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Struvite

recovery from urine at community scale in Nepal

Project intermediate report submitted to EPFL

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Struvite recovery from urine at community scale in Nepal STUN

STUN is a joint collaboration project of Eawag (Swiss Federal Institute of Aquatic Science and Technology) and UN-Habitat Nepal (The United Nations Human Settlement Programme). The present report is submitted to EPFL (Swiss Federal Institute of Technology Lausanne) as project report for the MSc in Environmental Sciences and Engineering.

Projet SIE

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Abstract

The practical part of the STUN project, dealing with the set-up and operation of a pilot scale struvite production process, has provided valuable information on the following aspects:

- Volumes of 300 to 400 litres of urine per day can be easily collected by the 'pee-cycle' from toilets from the surrounding area.
- Setting up a struvite reactor with locally available materials will cost less than 100 NRs (1 €) per litre treatment capacity.
- Struvite precipitation using locally available industrial grade MgSO_4 does not achieve maximum efficiency.
- Bittern, the waste-product from sea salt manufacture, may be used as an efficient struvite precipitating agent, due to its high Mg content.
- Struvite settles completely to the reactor's bottom within 1 to 2 days.
- Separating the struvite powder from the liquid is of major concern, as the tested filters retained a maximum of 50% solids.
- Further processing of the process effluent will increase the benefits of struvite production.
- The STUN project received a broad interest from various stakeholders.

Acronyms

- AIC Agriculture Input Company
- CIUD Centre for Integrated Urban Development
- DAP di-ammonium phosphate (NH₄)₂HPO₄
- Eawag Swiss Federal Institute of Aquatic Science and Technology
- EcoSan ecological sanitation
- ENPHO Environmental and Public Health Organization
- EPFL Swiss Federal Institute of Technology Lausanne
- FAO Food and Agriculture Organization of the United Nations
- HRT hydraulic retention time
- NARC National Agricultural Research Council
- NRs Nepalese rupees (present exchange rate: 1 € ≈ 100 NRs)
- PE polyethylene
- PET polyethylene terephthalate
- PP polypropylene
- Sandec Department for Water and Sanitation in Developing Countries (at Eawag)
- SDC Swiss Agency for Development and Cooperation
- STUN Struvite recovery from urine at community scale in Nepal
- UC user committee
- UD urine diversion
- UN-Habitat The United Nations Human Settlement Programme
- VDC village development committee
- WAC Water for Asian Cities (Programme of UN-Habitat)

Nepali Glossary

- Aanaa Area unit used in Nepal. 1 Aanaa ≈ 30 m²
- Lalitpur District to the south of Kathmandu, containing Lalitpur Sub-Metropolitan City as well as peri-urban settlements
- Nauga Ash pit at the bottom of the staircase of a Newari house
- Newari Indigenous people of the Kathmandu Valley
- Ropani Area unit used in Nepal. 1 Ropani = 16 Aanaa ≈ 500 m²
- Rupee Present exchange rate: 1 € ≈ 100 NRs
- Saaga Traditional compost pit in the courtyard garden of a Newari house
- Sukul Woven rice straw mat crafted in Siddhipur

1

Introduction

*Converting urine into
fertilizer – giving an
extra value to human
excreta*

Just flush, and your excreta go down the drain. In a conventional sanitation approach, our urine and faeces are flushed away by water, only to disappear in the sewer and reach, at some point, treated or untreated, the nearby river, lake or sea. The numerous nutrients contained in the urine and faeces are hereby lost.

EcoSan, the concept 'ecological sanitation' remedies the issues of this "all down the gutter" approach by locally separating urine and faeces, to store them for further use. Faeces find their way back to mother earth through composting, whereas urine, as a valuable nutrient source, can be applied to the field as a natural fertilizer. Nevertheless, collecting, transporting and spreading urine might not always be that straightforward. Large volumes impede cost-effective storage and transportation.

