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Tynar is an energetic director of the Central Asian Alliance for Water. After starting his work in CAAW as a member of the organization, he is now the director of the activities. CAAW is one of the main organizations in Southern Kyrgyzstan with water, dry sanitation and women development. Tynar has been an active part in the development of the current dry sanitation situation in Southern Kyrgyzstan. After receiving his Master degree, he has been working in Turkey, Russia and now in Kyrgyzstan with dry sanitation, gender issues and water.

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Title of abstract: Low cost domestic struvite technology for the treatment of source separated human urine from urine diverting dry toilets (UDDT's) in rural areas of Kyrgyzstan
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Abstract

This research studied the possibility of implementing low cost struvite technology in Kyrgyzstan. Struvite technology has provided promising results around the world in developing countries, such as South Africa and Nepal. The resource oriented sanitation model is going to become increasingly important with the growing environmental pressure caused by increasing population problems, which can create problems to human health and sustainability in long term. Phosphorus recycling is one of the key points in securing future food production and struvite technology is a proven tool to assist in that need. Struvite can be produced in low-cost and simple conditions. A 150 L household reactor can process up to 3.2 m^3 of urine per year. This can provide 3-6 kilograms of struvite depending of the filtering efficiencies and urine phosphorus concentrations. A reactor in Kyrgyzstan was estimated to cost 4100 som (57 euro; 4/2015). A single household reactor will not provide much return in form of sold struvite as the fertilizer market price was found to be 25 som/kg (0.4 euro). However, the potential economic benefit of improved soil condition, higher crop yields created by struvite use and added value created from environmental protection can be potentially added to the struvite user potential. Struvite technology can offer a simple, low-cost choice for farmers, who wish to utilize the nutrient potential of urine but are unable to do so due to religious, personal or other obstacles. The costs of technology need to be brought down to improve the profit marginal of struvite production, but this can be possibly done with careful planning and organizing the production of reactors with a long-term provider.

KEYWORDS: Struvite, low cost resource recovery, sustainable sanitation, resource oriented sanitation.

Introduction

Struvite technology is gaining popularity among the scientific community. Struvite technology will be needed increasingly in the future, due its potential to provide a partial solution to depleting phosphate reserves issue. (Cordell et al.2010; Wilsenach, 2007). Struvite ($MgNH_4PO_4*6H_2O$) is a mineral that can be separated and collected from source separated human urine with the help of a simple precipitation reaction when magnesium and phosphate molar ratios are 1:1, in supersaturated conditions and when pH of the solution is 9. Struvite can be filtered after this process from the human urine with a conventional low-cost liquid-solid separation technique, for example a nylon or cotton bag (Etter et al. 2011; Wilsenach, 2007; Tilley, 2006). Human urine separated struvite works as a substitute for common phosphate fertilizer with a corresponding NPK value of 6-29-0+10Mg (Antonini et al. 2012). Struvite technology has been tested by many researchers around the world and found fit for replacing parts of diammonium phosphate (DAP) fertilizers and possibly even P2O5-fertilizers (Antonini et al. 2012; Ganrot et al. 2007). The growth tests with struvite have shown struvite having similar or better fertilizer pontential than conventional chemical phosphate fertilizers but also an potential to work as a soil conditioner (Ganrot et al. 2007). The heavy metals and salt concentrations of produced struvite, that are perceived as a risk generally, have been identified to remain below the European Union risk levels and thus provide evidence of a safe fertilizer (Ronteltap, 2007). Struvite has been found to provide half of the needed phosphorus, parts of nitrogen and all magnesium for a growth season for maize pot in tests (Antonini et al. 2012). Struvite can thus provide a realistic source for phosphate fertilizers in communities with poor access to fertilizers in many developing countries, such as Nepal, South Africa and now Kyrgyzstan (Grau et al. 2014; Etter et al. 2011).

Struvite can be separated from urine with the help of a simple reactor that can be produced from local materials with relatively low costs (Etter et al. 2011). In this study a reactor was implemented that had final costs of approx. 57 euros. The benefits of this technology is the ability to manufacture high quality, slow release fertilizers and recycle nutrients in a sustainable manner. Also it might be possible that in some cases, the technology can provide a potential for extra income to people in low income communities, where source separated human urine is of abundance and demand for fertilizers are high and the costs of production can be kept low. The costs of technology need to be brought down to improve the profit marginal of struvite production but this can be possibly done with careful planning and organizing the production of reactors with a long-term provider.

