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SUSTAINABLE WATER AND SANITATION SERVICES
FOR ALL IN A FAST CHANGING WORLD

Household-level application of hydrated lime for on-site treatment and agricultural use of latrine sludge

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BRIEFING PAPER

Rural areas of Cambodia have no safe waste management strategies for household latrine waste. Household application of lime (calcium hydroxide, $Ca(OH)_2$) would enable households to treat waste easily on-site and significantly reduce the risk of latrine sludge causing negative impacts on human health and the environment, whilst transforming latrines into incubators of a valuable agricultural additive. Initial investigative work – including human centered design research, supply chain analysis and bench scale laboratory tests – have demonstrated that lime treatment of sludge has potential to provide a sustainable and effective solution to closing the sanitation loop in rural Cambodia, with promising application for urban environments as well.

Background

Poor water, sanitation, and hygiene practices (WASH) are a major cause of diarrheal diseases, which are the leading cause of sickness and death amongst children in Cambodia. Access to basic and improved sanitation is increasing in Cambodia, but latrine pits are filling up. Although some advanced solutions exist, they are not appropriate for poor, rural households, who constitute 80% of Cambodia's population and 48% of the world population. As a result, the waste accrued is often ignored or disposed of unsafely, jeopardizing the health benefits that an improved, waste-segregating toilet offers.

Why lime?

Chemically stabilizing human waste with hydrated lime increases the pH of waste material to 12. Such conditions are inhospitable to pathogens and convert the waste into an effective soil amendment. Using lime is as effective as pasteurization, and that the final product conforms to US EPA standards for biosolids, killing fecal coliforms, helminth eggs and pathogenic bacteria (Smith and Surampalli 2007). The high pH also provides a vector attraction barrier, preventing flies and other insects from infecting the treated waste (Brobst 1995). Furthermore, the efficacy of lime as a waste sterilization agent is not reduced by the presence of most complementary sanitary products such as paper, cloth, or soap. Alkaline stabilization with lime has already been used for waste sterilization worldwide, from large facilities in the developed world (Wurtz 1981) to wastewater flows in the developing world (Franco-Fernandez 2003).

Lime has also been used in agricultural settings for centuries (Johnston 1849) and has been demonstrated to improve crop yields (Acosta-Martínez et al. 2000). Lime adds valuable calcium and magnesium to soils (Mitchell 2000), and the raised pH suppresses root-borne diseases such as bacterial wilt (Lemaga and Ebanyat 2004). Yield of Cambodia's acidic soils improves greatly following lime application. For Cambodian households, fertilizer is a major expense, and this high cost contributes to the under-fertilization seen in the country's agricultural system (Ross 1987). Human waste can be a valuable soil amendment, and while it may will not replace all chemical fertilizer, it is estimated to have an annual value of around USD30 per household. Thus, combining lime and waste into a single product removes pathogenic concerns associated with handling untreated waste as well as leverages the soil amendment qualities of both the sludge and the lime (Gensch 2011).

Lime is readily available through an agricultural supply chain and at USD 0.38/kg is extremely affordable. Hydrated lime is a stable compound and with appropriate precautions can be used safely by households. Furthermore, adding lime to latrines eliminates odors, a key selling point for rural households (iDE 2013).

Project Objectives

The aim of this research is to determine if lime will serve as an effective method for waste treatment and crop enhancement for Cambodia. The phases of research covered at present are the gathering of user insights, a lime supply chain analysis and bench scale tests. Further, a trial to test lime application approaches by households, and agricultural trial on effect of limed sludge on crop yield will be carried out. Prototypes of lime dispensers and market testing of possible products will also be carried out.