As an alternative, urine may be converted into powder, concentrating some of its beneficial values in a white, odourless material. Implementing this process, known as struvite precipitation, in a heavily urbanized Kathmandu Valley seemed like a great challenge, when I heard about the proposition for an internship in Nepal.

Although struvite precipitation has been used in various settings, it had remained a rather exclusive technology used in pilot plants and conceptual sewer systems. To combine these features with a practical research project, including some 'bricolage' of course, caught my attention.

According to our goals, the powdered urine shall facilitate nutrient recycling, transportation and storage, in order to combine sanitation and sustainable soil management. Everybody will be able to contribute his or her share to healthy vegetables from the farm.

2

Background

*Urine diversion and
nutrient recovery
around the world*

2.1 Urine separation as a sanitation technology in Nepal – giving a value to human waste

The rural exodus leading to rapidly growing cities and densely populated urban areas has made sanitation one of the main concerns of public health and environmental preservation. In a traditional Nepal, scattered settlements in a mountainous region did not require any special treatment for human waste. Most people practiced and still practice open defecation, closing thereby the nutrient cycle at a most local level.

Many households still lack proper sanitary installations. In some peri-urban settlements, designated public defecation areas are available for the families, who do not have a toilet at their home. These public defecation areas consist mainly of a paved surface surrounded by a brick wall to guarantee the users a minimum of privacy for their business below the open sky.

Sewer systems are limited to the central metropolitan area of Kathmandu City, as well as parts of Lalitpur Sub-Metropolitan City. Historically, the Newar cities of Kathmandu and Lalitpur comprehended sophisticated drinking water supply, drainage and sewer systems comparable to the ones found in the cities of the Roman Empire. The Newars conveyed their wastewater to vast infiltration beds at the outskirts of the city. With the ongoing expansion of the cities, the sewer pipes have simply been extended to the banks of Bagmati River, which nowadays serves as main sewer for all of Greater Kathmandu. The heavy pollution of Bagmati has led to eutrophication of large areas and causes severe environmental and public health risks.

The urine diversion (UD) concept of Eco-San was first brought to Nepal in 2002 [ENPHO, 2007], as an innovative approach to low-cost and efficient human waste management. By diverting the various waste streams – urine and faeces – the system creates additional value; the waste products find their way back to the nutrient cycle, instead of entailing costly and technology intensive treatment.

In an UD toilet, faeces are stored togeth-



ENPHO

An EcoSan toilet pan – The urine is diverted into a plastic storage tank.



ENPHO

An EcoSan toilet in Siddhipur – The dehydration vaults are made of concrete, the superstructure of brick masonry. The urine is diverted into a 100 L PP tank adjacent to the construction

er with some additives, such as sawdust, straw or ashes. The subsequent desiccation provides an appropriate hygienization, in order to prevent the spreading of pathogens to food crops. Pathogens in the urine will be eliminated with storage time, as degradation of urea into ammonium, will cause pH to increase to 9 - 9.3 [Jönsson, 2004]. Joint storage of urine and faeces creates a humid and pH buffered medium, and therefore an ideal breeding ground for pathogens.

In Nepal, the most commonly adopted system for EcoSan toilets contains two dehydration vaults for alternating use, as described by the Environment and Public Health Organization ENPHO [2007]. At present, about 500 EcoSan toilets are operable throughout the country, to a majority in the Kathmandu Valley. The Nepalese EcoSan version is completely constructed above the ground, as groundwater tables are close to the surface, thus dug pits are not appropriate.

From the most recent series of EcoSan toilets constructed by ENPHO, the urine is diverted directly into a 100 L plastic storage tank with a tap at its bottom for easy emptying. The urine in these storage tanks is continuously turned over, wherefore optimum hygienization might not be obtained [Spuhler, 2008].

