planned influent pipe (Figure 5 – b)) is not operational.

Samples were taken in the influent area and diagonally across the lagoon in the vicinity of the effluent structure (Figure 5 – c)).

The dumpsite was only sampled once during the field trial. The analytical results are shown in Table 1.

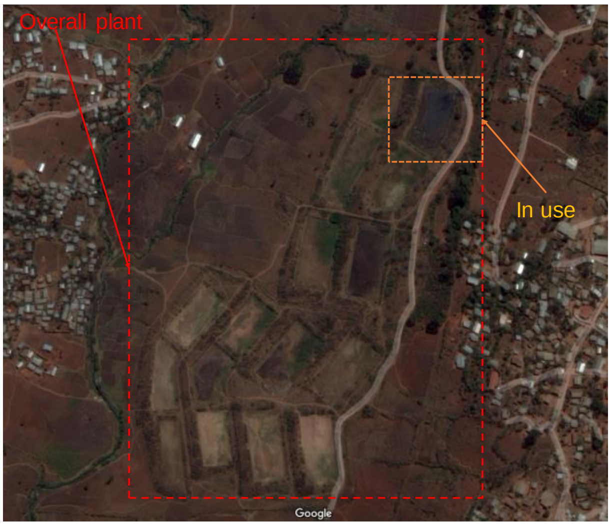

Figure 3: Satellite view of the Limbe dumpsite (©Google Maps)

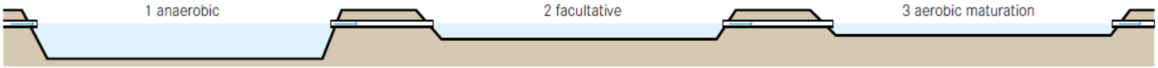

Figure 4: Scheme of a lagoon type plant. (Tilley *et al.*, 2014)

Figure 5: Limbe dumpsite a) dumping slope, b) view over the dumpsite, c) outflow structure (Pictures by Johannes Bousek)

Table 1: Results from the Lime dumpsite sampling

17.08.2017	e-Coli (CFU/ml)	Enterococcus (CFU/ml)	Salmonella (CFU/ml)	pH	COD (g O2/l)	Total solids (g/kg)	Ammonia (mg/l)
Influent	1.00E+06	3.00E+05	1.00E+05	7.10	2.18	27.60	54.00
Effluent	3.00E+05	3.00E+05	4.00E+04	7.50	1.29	4.80	8.00
	e-coli (log reduction)	enterococcus (log reduction)	Salmonella (log reduction)			COD (% reduction)	Total solids (% reduction)
Reduction	0.52	0.00	0.40		41%	83%	85%

4.2. Manase wastewater treatment plant

The Manase wastewater treatment plant (WWTP) was built during the 1950ies and refurbished in the late 1970ies.This plant only treats wastewater. The original plant consisted of a series of settlings tanks, trickling filters, polishing ponds for wastewater and open sludge digesters and drying beds for sludge treatment (Figure 6). Due to technical and maintenance problems the plant became inoperational and only the polishing ponds are currently in use. The first two ponds are used as a mixture of anaerobic and facultative lagoon, while the last pond is a kind of free water surface constructed wetland (Figure 7). The effluent of the plant is discharged into a small river. The Manase wastewater treatment plant was sampled three times during the field trail and its extension. The results and the treatment efficiency are shown in Table 2 andTable 3.

Figure 6: Satellite view of Manase wastewater treatment plant (©Google Maps)

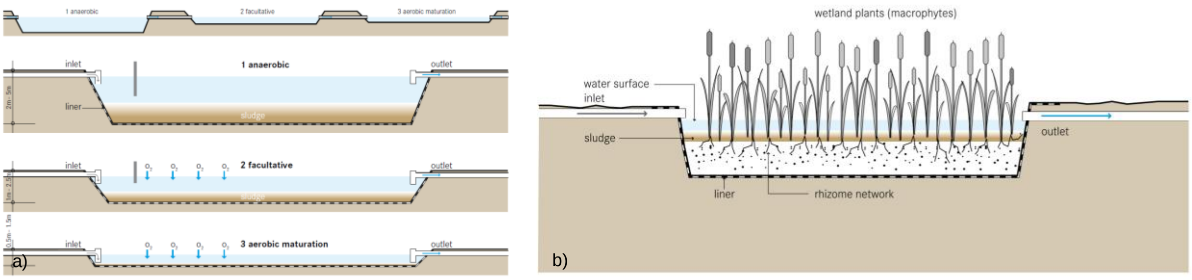

Figure 7: Scheme of a) lagoon style wastewater treatment plant and b) free water surface constructed wetland (Tilley *et al.*, 2014)

