VUNA – Nutrient Harvesting from Urine: Lessons from Field Studies

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ABSTRACT

By recovering nutrients from urine, the VUNA project (www.vuna.ch) aims to contribute to a sanitation system, which is affordable, produces a valuable fertiliser, and reduces pollution of water resources. This project integrates science and practice to establish the processes and management methods for recovering nutrients from urine at pilot scale in South Africa and Switzerland. The present article presents an overview on the project; four further articles presented at the WISA Conference 2014 describe VUNA's components more in detail (see references).

By testing reactors with different technologies and at varying scale, the researchers explored a broad range of potential treatment options. The combined nitrification-evaporation process recovers all nutrients contained in urine in a concentrated nutrient solution. Further processes, such as struvite precipitation and electrochemical urine treatment were also investigated. Accompanying studies examined to what extent the processes degrade micro-pollutants or deactivate pathogens.

In the peri-urban areas of the eThekwini municipality, various set-ups have been tested to collect urine from urine-diverting dry toilets (UDDT). Both practice and accompanying economic and logistic studies showed that optimising urine yield through collection relies on multiple aspects ranging from urine tank size, collection frequency and mode, to community awareness and social acceptance.

To explore the socio-economic boundaries of fertiliser production from urine, field studies backed up with community surveys have been conducted. In two on-going studies, social acceptance of urine-diverting toilets and use of urine-derived fertilisers are under investigation. To institutionalise the supply chain from urine collection to fertiliser production and sale, various scenarios for a business model are currently examined. Furthermore, to assure an efficient and safe end-product, crop scientists in Zurich and Durban have tested the urine-derived fertilisers in greenhouse and field trials. The results show that the products equal or outperform comparable synthetic fertiliser in quality.

KEYWORDS

Sanitation, Nutrient Recovery, Urine Treatment, Fertiliser Production, Public Health

1 INTRODUCTION to VUNA

By recovering nutrients from urine, the VUNA project (www.vuna.ch) aims to contribute to a sanitation system, which is affordable, produces a valuable fertiliser, and reduces pollution of water resources. The idea to start harvesting nutrients from urine in South Africa and produce a fertiliser („vuna" means „to harvest" in isiZulu) initially emerged from the need to respond to sanitation challenges in the eThekwini Municipality. At the WISA Conference 2014, several articles as well as presentations cover the activities in the VUNA project. The present article introduces the project's background and presents an overview on the different activities. For details on the activities, please refer to the cited publications.

2 BACKGROUND

Adequate sanitation in South Africa

Providing adequate sanitation is a pressing problem in low- and middle-income countries. Within South Africa, the Basic Sanitation White Paper (DWAF, 2001) calls for universal access to basic sanitation by March 2010 (subsequently moved to 2014) and gives the municipalities authority and financial resources to meet the demands. The draft White Paper on National Sanitation Policy issued in 2002 (DWAF), uses the term "adequate sanitation" rather than basic sanitation and the criteria include that the service should promote health and safety, should be attainable and socially acceptable, environmentally friendly and technically sustainable. As a result, a number of innovative technological solutions have been developed and implemented, one of which is the urine diversion dehydration toilet (UDDT) applied within the rural areas of the eThekwini Municipality (Gounden et al., 2006).

Why urine diversion in eThekwini?

To date, in the region of 80 000 UDDTs have been installed in eThekwini, and these toilets operate by separating the urine and faeces at source, such that the urine flows into a soak away while the faeces are collected in a vault. Without the addition of water or urine, the faeces dehydrate rapidly and can be removed by the owner and buried on site. Infiltration of the urine into the soil is considered to be a preliminary solution as this will impact the environment if applied on a large scale (Nyenje et al., 2010). To explore new solutions for further urine use has been the main motivation for the VUNA project, which is described in this paper.

Previously, the eThekwini Municipality had also installed ventilation improved pit latrines (VIP) in certain areas. However, VIPs require regular emptying of considerable volumes of faecal sludge, which is inconvenient to handle. The liquid from latrine pits infiltrates into the ground and may reach the groundwater, thereby causing not only environmental pollution but also a health hazard

(Jacks et al., 1998, Cronin et al, 2007).