The acceptance of EcoSan as sanitation technology depends upon the tradition of recycling human excreta in agriculture, varying from one ethnic group to another. The social pattern in Nepal has maintained an extreme diversity with numerous ethnic groups living mainly in separated villages but yet close to one another. The indigenous inhabitants of the Kathmandu Valley, the Newar people, have practised composting and farmyard manure application for many centuries. Thus, Newars do not hesitate to use human excreta as a fertilizer.

As for higher casts of the traditional Hindu cast system, such as Chetri and Brahmin, recycling human waste is an unknown practice. Acceptance in these social groups might be lower, although the cast system loses its influence day by day [Khadka, R.].

2.2 Nutrient recovery from waste streams – closing cycles at different levels

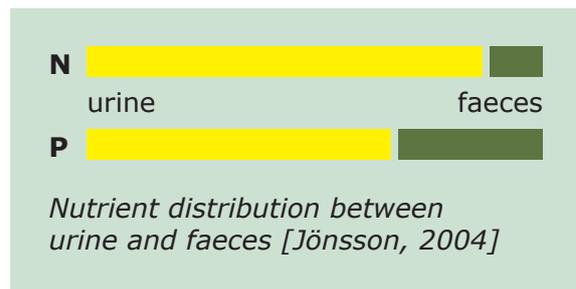
The FAO distinguishes three levels of plant nutrient cycles linking production and consumption [Roy, 2006]:

1. On-farm nutrient cycles: The nutrient cycles within a farm can never be completely closed due to natural losses or gains, for instance ammonia evaporation or biological nitrogen fixation. Nevertheless, an appropriate management of the farm's waste streams can prevent useless losses and reduce need for external nutrient supply.
2. Regional nutrient transfer: Increasing urbanization leads to a steady nutrient flow to the urban areas. At this level, efforts have been made to recover nutrients from wastewater, in order to transfer them back to agricultural production. Nevertheless, the quality of these recycled nutrients has shown to be doubtful, as in the case of heavy metal pollution in sewer sludge.
3. International nutrient transfer: Nutrients are transferred at an international level both with synthetic fertilizer trade and import respectively exports of large quantities of food crops.

According to FAO Plant Nutrition for Food Security - A Guide for Integrated Nutrient Management [Roy, 2006]: 'Only strict rules for recycling and efficient use could postpone the first serious shortage of an essential plant nutrient.'

Human waste products – the raw material for nutrient recovery

Jönsson et al. [2004] measured the partition of nutrients between urine and faeces for Sweden: 88% of the nitrogen and 67% of the phosphorous excreted by the human body are found in the urine. These results were combined with food supply estimations for different countries, to calculate the nutrient content in urine as a function of the diet. According to these estimations, an average Indian excretes 2.3 kg N and 0.3 P per year in his urine. Besides N and P, urine also contains considerable amounts of potassium and sul-



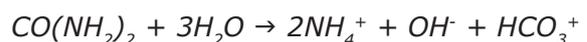
phur, as well as other essential minerals in smaller quantities (Mg, Ca etc.).

These figures explain, why urine separation at the source is the most efficient way of nutrient recovery from human waste products. Great efforts have been undertaken to improve nutrient recycling at the different levels. The following paragraphs shall present an overview on the various nutrient recovery approaches and technologies, from a local to a global scale:

Direct application – closing cycles as locally as possible

The nutrients excreted in urine are all readily plant-available and thus a quick-acting fertilizer, if applied correctly [Jönsson, 2004]:

N 75-90% of N is excreted as urea and the rest mainly as ammonium and creatinine $C_7H_4N_3O$. If applied immediately to the field, the urease present in the soil degrades the urea into ammonium according to the following equation. The same process takes place, if urine is stored, given that urease is present nearly anywhere in a natural environment. Ammonium is directly available to plants:



P Almost entirely excreted as PO_4^{3-} , which is readily plant-available.

K Entirely ionic composition, direct uptake by the plants.

S Excreted as SO_4^{2-} , another plant-available ion.

Urine has to be stored in tight containers in order to prevent N losses due to ammonium evaporation. For the same reason, the urine has to be spread as close to the soil as possible, in order to prevent prolonged contact with the air.