Source separated human urine phosphate concentrations were defined based on literature values, which vary from 0.38g(P)/L to 1.2 g(P)/L (Karak et al. 2011; Etter et al. 2009). This variation has been documented by Karak et al. (2011) and later on by many others (von Munich & Winker, 2013; Heinonen-Tanski, 2005). During this study similar values with Etter et al. (2011) were used. The 0.38 g-P/L was perceived low enough to provide a reference value for struvite production and economic calculations regarding produced struvite. One household (6 people) can be expected to produce 50-60 Liters of source separated urine per week. This amounts to 3.2 m^3 or urine per year. It was estimated by Karak et al (2011) that one person generates 2.5-4.3 kg of N, 0.7-1 kg or P and 0.9-1.0 kg K per year. This translates through the stoichiometric calculations into 8 kilograms of struvite per year. However, using the reference value from literature of 0.38 g P /L the final calculated struvite yield per annum is 1.1 kg-struvite/person per year. This is an indication that most likely urine contains much more phosphorus than 0.38 gP/L in general, but needs further studying for confirmation. However, even a small amount of phosphorus recovered from human urine can assist low income households in increasing their crops yields in gardens or fields.

The UDDT technology has been implemented in Kyrgyzstan since a decade. So far 150 toilets have been built to the target region of this study in Aravan and Mangyt villages of Osh oblast in southern Kyrgyzstan. The UDDT technology allows the reuse of human feces in agriculture (Heinonen-Tanski et al., 2003). Feces and human urine are used as direct fertilizer after sufficient processing and time of storage. Sometimes the climate conditions, personal status, religion or personal situation does not allow the reuse of urine directly, for example due to Islamic religious beliefs or winter season. This is when struvite could be used to separate valuable nutrients from urine for the later use in the spring. This approach could offer a choice to correspond with the local seasonal and cultural restrictions.

Objective

Objective of this study was to evaluate if struvite technology is feasible in terms of social, economic and technological aspects for phosphorus recovery and re-use in Kyrgyzstan, especially in cases where urine use in agriculture is not directly suitable. In addition to this, user interphase feedback was collected from the users for further technological development of the technology. This article will present the findings of the technological feasibility study and present the related economic evaluations of the implemented solution. User feedback information was not received by the release date of this article.

Methodology

Location

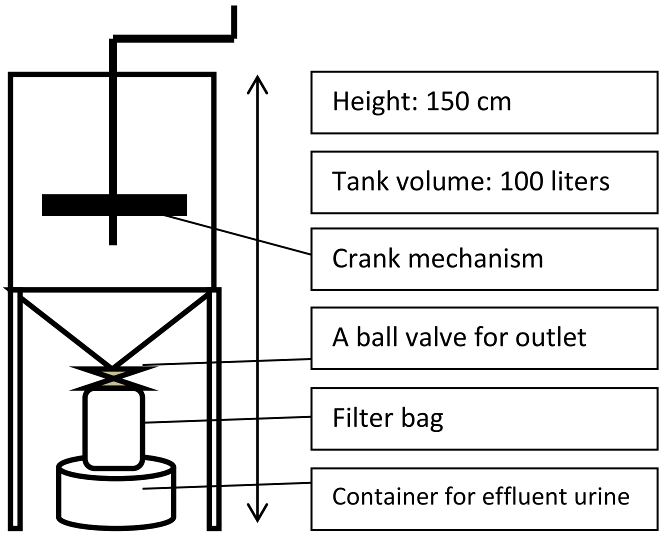
The location of the study region was in southern Kyrgyzstan, Fergana Valley in Osh Oblast, Kyrgyzstan. Only 25% of the population has an access to centralized sanitation and pit defecation is common (WECF, 2014). In Osh oblast, UDDT's have been built to schools, around 150 UDDT's in private households and more are planned to be built in the near future both to schools and private households. The technology has received good feedback from its users and is gaining popularity in households, where it is used accordingly (CAAW, 2014). The region relies on agriculture as the main livelihood and is mainly Muslim, which gave a further incentive to use the region as a subject site, as the use of human waste as fertilizer is controversial with the Islamic religion.