Figure 8: Impression from the Manase WWTP, a) Influent 1st lagoon, b) surface aerator (not operational), c) aerated lagoon, d) effluent structure (Pictures by Johannes Bousek)

Table 2: Analytical results from the Manase WWTP samples

Influent	e-Coli (CFU/ml)	Enterococcus (CFU/ml)	Salmonella (CFU/ml)	pH	COD (g O2/l)	Total solids (g/kg)	Ammonia (mg/l)
21.08.2017	2.00E+05	1.00E+05	8.00E+03	6.9	1.36		16
31.08.2017	1.67E+04	2.00E+04		8.4	1.69		19
25.10.2017				7.5	1.64	0.5	
Effluent							
21.08.2017	4.00E+05	2.00E+03	1.00E+04	7.5	0.21		17.5
31.08.2017	2.00E+04		4.00E+02	7.5	0.16		27.5
25.10.2017				7.2	0.22	0.02	

Table 3: Manase wwtp treatment efficiency

Reduction	e-Coli (log reduction)	Enterococcus (log reduction)	Salmonella (log reduction)	COD (% reduction)	Total solids (% reduction)
21.08.2017	-0.30	1.70	-0.10	85%	
31.08.2017	-0.08			91%	
25.10.2017				87%	96%

4.3. Soche wastewater treatment plant

The Soche wastewater treatment plant (Figure 9) treats wastewater and faecal sludge. Similar to the Manase wastewater treatment plant, the Soche plant was also built during the 1950ies. The treatment cascade consists of a bar screen (Figure 10 – a)) primary settling tanks, trickling filters (Figure 10 – b)), secondary settling tanks and an effluent sand filter (Figure 10 – c)). The effluent should be discharged into a small river; however, it is normally used for crop irrigation.

The plant was sampled three times. The results are shown in Table 4 andTable 5.

Figure 9: Satellite view of Soche WWTP (©Google Maps)

Figure 10: Impressions from Soche WWTP, a) Bar screen, b) Trickling filter, c) Effluent sand filter, d) Effluent stream (Pictures by Johannes Bousek)

Table 4: Analytical results of the Soche samples

Influent	e-Coli (CFU/ml)	Enterococcus (CFU/ml)	Salmonella (CFU/ml)	pH	COD (g O2/l)	Total solids (g/kg)	Ammonia (mg/l)
17.08.2017	1.05E+04	8.00E+04	2.00E+04	7	0.61		25
24.08.2017				7.2	0.74	0.15	13
13.09.2017	1.53E+04		8.50E+03	7.2	0.86	0.2	25
Effluent							
17.08.2017	6.50E+02	1.00E+03	1.00E+03	7.5	0.17	1	24

24.08.2017	1.53E+04		8.50E+03	7.2	0.13	0.2	18.3
13.09.2017	2.02E+04		2.02E+04	8.1	0.13	0.02	20.5
Sludge							
17.08.2017	1.00E+04	4.00E+05	2.00E+06		6.87	353	

Table 5: Soche WWTP treatment efficiency

Reduction	e-Coli (log reduction)	Enterococcus (log reduction)	Salmonella (log reduction)	COD (% reduction)	Total solids (% reduction)
17.08.2017	1.21	1.90	1.30	72%	
24.08.2017				82%	-33%
13.09.2017	-0.12		-0.38	85%	90%

4.4. Namisu Flexigester

The Namisu flexigester is a tubular biogas plant (Figure 11 – a)) installed at the school of a children's village. The plant treats the faecal sludge collected in the latrines. The biogas is used for cooking. To increase biogas production and to sustain the biogas reactor during summer vacation cow dung is used as co-substrate. The digestate, effluent of the biogas plant, is let onto composted piles for further biological treatment and drying. The plant was sampled twice. The first sample was taken during the field trail in August. Due to Malawian school vacation in August the plant treated only a small quantity of faecal sludge. The flexigester was sampled later on during school time in the extended lab activities. The results are shown in Table 6 Table 7.