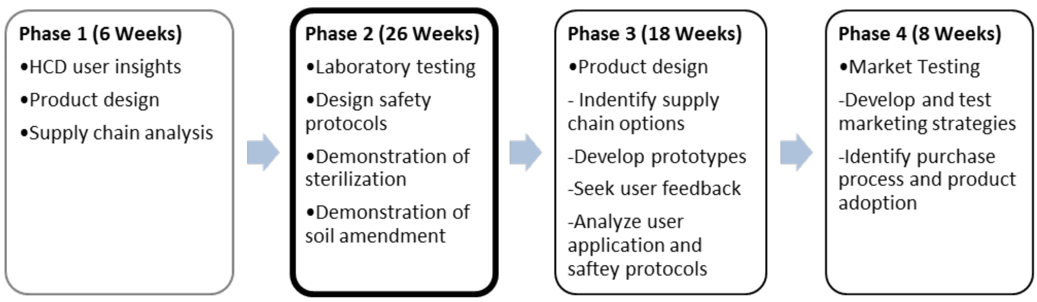

Figure 1. Key phases of project and timeline. Current research phase is in bold

User Insights: Human Centered Design Research

Prior to technical research, human-centered design (HCD) methodology was used to gather user insights to better understand current waste management practices and lime use in rural Cambodia. Residents of three villages in Kampong Cham province were interviewed on latrine use, latrine cleaning and pit emptying practices, awareness of lime, perceptions of waste reuse, and general aspirations and concerns about the waste treatment and disposal process. Key highlights of this research are summarized in Figure 2.

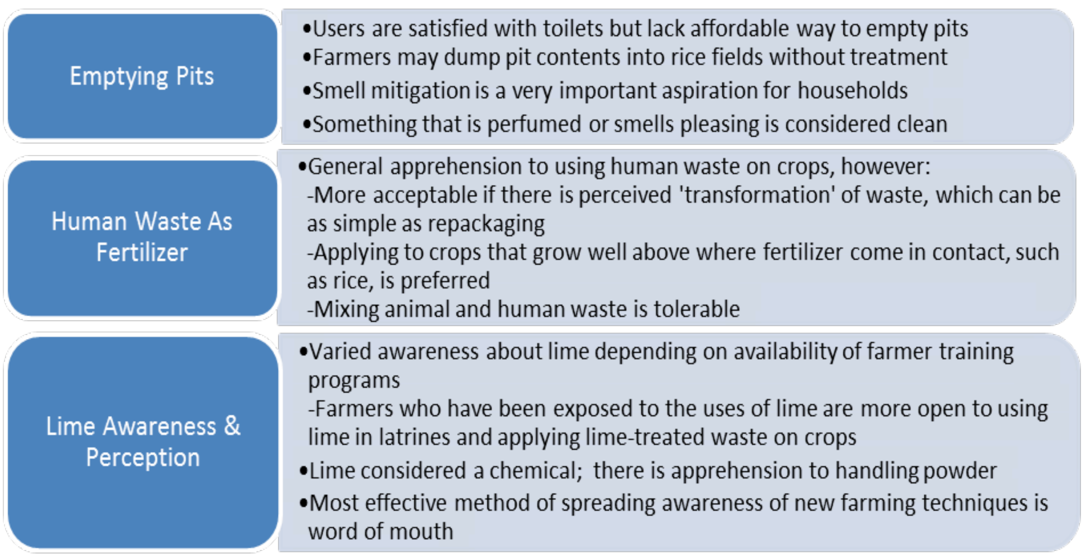

Figure 2. Key insights from user interviews

The insights emphasize the need for a user-sensitive approach to lime application. Although there is currently an urgent need for improving pit-emptying practices, households are apprehensive of using any form of human waste in soil for food crops. However, the popularity of soil liming is currently increasing among, and thus this may be an opportune time to promote lime in sludge disinfection. This information will direct both the development of a lime product and a strategy for its safe and effective application.

Lime Supply Chain

A supply chain assessment was mapped out for known uses of lime in construction, agriculture, and in households. Currently, lime sold in Cambodia is quarried in Cambodia, Thailand, and Vietnam. A preliminary supply chain analysis in Svay Rieng and Prey Veng provinces and the city of Phnom Penh consisted of interviews with lime wholesale and retail suppliers, users, and an agronomist who trains farmers for iDE's agricultural extension program (the Farm Business Advisor (FBA) program). The goal of the analysis was to gain a better overall understanding of lime use in Cambodia, where businesses and individuals were purchasing lime and whether hydrated lime may be sourced from Cambodian sources.