Magnesium source

Magnesium oxide (MgO) was used as a magnesium source and was found after a long and effort taking process from the local university. In the future, use of online providers are suggested. Magnesium Oxide (MgO) chemical can be purchased from China (Liaoning Jiashun Chemical Science and Technology Co., Ltd , Dalian , China**)**, which is a neighbouring country to Kyrgyzstan, via Alibaba.com, who sell chemicals online. The magnesium oxide was added to the reactor and mixed with human urine. The magnesium-phosphate (Mg^{2+}-PO_4 ratio) was 1.1:1 mol/mol magnesium-phosphorus. Magnesium was dosed by using the phosphate concentration of 0.38 gP/L in all tests to ensure the supersaturation of magnesium (Wilsenach, 2006)

Reactor type and model

A cast iron struvite reactor was built according to the guidelines given by Etter et al. (2011). The reactor drawings are presented below. The reactor was tested 4 times before giving it to a rural household that was subjected as test user. The reactor was tested with urine batches of 50 liters. A manual was made to assist the users in the use of the reactor. During first two times of testing, the urine was stored more than 3 months with a pH of 8.6 and during the two last times, urine was fresh with a pH of 6.8. User feedback was collected qualitatively from the household with a questionnaire in order to gather information about the user interphase, user opinions and user preferences for further development. Struvite was made by using MgO and source separated, stored and fresh urine. The struvite was filtered with a cotton cloth, cheaply available at the local market. Struvite was filtered, dried and collected for weighing. After this the reactor was given to an agricultural household and user experiences were collected quantitatively with a survey. Due to missing laboratory equipment, only literature references for urine phosphorus content were used, a reference value of 38mg/L given by Etter et al. (2011).



Picture 1. Illustration (simplified) of the struvite reactor built in Kyrgyzstan according to Etter et al. (2011)

Filter system and caking

A simple filter system was designed and implemented for the liquid solids separation tests. Material used was easily available cotton clothes that were cheaply available and of different pore sizes. Pore sizes of 140µ±50 and 400 µm±50 were used. The cotton cloths were sown into a bag and a nylon line was attached to each bag. The cost of one filter bag was approximately 20 com (0,25 Euro). The bags were reusable and could be washed in between uses. The aim of the filter bag was to form a filter cake of the precipitated struvite which would enhance the filtering ability of the bag. The formed cake makes an extra layer to the bottom of the filter bag and allows a higher filtering efficiency. The filtering process was given 8-24 hours per batch to ensure the high capture of precipitated struvite. The struvite granule size was not measured with any analytical methods due to missing equipment.

Urine sources

Source separated urine was collected directly from households with UDDT's in Aravan and Mangyt villages in Osh Oblast, Kyrgyzstan. Each batch was about 25-30 liters, which was measured by filling the tank halfway during each batch. The urine was collected directly from the UDDT users for the tests and was found to be in closed container for stored and in an open container for the fresh one. All in all 100 liters of source separated urine was collected and used in the tests. Urine pH was measured with a simple aquarium pH meter (Shenzhen Cyber Technology Ltd.). Urine phosphorus concentrations were not measured and were defined by using literature references of 190 mgP/L for stored urine and 380 mgP/L for fresh urine (Etter et al. 2011).

Results

Reactor efficiencies

The reactor was tested in total 4 times with both stored and fresh source separated urine with a total volume of 100 liters influent for feasibility tests in batches of 25 liters each. An average collected struvite yield was per average 45g±5g per batch of 25-30 liters stored urine and 25 g±5g for fresh urine making the reactor efficiency around 60-65 % when urine P concentration was assumed being 190mg/L and 380 mg/L for stored and fresh urine. Part of the phosphorus was expected to be already precipitated in the stored urine which is the reason for the lower phoshorus concentrations in the stored urine. During the tests it was noted that stored urine behaved more optimally in terms of struvite precipitation and collection compared with fresh urine. The struvite yields were higher in stored urine batches than during the fresh urine test runs which is mainly due to the pH effect.

Filtering and filtering efficiencies

Filter caking process happens as the precipitated struvite is captured to the bottom of the filter bag and collected into a cake, which works in favor of capturing the solids (Tilley, 2014). The caking took place as expected as it could be seen after 30 minutes from filtration and becoming more visible with the passing hours. The filtering period took up to 8-24 hours per batch. The slower the filtration process and effluent flow, the better the capturing of the particles was, as explained by Tilley (2014) and as a part of the work of Etter et al. (2011). What is more important to notice is the presence of possible collected *Ascaris suum*-eggs which can be a problem and need to be properly disinfected in 40-55°C but without losing the ammonium (NH_4) that evaporates above 55°C from the struvite (Decrey et al 2011).