Figure 11: a) Flexigester at the Namisu Children's Village ; b) compost heap used for digestate drying (Pictures by Christopher Friedrich)

Table 6: Analytical results of the Namiso anaerobic digester

Influent	e-Coli (CFU/ml)	Enterococcus (CFU/ml)	Salmonella (CFU/ml)	pH	COD (g O2/l)	Ammonia (mg/l)
16.08.2017	1.00E+07	2.00E+06	5.00E+05	8.6	14.6	280
03.10.2017	6.88E+05	6.98E+04	1.12E+06	8.3	2.09	400
Effluent						
16.08.2017		2.00E+04	3.00E+05	7.9	1.48	650

03.10.2017	7.33E+03	2.33E+06	4.67E+05	7.5	0.6

Table 7: Namisu AD treatment efficiency

Reduction	e-Coli (log reduction)	Enterococcus (log reduction)	Salmonella (log reduction)	COD (% reduction)
16.08.2017		2.00	0.22	90%
03.10.2017	1.97	-1.52	0.38	70%

4.5. Mangochi Anaerobic baffled reactor

The faecal sludge of several latrine stalls at the public market of Mangochi is treated by an anaerobic baffled reactor (ABR). In an ABR the total reactor volume is separated into several connected compartments. As can be seen in Figure 12 the chamber of an ABR also functions as settling tanks. In each chamber the influent sludge sinks to the bottom and the cleared effluent flows into the next compartment. The effluent from the final chamber, leaves the ABR and is infiltrated into the ground through a soak pit.

The results from both sampling points are shown in Table 8Table 9.

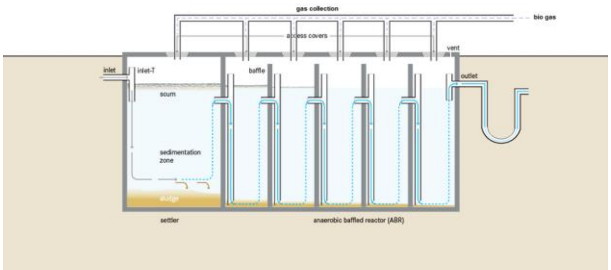

Figure 12: Scheme of an anaerobic baffled reactor (Tilley *et al.*, 2014)

Table 8: Analytical results of the Mangochi samples

Influent	e-Coli (CFU/ml)	Enterococcus (CFU/ml)	Salmonella (CFU/ml)	pH	COD (g O2/l)	Total solids (g/kg)	Ammonia (mg/l)
27.08.2017	7.29E+05	3.00E+06	3.00E+04	7.50	13.90	1.55	
17.09.2017	2.04E+06	1.30E+06	2.03E+05	7.20	11.50	4.63	180.00
Effluent							
27.08.2017	8.67E+04	2.00E+05	3.00E+06	7.30	0.53	0.02	
17.09.2017	1.79E+05	2.84E+06	3.28E+04	7.50	0.52	0.40	400.00

Table 9: Mangochi ABR treatment efficiency

Reduction	e-Coli (log reduction)	Enterococcus (log reduction)	Salmonella (log reduction)	COD (% reduction)	Total solids (% reduction)
27.08.2017	0.92	1.18	-2.00	96%	99%
17.09.2017	1.06	-0.34	0.79	95%	91%

5. Helminth detection workshop

A half-day workshop on helminth egg detection using MiniFlotac and FillFlotac was held at the College of Medicine, University of Malawi in Blantyre during the field trial in Malawi. The laboratory of the College of Medicine was used as reference lab for Helminth egg analysis for specific samples. The lab staff expressed their interest in the analytical technique used by the field lab.

The workshop was attended by laboratory staff of the College of Medicine and the Polytechnic and covered the following topics

- Introduction to the Flotac family
- Practical demonstration of the equipment
- Practical comparison of the field method and the fixed lab method

Mini and FillFlotac were received with a lot of interest by the participants. Especially, the handling and readability of the MiniFlotac discs were well regarded.

The College of Medicine was highly interested in the original usage of the Foltac family. Fill- & MiniFlotac might offer them an easy method for analysing stool samples directly in the field.