33% of EcoSan users in Nepal use direct application of urine to the fields, during the plants' growing period [ENPHO, 2007]. Its nutrients are best utilized if the urine is applied from prior to sowing, up until two-thirds of the period between sowing and harvest [Jönsson et al, 2004].

During storage, the urea present in fresh urine is degraded into ammonium and CO₂ by urease. This brings about an increase in pH and in the ammonium concentration in the stored urine. This increase in pH causes the magnesium contained naturally in the urine to react with part of the phosphate and ammonium, forming a natural struvite deposit in the storage tank. To prevent clogging and accumulation of excess struvite, the content of the storage tank has to be thoroughly mixed prior to urine extraction for direct application as fertilizer.

Through the pH increase caused by urea degradation during urine storage, pathogens are eliminated efficiently. Remains of ecotoxic substances in the urine, such as antibiotics or endocrine disrupters, might reduce the adequacy of urine as direct fertilizer.



Improved compost covered with maize husks, as recommended by the Sustainable Soil Management Programme SSMP.

Co-composting – the convenient solution

The desiccated faeces produced in EcoSan toilets are stored outside the toilet's dehydration vaults before being applied to the fields. At this stage, many EcoSan users in the Kathmandu Valley practice the so-called co-composting, by pouring the urine from the collection tank onto the compost pile. It prevents the farmers from transporting large volumes of urine to their fields, which may lie at up to 1 hour walking distance. The negative aspect of co-composting is its high N losses due to high ammonium evaporation.

46% of EcoSan users in Nepal use mainly co-composting for the treatment of their urine [ENPHO, 2007], whereas 19% pour the urine down the drain if it is not needed on the field or not used for composting. The remaining 2% of EcoSan users state that they supply their urine to their neighbours for further use on the fields.

Improved farmyard manure – using cattle urine as fertilizer

Within the framework of the Sustainable Soil Management Programme SSMP by Helvetas Nepal, the use of cattle urine is promoted in rural communities [Rajbhandari, N.]. The SSMP describes its recommendations on various fact sheets of the NEPCAT series (Nepal Conservation Approaches and Technologies). The implemented techniques range from improved composting of farmyard manure through sunlight, rain and runoff protection to urine collection from cow sheds. The fact sheets propose direct application of the urine or a combination with drip irrigation, so-called fertigation [ICIMOD, 2008].

At present, SSMP focuses mainly on N recycling, as it is the most important nutrient and deficient in many mountainous areas throughout Nepal [Allen, R.]. For the purpose of poverty alleviation and soil conservation in rural areas, P recovery requires too complicated technology. The SSMP prioritizes local nutrient retention (e.g. cultivation of leguminous plants for gaseous N fixation or storage and reuse of cattle urine). If local nutrients are not sufficient, external resources have to bridge the nutrient gap.

Industrial processing – closing the loop with high energy use

A wide range of nutrient recovery technologies has been developed and studied for wastewater treatment. Few of them have found their way into the practice of municipal or industrial wastewater treatment. Considering N, there are two principles of recovering this nutrient from wastewater and making it available for farming [Maurer, 2003]:

- Transformation of nitrogen compounds into gaseous nitrogen by nitrification and denitrification, and technical ammonia production with the Haber-Bosch process ('recycling over the atmosphere').
- Direct recovery from liquid waste and conversion into a reusable form.

For the direct recovery of nutrients, including P, few applications at real scale exist. Some of the studied technologies:

- *Ammonia stripping* with air and subsequent dissolution of the ammonia in an acid solution.
- *Concentration* of nutrients through evaporation of excess liquid.
- *Freeze-thawing* with extraction of concentrated liquid.
- *Reverse osmosis*: nutrients are retained by a membrane.
- *Ion exchange on zeolites*: fixation of ammonium-ions.
- *Electrodialysis*: the ions are separated through an electric current.