Effluent treatment and other health aspects

The effluent contains pathogens, possibly unfiltered *Ascaris suum*-eggs and a significant amount of salts (Na,Cl etc), as well as large parts of urine based nitrogen in form of ammonia (NH_4^+) (Etter et al. 2011). The effluent must be treated or disposed in a cheap, logical, useful and environmentally safe manner suitable for local conditions. The most important issues related to this matter are the adverse environmental impact of untreated human urine to ground waters, soil microbes and to human health. Therefore, phosphorus depleted urine should be treated properly and most preferably all available nutrients should be collected for re-use. Proper effluent treatment mechanisms need to be developed based on-site demands but Etter et al. (2011) and Pronk& Kone (2008) give some options for urine re-use. In the summer time, a solar evaporation unit could work in Kyrgyzstan due to high solar irradiance during summer months, April to October. Also in the summer time a constructed wetland system (CWS) could provide a solution to proper management of phosphorus depleted urine effluent. The urine contains most of the nitrogen, sulfur, potassium and all salt content Heinonen-Tanski et al. (2003). Also Maurer et al. (2006) suggest freeze thawing in the winter time. According to Maurer et al. (2006) freeze-thawing can concentrate 80% of the available nutrients to 20% of the liquid volume. These two mechanisms can provide a solution for full utilization of urine nutrients in harsh climate Kyrgyzstan, where winters are cold and summers hot. Also, the effluent can be collected and used in drip irrigation to avoid the loss of ammonia by volatilization (Etter et al. 2011; Pronk and Kone, 2008; Maurer et al. 2006).

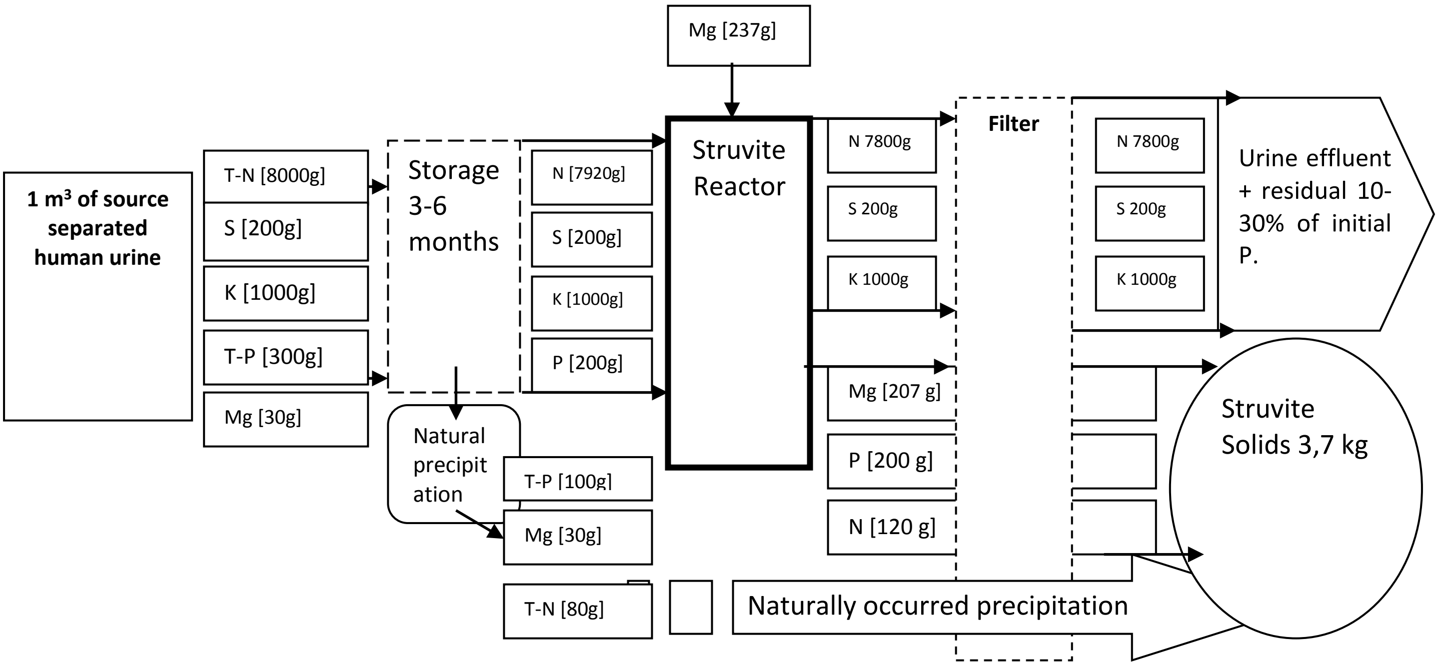
Cost table

The complete price with metal works included of the reactor was in total 4100 som (57 euro). Struvite was successfully produced in very simple conditions with very simple, basic everyday tools which did not bring extra costs. The market price of struvite was found out to be 25 som/kg (0.4 euro). With one household reactor and produced urine it is possible to produce 3,7-6,2 kg of struvite. If more struvite is to be produced, then more urine needs to be collected from neighboring household, which is possible.