Lime Origin	•Source is based on location in the Cambodia; eastern provinces buy mainly from Vietnam, western and northern provinces from Thailand while Phnom Penh varies between Vietnam, Kampot and Thailand •Limestone quarries exist in Kampot and Battambang provinces •iDE does not have a Cambodia-based supplier
Lime Use	•Most lime is used for cement or other construction applications. •Common uses in rural areas include disinfection of ponds and animal pens and soil amendement •Small market for lime sales; many people are unaware of use for agriculture or disinfection
Lime Sales	•Average price from Cambodian seller is USD 0.375 per kilogram •Wholesalers tend to have lime shipped from other countries in large quantities while smaller retailers buy on as-needed basis •Cambodian retailers sell lime in 25-30 kg bags or by the kilogram •For both wholesalers and retailers, lime sales are not significant revenue for the business
Type of Lime Sold	•Many types of lime sold for agriculture -CaO concentrations rage from 40-90%; little understanding of what the lime concentration meant in Cambodia •The same type of lime may be sold for agriculture and construction use •General undersanding that construction lime gets hot when in contact with water (indicating high CaO concentration)

Figure 3. Key insights from supply chain analysis of lime

To ensure safety and efficacy, the project will determine the most cost-effective method of consistently procuring quality lime. Based on the research, a map of the lime supply chain was created (Figure 4).

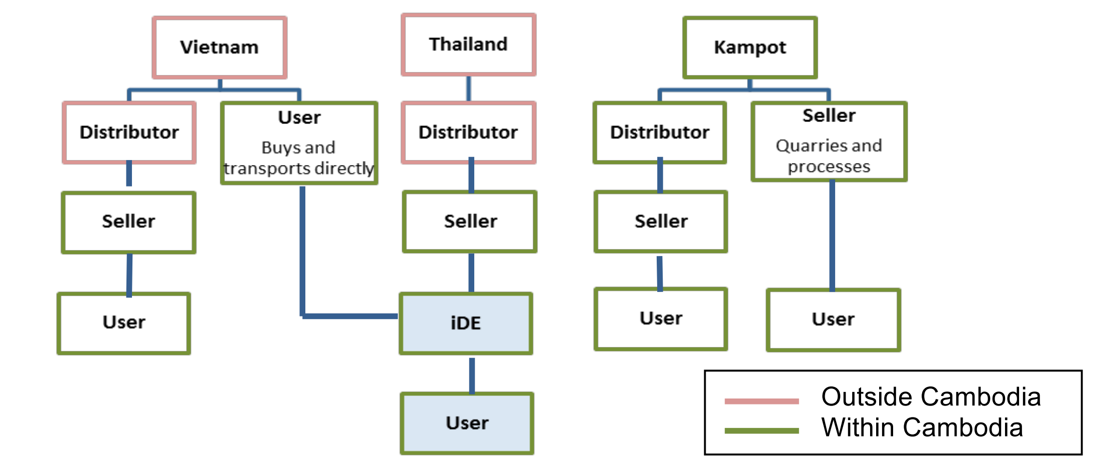

Figure 4. Summary of lime supply chain in Cambodia

While the supply chain research has clarified the use, sources and availability of lime in Cambodia, some elements will require further inquiry. There is little understanding in the rural communities exactly what type of lime is being sold and used and what the differences are between them. In addition, while limestone is quarried in Cambodia, it is unclear if hydrated lime is being produced.

Laboratory Bench Tests

The goal of the bench-scale tests was to determine the efficacy of locally available lime on treating sludge from a typical household latrine. A pH of 12 eliminates *E. coli* and most viruses within several hours, and maintaining the pH at 12 or higher for a minimum of two weeks eliminates any viable *Ascaris* eggs.

Parameters investigated were 1) maintenance of pH at different concentrations of lime over time; 2) efficacy of lime in removing *E. coli* and *Ascaris* from sludge; 3) effect of lime on the composition of the supernatant and sediment of treated sludge; 4) adequacy of passive mixing, achieved by simulation of applying lime by user at every use, in ensuring a sufficient rise of pH; and 5) difference in efficacy when applying lime as a slurry as opposed to in powdered form.

Methods

Sludge was collected from a latrine that was being used under conditions typical of a rural household (pour-flush squat latrine, regular cleaning).

To test the concentration of lime needed to maintain pH of sludge at 12, different levels of lime were applied, and treatments were incubated for 25 day. pH was monitored on a daily basis. A sample of the sludge at the start of the incubation was analyzed for total nitrogen, ammonia, total solids, *E. coli* and *Ascaris*. At the end of the incubation, the supernatant and sediment were analyzed separately, for ammonia, total nitrogen, total organic carbon, total suspended solids, calcium and *E. coli*; and total nitrogen, total organic carbon, total solids, calcium and *E. coli*, respectively.