All of the above mentioned technologies require a high energy supply. For the context of a developing country, such as Nepal, they are certainly not appropriate. As an option to these high-energy technologies, struvite production is based on a simple precipitation reaction and does not require any extra energy source except for mixing. The process shall be explained in detail in the following chapter.

At present, struvite reactors have been developed for small-scale treatment plants

for nutrient recovery from municipal wastewater (the nutrients are mostly recovered from the digester supernatants), landfill leachates or animal waste slurries.

Research at Eawag – struvite from problem to opportunity

Eawag has investigated struvite precipitation from the problem it causes in pipes [Udert, 2003a,b,c] to the opportunity it creates for nutrient recycling. The long-term project NOVAQUATIS gathered valuable practical experience on nutrient recovery from source separated urine. The new Eawag office building in Dübendorf near Zürich is completely equipped with UD NoMix toilets to collect urine for experimental purposes.

The research on nutrient recovery from urine conducted at Eawag includes aspects such as thermodynamics, solubility [Ronteltap, 2007a] and quality concerning micro-pollutants [Ronteltap, 2007b]. Urine processing was also examined from an energetic point of view [Maurer, 2003 & 2006].

Up to now, the research at Eawag has focused mainly on high-end solutions, for complex sanitation infrastructures, without considering simple technologies for application in developing countries. The STUN project, described in this report, aims to develop the first low-cost precipitation reactor for struvite production in developing countries.

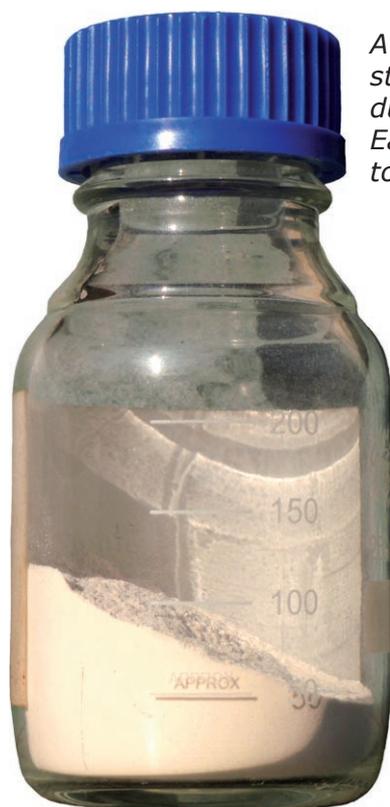
2.3 Struvite precipitation from urine

Amongst the possibilities for nutrient recovery from urine, struvite precipitation is technologically most accessible, as it does not necessarily involve any sophisticated apparatus. Combined with the concept of EcoSan toilets, this technology will hopefully provide some improved sanitation coverage.

Where direct application of urine is not an option, and external sources of nutrients are not available or economically or environmentally not adequate, struvite may serve as an intermediate solution between on-farm nutrient recycling and global nutrient transfer.

Why produce struvite? – concentrating the urine's nutrients

In comparison with directly applied urine, struvite compacts the nutrients contained in urine into a white odourless powder. Therefore, weight and volume are reduced to a strict minimum, in order to facilitate transportation, storage over longer time periods and handling.



A sample of struvite produced in the Eawag laboratory.

Reaction formula and dynamics

By adding a source of Mg-ions to stored urine, struvite (magnesium ammonium phosphate hexa-hydrate) will precipitate according to the following formula:



Struvite is least soluble in an alkaline medium (pH 9), thus stored urine (pH 9 to 9.3) provides ideal precipitation conditions. At laboratory scale, magnesium oxide MgO, magnesium chloride MgCl₂ or magnesium sulphate MgSO₄ solutions are added to the stored urine to trigger precipitation.

Magnesium may also be obtained from different sources, such as bittern (the remaining salt brine after NaCl extraction from seawater) or magnesite minerals. For further description of alternative magnesium sources refer to chapter 5.2 (p. 33).