Although UDDTs have responded to the criteria of sustainability set by the municipality, low satisfaction levels with the facilities by the users have been reported. The social acceptance research, which was carried out a decade after the installation of UDDTs started, emphasises the importance of educational activities that stress the value derived from reusing urine in agriculture (Roma et al., 2013).

Urine as a resource

In view of the increasing pollution of water resources and uncertain access to fertiliser in low-income countries, nutrient recovery from waste streams has gained popularity over the past years. The fact that urine contains most nutrients excreted by humans (Larsen & Gujer, 1996) has attracted the attention of researchers. With eThekwini's sanitation programme envisioning the sustainable reuse of urine, adequate systems and technologies for nutrient recovery had to be installed. Several treatment technologies have been known to extract nutrients from urine such as electrodialysis (Pronk et al. 2006), struvite precipitation (Etter et al. 2011) or nitrification/distillation (Udert and Wächter, 2012). While some projects targeted sanitation issues in low-income countries, e.g. in Nepal (project STUN, Etter et al. 2011), a large trans-disciplinary study was conducted at Eawag (Swiss Federal Institute of Aquatic Science and Technology) to evaluate separate management of urine in an high-income country such as Switzerland (project Novaquatis, Larsen et al. 2009).

VUNA project: background and objectives

The VUNA (Valorisation of Urine Nutrients in Africa) project is a multi-disciplinary collaborative project funded by the Bill and Melinda Gates Foundation to undertake further research into the collection and processing of urine from UDDTs. The aim of the project is to recover the nutrients present in urine in order to produce a valuable product (fertiliser). Eawag, the Swiss Federal Institute of Aquatic Science and Technology is the lead organisation on this project, with eThekwini Water and Sanitation (EWS), the University of KwaZulu-Natal (Pollution Research Group, PRG), and the Swiss Federal Institutes of Technology Zurich and Lausanne (ETHZ resp. EPFL) as project partners.

The overall aim of the project is to establish a urine collection, processing and management system in eThekwini that can be used as a model for other regions in low and high-income countries. The eThekwini Municipality has identified a number of objectives it wishes to achieve through its involvement in the project. In other words, the sustainable use of urine is to:

- *Promote the use of toilets* by giving urine a value, ultimately reducing open defecation and resulting hygiene problems;
- *Produce a valuable fertiliser,* which can either be sold or used in the local agriculture, developing local businesses;
- *Protect the environment* by cutting down water use and preventing pollution of ground and surface waters by nutrients.

These three main objectives are encapsulated in the term ‚valorisation', which, in the case of VUNA, describes the concept of basing adequate sanitation on the recycling of nutrients from urine. Furthermore, by valorising nutrients, we aim to remove the stigma that dry sanitation is for poor people only. In order to develop a safe process, we are also analysing the hygienic risks associated with urine handling and processing, as well as the risks inherent to the final fertiliser product.

3 PROJECT ACTIVITIES

To develop a suitable sanitation system based on nutrient recovery from urine, the VUNA project embarked on a range of activities covering various aspects from the collection of urine over the processing to the final product. The project can be broadly divided into the following three research areas:

Reactor technology: develop reactor technology to process the urine on both a laboratory and field scale.

Network Management: establish a reliable urine collection network and management of a treatment network.

Socio-economic boundaries: testing whether the financial means derived from the fertiliser value of urine can be used to promote urine collection; and investigating the social acceptance of using fertilizer generated from urine.

Fig.1: Activities of the VUNA project covering a broad range of aspects on nutrient recovery from urine: from urine collection at the toilets to the final fertiliser product. Detailed descriptions on all activities can be downloaded from the project website: www.vuna.ch

Each of these objectives is structured as separate projects within VUNA and is led by various researchers from Eawag, UKZN, EWS, and ETHZ. Over the project duration, several activities have been expanded and add-on projects joined the VUNA framework, e.g. the research on hygiene issues associated to urine treatment (carried out at EPFL), the development of a business model embracing the service chain from urine collection to the final fertiliser product (Eawag Social Sciences Department), and the agricultural trials using the urine-derived fertilisers issued from the VUNA processes.