The goal was to simulate and test the efficiency of "passive" mixing resulting from the repeated addition of waste and lime; no additional mixing was performed . pH was monitored over a two week period. Three mixing regiments were tested in 20 L buckets: 1) To simulate per use addition of lime, the bucket was filled by repeatedly adding 0.6 g lime followed and 40 ml sludge, in an alternating manner, for a total of 10 L. This represents a user adding 1.5 % (w/v) lime to the waste combined with wash and flush water each time the toilet was used. 2) To simulate addition of lime at every cleaning event, 21 g lime with 1,400 ml sludge, for a total of 10 L. This represents a user adding 1.5 % (w/v) lime to the waste during a weekly cleaning episode, based on the total amount of waste expected to accumulate during the week. 3) To simulate the addition of lime as a single event prior to pit emptying, the entire mass of lime, 150 g, for the same final concentration 1.5 % (w/v), was added as a single dose.

Results

At 1.5 and 0.5 % (w/v) lime, pH was maintained at 12 and above for the 25 days of incubation, which is sufficient to ensure complete elimination of viable pathogens (Figure 5). Although adding 0.1 % lime initially had an effect on pH, within 6 days, the treatment was indistinguishable from unamended controls.

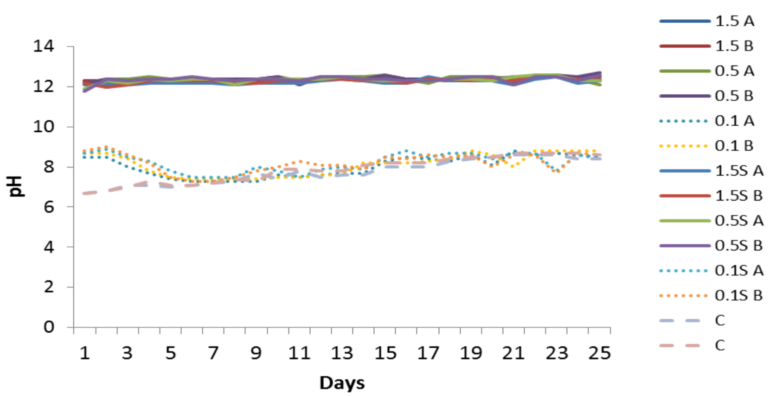

Figure 5. Effect of initial lime concentrations on pH over a 25 day incubation. A, B: duplicate incubations at the same concentration. S: lime added as a slurry C: unamended control.

In comparison with the control and 0.1 % of lime amendment, addition of 0.5 and 1.5 % of lime followed by thorough mixing, resulted in an almost instantaneous precipitation of solids to the bottom of the containers, and the formation of a clear supernatant. A distinct ammonia odor was detected. This odor persisted over the length of incubation. In contrast, the unamended control and at 0.1 % of lime, the liquid remained turbid for several days, and emitted a more typical, slightly sulfidic, sewage odor.

No difference was seen between applying the lime as a powder or a 50 % slurry in water. A pH of 12 was reached immediately following mixing with both application methods.

The sludge used for incubations was found to be free of viable *Ascaris* eggs. An additional analysis of pig manure also showed a negative results. Thus *Ascaris* was not tested for upon completion of the incubation.

Characteristics of the unamended controls were similar to those of the 0.1 % treatment level. 0.5 % and 1.5 % were similar to each other. In the results presented in Figures 6 and 7, 0.1 % treatment is grouped with the control ("low treatment"), and the 0.5 % is grouped with 1.5 % lime amendment ("high treatment").

In the supernatant of sludge following the 25 day incubation, no difference was seen between the high and low treatments in ammonia, total nitrogen, or total suspended solids. As expected, the high treatment had more than twice the concentration of calcium, and no detectable *E. coli*. Total organic carbon was also almost twice as high in the high treatment samples (Figure 6).

High treatment samples had significantly lower total nitrogen and total organic carbon in the sediment (Figure 7). No viable *E. coli* was detected in high treatment sediment samples, whereas low treatment samples had similar *E. coli* numbers to the supernatant (4.4 x10^3 cfu/100 ml). The addition of excess lime in high treatment sediments was reflected in the significantly higher value for total solids in comparison to the low treatment sediments.