Ronteltap et al. [2007] determined the conditional solubility product for struvite solubility in urine at 25°C, pH = 9, and ionic strength I = 0.4 M:

$$K_s^{cond} = [\text{Mg}_{aq}] \cdot [\text{NH}_4^+ + \text{NH}_3] \cdot [\text{P}_{ortho}] = 10^{-7.57} \text{ M}^3$$

In general, struvite precipitation is improved by increasing pH (optimum at pH = 9), and controlling the supersaturation ratio Mg/P [Pastor, 2008 and Mavinic, 2007]. Higher hydraulic retention times HRT tend to reduce the crystal size and thus filtering efficiency.

Process in practice – linking precipitation and filtering

As shown in the previous chapters, the production of struvite is controlled by a simple precipitation combined with a filtering process. At laboratory scale, these steps can easily be carried out with common laboratory equipment.

The majority of pilot scale and real scale struvite precipitation reactors are tank reactors with a tapered bottom and a stirring mechanism. The struvite containing sludge is drained into a filter bag through an outlet at the bottom of the reactor. The

settling time for struvite increases with tank size. After sufficient settling, the supernatants can be drained through a decantation outlet above the sludge.

The filter materials used for the bags vary from fleece [Huber, 2008] to monofilament nylon or non-woven polypropylene fabric [Szögi, 2006]. An alternative consists in continuous flow processes, where precipitation and settlement are separated in two different compartments of the reactor. However, the struvite is harvested as sludge rather than as dry powder [Wilsenach, 2007].

Although the process itself, from a chemical point of view, is not too complex, practical applications for the liquid-solid separation have been based on rather sophisticated equipment. The challenge of implementing struvite precipitation in Nepal consisted to a large extent in adapting the cited meth-

ods to the constraints of locally available and low-cost materials.

Enhancing filter efficiency – recovering the precipitate

The filtering’s importance has not gotten the sufficient attention in the practical research on struvite production processes. Struvite precipitated from natural waste streams (human and animal urine) was shown to have a broad granulometric distribution. This property confers a risk of filter clogging or reduced filtering efficiency, if the fraction of small-size crystals is considerable. Crystal size can be increased, and filtering efficiency enhanced, by the addition of polymers, such as anionic polyacrylamide with concentration greater than 20mg·L⁻¹ [Szögi, 2006]. The same authors recommend filters with mesh size < 200 µm.

NPK values of fertilizers currently available in Nepal

The NPK values express the percentage of mass of the respective nutrients [g N·g⁻¹; g P₂O₅·g⁻¹; g K₂O·g⁻¹]

Urea (CO(NH ₂) ₂)	46:0:0	<div style="display: inline-block; width: 100px; height: 15px; background-color: #0070C0; border: 1px solid black;"></div>
DAP (di-ammonium phosphate)	18:46:0	<div style="display: inline-block; width: 100px; height: 15px; background-color: #0070C0; background-image: linear-gradient(to right, #0070C0 50%, #FFD700 50%); border: 1px solid black;"></div>
MOP (myriate of potash)	0:0:40-60	<div style="display: inline-block; width: 100px; height: 15px; background-color: #008000; border: 1px solid black;"></div>

In comparison to struvite

Struvite (magnesium ammonium phosphate)	6:29:0	<div style="display: inline-block; width: 100px; height: 15px; background-color: #0070C0; background-image: linear-gradient(to right, #0070C0 50%, #FFD700 50%); border: 1px solid black;"></div>
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Component fertilizers, such as the NPK 20:20:0 fertilizer in the picture, are mostly of doubtful quality. Controls are effectuated only sporadically. (By the way, Sagarmatha is the Nepali name for Mt. Everest)

2.4 Struvite application and soil fertility

Metal ammonium phosphate fertilizers (general formula $\text{MeNH}_4\text{PO}_4 \cdot x\text{H}_2\text{O}$) have been known as slow-release N, P and metal fertilizers, given their low solubility in water and soil solutions.