Detailed documentation of each aspect will be undertaken on conclusion of the project by the relevant research team. At the WISA Conference 2014, several articles as well as presentations, will cover the respective activities comprised in the VUNA project. The present article introduces the project's background and presents an overview on the different activities. For details on the activities, please refer to the cited publications. Figure 1 gives an overview on the diverse activities embraced by the VUNA project.

Reactor technology: process urine to extract nutrients

Urine treatment processes were developed and tested in parallel in South Africa and Switzerland. By testing reactors with different technologies and at varying scale, the team of researchers was able to explore a broad range of potential treatment options. For a detailed description of all processes refer to the paper presented at the WISA Conference by Udert et al. (2014). In summary, the combined nitrification-distillation process proved to be the most comprehensive nutrient recovery process (Etter et al., 2013), recovering all nutrients (e.g. nitrogen, phosphorus, potassium, sulphur) contained in urine in a concentrated nutrient solution at the Eawag main building. In the field in eThekwini, struvite ($MgNH4PO4•6H2O$) precipitation from urine was thoroughly tested (Rhoton et al., 2014; Grau et al., 2012). Whereas nitrification-distillation recovers all nutrients, it is more complex in its operation, given that nitrification is a biological process, which requires close control of parameters, such as pH, and a reliable control mechanism. The process needs a constant inflow and is assumed to be more stable in larger installations. The most adequate plant size and spatial distribution will have to be balanced with the urine transport distance. As opposed to nitrification, struvite precipitation is a physicochemical process, which can be operated intermittently and on demand, though it recovers mainly phosphorus (> 90%), and only a minor fraction of the nitrogen (5%) contained in urine. In addition to the low overall recovery rates, struvite production requires to add chemical reactants (magnesium). Researchers at Eawag also investigated electrochemical treatment of urine. It features certain advantages in comparison with other nitrification or struvite precipitation: reactor dimensions can be kept to a minimum, i.e. small units in individual toilets could treat urine directly at the source. Treatment units can also be switched on and off on demand. Nevertheless, research on electrochemical urine treatment is still at an early stage at present. Thus, practical knowledge will yet have to be acquired (Zöllig et al., 2013).

Safety has been of concern for VUNA researchers and municipality staff, given that urine is likely to contain pathogens (e.g. helminths, bacteria, viruses) and pharmaceutical residues and their respective metabolites, which are excreted from the human body primarily via urine. Microbial studies have investigated the inactivation rates and mechanisms of different types of pathogens, which may be found in urine. Results indicate that helminth eggs and viruses are of concern in struvite, whereas bacteria are more likely to die off during the drying process (Decrey et al., 2011). In the nitrification process, similar results where found, i.e. viruses survive the nitrification process, whereas bacteria are in general inactivated during the biological process (Schertenleib, 2014). However, if distillation is used as the final process step, all pathogens are disintegrated due to the high temperatures. The present results from microbial studies lay the foundation for a potential future microbial risk assessment (MRA), which will provide guidance in establishing safe urine handling procedures. As an instance, the assessed risk will assist to select the most appropriate urine collection scheme.

Besides pathogens, pharmaceutical residues in urine may impede the quality of the final fertiliser product, given the substances' toxic effect on the environment. To determine, which substances are present in urine, a first screening was carried out on a collective sample in eThekwini. Based on the findings, relevant pharmaceuticals were selected for laboratory tests and degradation throughout urine storage and processing in the nitrification reactor was measured (Oezel et al., 2013). The study demonstrated that most pharmaceuticals are degraded during the nitrification process and that the remaining substances can be efficiently eliminated in an additional process step, i.e. through adsorption on activated carbon.

Network management: optimise urine collection schemes

In the peri-urban areas of the eThekwini municipality, various setups have been tested to collect urine from urine-diverting dry toilets (UDDT). The urine pick-up at a household or community level has been accompanied by economic studies (see below) and computer modelling to maximise the volumes of collected urine (Rossboth, 2013). Figure 2 shows the schematic pathway of the urine from the households to the treatment reactors and the final product. The study presented at the WISA Conference by Joseph and co-authors (2014) covers both logistic and economic aspects of the urine collection.