Figure 13: Impression from the workshop (Pictures by Elizabeth Tilley)

6. Discussion

6.1. Analytical methods & results

➢ Bacteriological testing

The public health monitoring methods are more complex, time consuming and prone to mistakes compared to process control methodology. Along with monitoring treatment plants and testing equipment, the field trial was also used as training opportunity. Since training and routine analytics were intermingled training mistakes in bacteriological testing were made.

regular samples

A general problem, already observed during the laboratory development phase and described in literature is the heterogeneity of wastewater and faecal sludge. When this fact is combined with the time delay between influent and effluent of a treatment plant (hydraulic retention time), the interpretation of results becomes quite complicated.

As already discussed, the colony counting of e .coli is problematic. During the field trial, Endo Nutrient Pad Sets (NPS) were used. One of the improvements gathered was switching from Endo NPS to Chromophoric NPS.

The methodological difficulties can be overcome by sufficient training and multiple samples/analysis of a plant.

Membrane filtration was selected for the bacteriological testing. This method is described in several standard textbooks for the analysis of wastewater (e.g. Apha et al., 1999) and is widely used by humanitarian aid organisations in water quality testing. The prototype development phase and as well as the field trial proved that the chosen methodology, while being adapted from industry standards, is complicated and requires trained personal.

During the field trial a search for easier bacteriological testing methods were started. While promising candidates (e.g. IDEXX Colilert, Aquagenx Compartment bag tests) were found, none of them were applicable for the field lab without a lengthy adaptation process.

Therefore, in future iterations of the field lab the bacteriological methodology might undergo changes to be easier to handle and cheaper to operate.

- Helminth egg detection

Due to effective deworming campaigns, no helminth eggs were found in the first taken samples during the field trial. Helminth egg tests were stopped altogether, because of the low chance of positive samples and high time demand for a single analysis.

- Total solids determination

The field lab was designed with faecal sludge treatment in mind. Faecal sludge often has quite a high total solids content (in the range of several percent, Strande et al., 2014). Thus, before the field trial, the method for total solids determination was designed for faecal sludge.

An adaption of this method was developed in the field during the test. Therefore, no total solids results for low solids samples (wastewater, settled effluent of anaerobic digesters) from early dates are available.

6.2. Treatment plants

The aim of the field lab is the monitoring of treatment plants. Effective monitoring of treatment plants requires regular and often sampling, especially if the plant is characterised for the first time.

However, the limited time of the field trial, the detached location of the lab and field training of lab staff led to a low sample number. Thus, only analytical snap shots were taken of each plant. Due to changing wastewater composition (e.g. daily volumetric flow variation, inflow of faecal sludge) and the hydraulic retention/treatment time within the plant the sampled influent does not correspond to the effluent of the same time. If treatment plants are continuously monitored this time difference does not make much of a difference. If, however, only a few samples are taken a qualitative characterisation of a plant becomes hard.

- Wastewater treatment plants

Both sampled wastewater treatment plants (Manase & Soche) had good COD reduction. On average a COD reduction of 88% and 80% respectively was reached. For both plants the reduction is in line with results reported by literature (U.S. EPA, 2000).

The analysed samples for both treatment plants showed no nitrogen reduction. The Soche wastewater treatment plant was constructed in the 1950ies and only one of the two trickling filters is operational.

Trickling filters built in this time were only designed for COD reduction, not for ammonia oxidation. Manase WWTP was originally built as a trickling filter plant, but functions today as a lagoon plant. In a lagoon plant ammonia oxidation and evaporation is possible, but it was not observed. The lagoons at Manase were originally designed as polishing ponds after the trickling filters. They were never thought to treat raw wastewater. In the case of the Manase WWTP seeing high COD removal with repurposed polishing pools is quite impressive.

As discussed above no total solids data was available for the plant due to analytical methods designed for faecal sludge.

A reduction of faecal indicator organisms of approximately 40% by trickling filters is reported by literature (Cheremisinoff, 2002). The results gathered throughout the field trial are inconsistent and were not reproducible by repeated sampling. As already discussed, the most probable reason are mistakes made during the lab operation.

- Anaerobic digestion

Two anaerobic digesters and an anaerobic lagoon were sampled during the field trial. While each of the plants was differently constructed the underlying treatment process, digestion of organic matter without the presence of oxygen, is the same.

The Namisu flexigester displayed an unusual high COD reduction (90%) for an AD plant of this design (normally between 50-70%, Amani et al., 2010; Braun, 1982) at the first sampling point. At the time the plant was not in use, due to the plant treating the faecal sludge of a school and vacation period at the time (3-5 users per day instead of 150). Therefore, the treatment time was longer than expected and the low inflow led to a sedimentation effect, which normally does not happen with this reactor design. The second sampling date was set during school time. The COD reduction (70%) observed than was in the expected range.