Table 1. The costs of the struvite reactor and production

Reactor size	100	L	
Urine T-P concentration	0.38	g/L	Etter et al. (2011)
Household urine production estimate per year (6 people)	3200	L	Karak et al. (2011)
Needed Magnesium Oxide per year	1	kg	
Filtering efficiency	60-90	%	
Produced struvite	3,7-6 ,2	kg	
Reactor life cycle	10	years	Etter et al . (2011)
INVESTMENT COSTS:	**som**		
Stand	1000	som	15 euro
Filter systems	100	som	1.5 euro
Metal sheets and parts	2000	som	30 euro
Work	1000	som	15 euro
Sub Total	**4100**	**som**	
RUNNING COSTS:			
Magnesium oxide (MgO)/kg	33	som	0.5 euro
Filter bags - 6 pcs	100	som	1.5 euro
Amortization cost/a	500	som	8.5 euro
Capital cost 12%	495	som	8.45 euro
Revenue			
Struvite fertilizer price/kg	25	som	0.4 euro
Total income of produced struvite	100-150	som/a	1.6-2.5 euro/a
Total profit/a	-5078	som	-80.7 euro

As can be seen from simple set of calculations in Table 1, there is no direct economic value regarding a single household reactor. The reactor will not have a breakeven point during its 10-year lifespan. However, if more urine could be collected, then the amount of income will become higher due to increased amounts of struvite. Also, the added value of the use of organic fertilizer and potential soil conditioner benefits are not included. However, there might still be potential in the technology as the production of struvite can be expanded with more urine and the potential benefits received from struvite use in agriculture can have positive impacts to the user, which are not quantified as a part of this study.



Graph 1. Struvite material flow chart (Etter et al. 2011; Karak et Bhattacharyya, 2011)

Graph 1 presents the material flows through the system in a struvite production process. One cubic meter of human urine has the minerals of 8kg T-N, 0,2 kg of S, 1 kg of K, 0,3 kg of T-P and around 0.03kg of Mg as mentioned by Karak et al. (2011). Part of the nitrogen, phosphorus and magnesium precipitates spontaneously and forms struvite during the storage phase. During the struvite production process, Mg is added to the system with molar ratio 1.1:1 (Etter et al. 2011). During the precipitation reaction all P, some N and most of the Mg is bind into struvite ($MgNH_4PO_4*6H_2O$). This is filtered out in the filtering process. Depending of the filtering efficiency, part of the precipitated struvite will be in the influent. An efficiency between 60-90% is realistic with a simple filter in the reactor model designed by Etter et al. (2011). The chart shows the importance of utilization of the effluent as a significant amount of nutrients is still present in the phosphorus depleted urine.

Discussion

High volumes of urine need to be handled in order to capture sufficient amounts of struvite. In order to achieve full potential of the technology, urine storing for 3-6 months is definitely recommended. Also the re-use of phosphorus depleted urine effluent is recommended for optimal recovery of resources. Phosphorus depleted urine should be treated according to recommendations that fit to the local climate. Even though the struvite yields remain low and urine quantities high, struvite technology still offers a solution for capturing phosphates from human urine. Increasing the amount of user experiences is one of the main developmental issues regarding application of this technology in Kyrgyzstan together with the treated urine re-use possibilities. The latter should be made as simple, low-cost and user friendly as possible to ensure the social acceptability of the technology. These points require more research and work, which can be re-evaluated based on the user feedback received after few growth seasons in Kyrgyzstan.