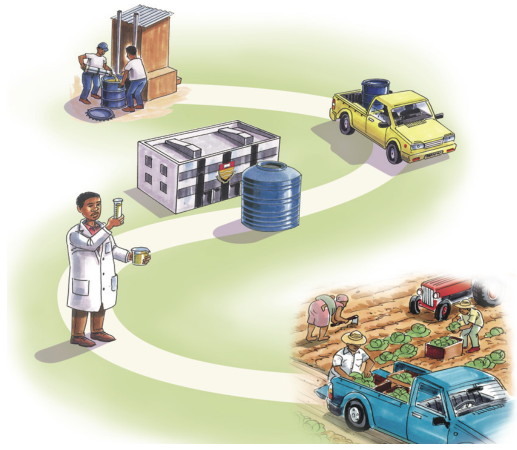

Fig. 2: The pathway of urine from collection to the final product.

Both practice and accompanying studies showed that optimising urine yield through collection relies on multiple aspects ranging from urine tank size, collection frequency and mode, to community awareness and social acceptance. At the Eawag buildings, urine is collected through an in-house pipe system from urine-diverting flush toilets. The same toilets will be integrated into the new building at the EWS headquarters in Durban. Currently, the urine is sourced from the waterless urinals in the building.

The volume of urine collected over the project period increased substantially in the peri-urban areas of eThekwini. We assume that initially low acceptance of UDDT by users led to low toilet usage rates, as reported by Roma et al. (2013). With the inception of the urine collection, people experienced additional motivation to use their toilet. In 2013, the capacity of the collection system attained several 1000 ℓ per week, which were collected from approximately 700 households. With the present setting (as of January 2014), urine volume stabilised at 1400 ℓ per week, which are currently collected from 300 households. In further trials to be launched in the coming months, new scenarios for urine collection will be tested at a larger scale (Joseph et al., 2014). The results of this study will direct the municipality on which type of collection scheme it will adopt.

Socio-economic boundaries: increase acceptance

To explore the socio-economic boundaries of fertiliser production from urine, field studies backed up with community surveys have been conducted. In a trial incentive scheme, the community was compensated to drop off urine at centralised collection points. Motivated field staff has proven to be crucial for a successful implementation. In two on-going studies, social acceptance of urine-diverting toilets and use of urine-derived fertilisers are under investigation and will be presented at the WISA conference (Mkhize et al., 2014). As low satisfaction of toilet users had been reported previously, the eThekwini Municipality has intensified its awareness programmes and developed educational material specifically designed for UDDT users. Currently, health promoters are visiting families to discuss the implications of toilet usage and good hygiene. As the concept of using urine as a fertiliser is new to the population (Benoit, 2012), both challenges and opportunities arise from it. As a consequence, the educational campaign along with other channels, such as agricultural trainings, will have to incorporate and properly divulgate nutrient recovery.

To institutionalise the supply chain from urine collection to fertiliser production and sale, various scenarios for a business model are currently examined (Joseph et al., 2014). Furthermore, to assure an efficient and safe end-product, crop scientists in Zurich (Bonvin, 2013; Meyer et al., 2014) and Durban have tested the urine-derived fertilisers in greenhouse and field trials. The results show that the products equal or outperform comparable synthetic fertiliser in quality. Further tests with a wider variety of crops and on several soil types will be carried out in the near future.

4 CONCLUSIONS AND OUTLOOK

In summary, a first scale-up of nutrient recovery technologies from urine has been successfully concluded in eThekwini. Further up-scaling steps are in the planning process. Based on the current findings, eThekwini is decisively moving forward towards broad application of nutrient recovery from urine. In this regard, the VUNA project has been instrumental in bringing together the varying aspects that have to be considered to develop and implement new systems and technologies.

Challenges to expand nutrient recovery from the current pilot scale to a wide-spread implementation lie in a first step in the collection logistics and management that have a major influence on the system‘s costs, then in the second step, in establishing stable processes to treat urine in an efficient way and obtain a high quality product, and thirdly, in assuring that the final products meet hygiene and environmental standards by assessing the associated microbial risk and eco-toxicity. If the VUNA project delivers solution to these challenges over the final project phase in the current year, nutrient recovery from urine is expected to unfold its potential over the near future.

5 ACKNOWLEDGEMENTS

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