The Mangochi anaerobic baffled reactor (ABR) displayed at both sampling points a high COD reduction. For maintstream anaerobic digestion COD reduction in this range is considered highly unusual. However, ABR relies heavily on settling effects, which also remove COD (bound in organics) from the liquid effluent. Literature also reports COD reduction in a similar range (Tilley *et al.*, 2014).

The Limbe dumping site is an uncovered anaerobic lagoon. The biogas produced by the digestion of faecal sludge is emitted in the environment. The measured COD reduction was with 43% higher than expected in a dysfunctional lagoon.

As was expected the effluent of both anaerobic digesters showed an increase in ammonia compared to the influent. Urea and nitrogen containing organic matter is digested to ammonia. The lower ammonia concentration of the effluent sample from the dumpsite resulted in the evaporation of ammonia from the sludge.

Microbiological results were similarly inconsistent as the results from the aerobic treatment.

6.3. Reference lab

The field trail was aimed at proving the functionality of the prototype of the field lab under simulated-mission conditions. Also, checking the analytical accuracy of the field lab in field conditions was also an important part of the trial. For the purpose of monitoring the field lab, a cooperation between the University of Malawi and Waste, Malawi was started. The labs of the Polytechnic (chemical and physical parameters) and the College of Medicine (public health parameters) were used. To reduce the additional load on both labs, it was decided only to submit influent and effluent samples.

However, the cooperation was far from smooth. Several delays with the reference lab allowed the first samples to be handed over in the third week of the field trial. The results from the first samples, influent and effluent of Manase wastewater treatment plant instilled doubts in labs accuracy.

7. Outcomes

7.1. Improvements

The operation of the field lab in Malawi for one month let to a list of improvements. Especially the input from Austrian Red Cross ERU volunteer, Christopher Friedrich, were highly valuable due to his previous experience in the operation of a field lab and a fresh perspective on the topic. After the field trial, this list was evaluated and implemented in the data transferred to Butyl Products for the development of the product.

At the end of the project it was discussed to start a continuous improvement process. Which should allow the inclusion of and search for further improvements in the future. How this process will look like has not yet been defined. However, a follow-up diffusion project has been proposed to HIF by parts of the original project consortium (Austrian Red Cross and Butyl Products Ltd.). If granted, this project will also deal with including further improvements.

7.2. Staff needs

The staff needs of the field lab strongly depend on several different factors:

- The number of samples (public health, process control) to be analysed per week. The broad range of different parameters and some of the more labour intensive analytical field methods, makes analysing a single sample time intensive.
- The location of the lab and the distance to the monitored treatment plant.
- Training level and experience of the lab team.

During the field trial, the lab team consisted of up to three people. From experience gained during the prototype development in the lab and the pre-field trial it was estimated that two sampling rounds (each including two of Blantyre's treatment plants) could be done per week (in total 4 treatment plants/week). The field trial showed that this estimation was optimistic. The need to train lab techs slowed lab work. During the field trial between 2-3 treatment plants were sampled per week.

Table 10 shows an estimated time need per sample based on the experience gathered in Malawi. This estimate does not scale linear. However, analysing 4 samples per day in either process control or public health monitoring seems to be the maximum.

Table 10: Estimation of time need per sample

Task	Working days per sample	Working days per 4 sample
Sampling	0.25	0.5
Bacteriological analysis	0.5	1
Helminth egg analysis	0.5	1
Process control	0.5	1
Data management	0.25	0.5
Total working days per sample	2	4

7.3. Training estimations

The experience of the field trail in Malawi led to the following estimations for field training requirements.

- Lab tech 1-2 weeks

- Layman 1-2 months

With these training times lab techs should be able to operate the field lab (analytical methods and support equipment). However, training staff directly in the field has certain disadvantages, which will adversely influence the operation of lab. To list few points, lab work takes longer and more analytical mistakes are made. In the case of the field trial in Malawi the lab was not attached to a single faecal sludge treatment plant. Sampling a single treatment plant took approximately a half day. Thus, plants were only sampled a few times during the field trial. Losing sample information due to training mistakes is therefore especially painful.

If lab staff is trained in "peace time" training periods can be intensified, shortened and lab operation in the field is smoother.

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