Conclusion

The reactor can provide a solution to low cost phosphorus recovery from households that are not interested in urine re-use by fertigation due to social, religious, hygienic or technical reasons. However, a single household reactor will most likely not provide any extra income in form of sold struvite due to low production yields and due to high material costs. Finding a reliable magnesium source is the biggest bottleneck for struvite production in Kyrgyzstan at the moment. Developing the concept further and collection of user interface experiences will help in introducing the struvite technology among the users having a UDD toilet. But the most important fact is that struvite technology has been implemented in Kyrgyzstan and more similar experiences are needed to receive more information of the future impacts of struvite technology to the local communities. In order to harness the optimal potential of the technology, a further study is needed to estimate the user acceptability and real value of the technology to its users in Kyrgyzstan in long-term.

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References

[1] Antonini, S. , Arias M-A., Eichert, T, Clemens, J. 2012: "Greenhouse evaluation and environmental impact assessment of different urine-derived struvite fertilizers as phosphorus sources for plants". Chemosphere 89, pp. 1202-1210. Available online at: http://hss.ulb.uni-bonn.de/2013/3214/3214.pdf#page=47, accessed: 2.2.2015

[2] Cordell, D. , Drangert, J-O, White, S. (2009) The story of phosphorus: Global food security and food for thought. Global Environmental change 19 (2009) pp. 292-305

[3] Decrey, L., Kohn, T., Pecson, B., Tilley, E., Udert, K., (2011): " Fate of the pathogen indicators phage ΦЖ174 and *Ascaris Suum* eggs during the production of struvite fertilizer from source-separated urine". Water Research 45, (2011), pp.4960-4972

[4] Etter et al. (2011): Low-cost struvite production using source-separated urine in Nepal, Water Research 45-2, 852-862

[5] Ganrot, Z., Nilsson E. , Dave G. (2007): "Recovery of N and P from human urine by freezing, struvite precipitation and absorption to zeolite and active carbon. Bioresource technology 2007; 98 (16) pp. 3112-21. Available online at: http://www.ncbi.nlm.nih.gov/pubmed/17321132

[6] Grau M. , Etter, B. Udert, K. et al. (2014) : "Development and operation of struvite reactors to recover phosphorus from source separated urine in eThekwini. Univeristy of KwaZulu-Natal, Durban, SA. 2014.

[7] Heinonen-Tanski, H. & van Wijk-Sibesma C. (2003): "Human excreta for plant production". Bioresource technology 96, (2005) pp. 403-411.

[8] Karak, T., Bhattacharyya, P. , (2011): "Human urine as a source of alternative natural fertilizer in agriculture: A flight of fancy or an achievable reality". Resources, Conservation and Recycling 55 (2011) pp. 400-408

[9] Maurer et al. (2006): "Treatment processes for source separated urine ". Water Research, Vol 40, Issue 17, October 2006, p.3151-3166.

[10] Pronk & Kone (2008) : "Options for urine treatment in developing countries", Desalination 248 (2009) pp. 360-368. Available online at: doi:10.1016/j.desal.2008.05.076. Accessed 12.2.2015

[11] Ronteltap, M. , Maurer, M., Gujer, W., (2007a) "Struvite precipitation in source-separated urine ". Water Research 41 (2007) pp. 977-984

[12] Tilley, E.A (2003) : "Urine storage conditions on struvite recovery", M.Sc. Thesis. University of Waterloo. Available online at: http://www.researchgate.net/publication/259929844_The_effects_of_urine_storage_conditions_on_struvite_recovery. Accessed 2nd of February, 2015.

[13] Udert K. , Larsen, T. , Gujer, W. (2003) : " Estimating the precipitation potential in urine collecting systems". Journal of Water Research 37, (2003) pp. 2667-2677.

[14] Wendland, C. et al 2012 Experiences with urine diverting dry toilets (UDDTs) for households, schools and kindergarten in Eastern Europe, the Caucasus and Central Asia (EECCA), http://www.wecf.eu/download/2011/February/SSP-06_Jan2011_16-221.pdf

[15] Wilsenach, J. , Schuurbiers, C. , Loosdrecht M. C. M. (2007): "Phosphate and potassium recovery from source separated urine through struvite precipitation". Water Research 41 (2007), pp. 458-466

[16] WECF Publications (2014): Gender aspects to access clean drinking water and sanitation", WECF. Ed. Stock, Wendland, C., Samwell A. 2014. Available online at: http://www.wecf.eu/download/2014/November/WPGender-SDW-Sanitation25nov.pdf

[17] CAAW –Central Asian Alliance for Water, Private communication with Director Tynar Musabaev on UDDT situation and prospects in Aravan region, Osh Oblast, Kyrgyzstan. 01.11.2014.

[18] Tilley, E. Private communication, 10.10.2014.