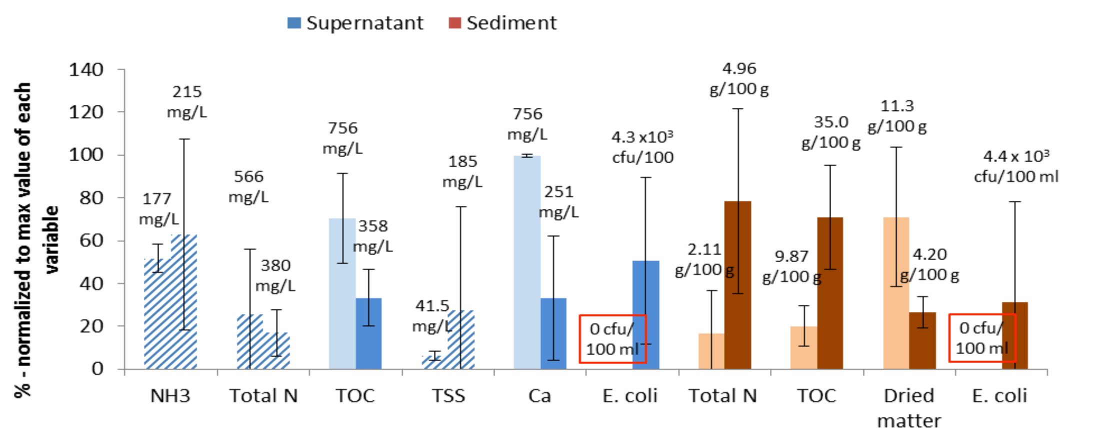

Figure 6. Characteristics of supernatant and sediment after incubation. For each parameter, the left column is average of high lime-amended ("high treatment", 0.5 and 1.5 % w/v lime) incubations and the right column is average of control and amendment at 0.1 % (w/v) lime ("low treatment"). Hashed columns are not significantly difference. Solid fill represents difference at p(same) < 0.05.

Incremental addition of lime and sludge to a final concentration of 1.5 % (w/v) lime was sufficient to raise and maintain the pH at 12 (250 increments, data not shown). An application of fewer increments (7 increments), to simulate addition of lime at weekly cleaning events had the same effect. With both applications, a clear supernatant was formed, with rapid settling of solids. However, the addition of the same total mass of lime as a single dose was not sufficient to raise the pH of the sludge to 12, with pH reaching 10 at the time of application and falling to 8 within one week.

Based on the outcome of the bench-scale studies, a concentration of 1.5 % (w/v) lime will be used in household and agricultural trials, to reliably ensure the desired increase in pH and a clear supernatant. Lime treated sludge provides a nitrogen-rich supernatant, with low suspended solid content, and no pathogens. The clarity of the supernatant is a favorable property, likely to increase its desirability among users as a soil amendment, because it bears little resemblance to the turbid content of freshly opened, untreated latrine pits.

Although lime treated sludge has approximately the same concentration of ammonia as untreated sludge, high pH in lime-treated incubations results in predominance of the highly volatile deprotonated form, and thus a consistently pungent odour. A strong focus of the household level trials will be to evaluate the perceived importance of ammonia odours to users.

The presence of lower levels of total nitrogen and total organic carbon in the sediment, and higher levels of both in the supernatant (if volatilization of ammonia is accounted for), indicates that lime treated sludge provides a more readily available source of both nitrogen and carbon to soil. Higher concentrations of carbon and nitrogen may have an additional positive impact on crop yields, beyond reducing acidity, increasing calcium content, and reduced disease burden.

On-going and Future work

The project seeks to further understand the potential for lime disinfection of sludge by investigating household usage of lime, and application of lime-treated sludge to small-scale vegetable cultivation.

1. **Test lime application protocols at the household-level:** Participating households will be advised on a range of protocols for adding lime to latrine pits. Compliance to different addition methods and effectiveness of disinfection, along with user feedback will be evaluated.
2. **Agricultural benefit:** Lime treated sludge will be used in agricultural field trials to determine its effect on the yield on vegetable crops. Plots will be set up to measure the difference in yield between plants grown on lime treated-sludge amended soil and non-amended soil.
3. **Pilot marketing and sales:** Business models will be prototyped based on identified potential producers, sellers, and value proposition for customers. Further iterations on the product and business model will be made based on market feedback, which will inform opportunities and constraints for commercialization.

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