Due to the slow nutrient release, these fertilizers can be applied to plants at superior rates without risk of burning the roots or leaves. Bridger et al. [1962] tested the use of different metal ammonium phosphates as fertilizer. They obtained promising yield improvements after application of struvite in forest and agricultural species.

Struvite has been compared to commercial fertilizers in greenhouse and field studies. The effectiveness of the fertilizer powder recovered from urine was comparable to the one of commercial P fertilizers (di-ammonium phosphate DAP) [Ganrot, 2005 & 2007]. At certain instances, struvite was even proved to be more stimulating for plant growth than commercially available NPK fertilizers [El Diwani, 2007].

Negligible health risk arising from struvite use

Concerns on health risks due to heavy metal content or pharmaceutical residues in struvite fertilizer have been clarified, as no such harmful substances were found [Ronteltap, 2007]. As for commercial fertilizers, heavy metal concentration is certainly more doubtful and some deeper examination would be advisable.

Effects of the struvite production process on agriculture

In general, the application of Mg fertilizers tends to increase the pH in soils. As a positive side-effect, P becomes more plant-available in alkaline soils. Mg compounds, such as dolomite $(\text{Ca,Mg})\text{CO}_3$ have been used for correction of low pH in agricultural soils.

In parallel to struvite, the N-rich effluent of the struvite precipitation process may be used as liquid fertilizer. Practical aspects of this fertilizer's use are currently studied at the same site as the struvite recovery

in Nepal. Liquid or powder fertilizers can be combined with water in a drip irrigation system. The resulting technique is called 'fertigation'.



Jiban Maharjan from Siddhipur proudly displaying his radish grown using urine collected in his EcoSan toilet as fertilizer (through direct application).

2.5 Fertilizer balance in Nepal and Kathmandu Valley

The Kathmandu Valley is a wide plain nestled amidst the Himalayan foothills. Within the hilly region of Nepal, it constitutes one of the largest extents of flat land, wherefore people from all over the country have favoured this site for settlement. During the prehistoric era, the Valley was once covered by an enormous lake, which was only drained, when the Bagmati River dug its way through the rock barrier to the south of the Valley.

Clayey soils and urbanization pressure

Due to this past, the soils in the Kathmandu Valley have been renowned for their fertility. The fluvial and lacustrine deposits contain important clay and loam fractions. To a certain extent, the clayey topsoil has

been mined for brick manufacturing, leaving bare scars in the remaining cultural landscape of the Valley.

Nowadays, the on-going urbanization exercises steady pressure on soil resources in the Kathmandu Valley. According to local estimations, the Valley will be completely urbanized within 10 to 20 years. For the moment, the remaining agricultural land is mainly used for rice/paddy cultivation during the monsoon season, wheat cultivation during the dry season in the winter months.

Small fields close to the houses also serve for vegetable cultivation (eggplants, potato, cauliflower, spinach, onions, garlic, etc.). The vegetation period lasts all year round with the sole change between irrigation-intensive and dry-climate crops.



After the rice harvest, the fields are prepared for the wheat and potato crops. The soil in the entire Kathmandu Valley contains a high percentage of clays and loams.



Kathmandu City disappears in the haze. Millions of people have come to the city in the need of more security during the maoist conflict era. Nowadays, greater Kathmandu counts 5 million inhabitants.

Soil sampling at the STUN study site.



Acidity and nutrient deficiency

Soils in the Kathmandu Valley are in general acidic [Karki, K.B.]. Due to the continuous use, main nutrients are naturally deficient, and must be added from external sources. The practices of composting and manure application are not widely known throughout the Valley and frequently limited to the application of solid manure from livestock.

As a natural curative for soil acidity, ground dolomite is sometimes added to the soils. The SSMP recommends composting with addition of eggshells, in order to correct the pH at the compost level.

Cheap fertilizer for craving soils

Besides the SSMP, we have been working with the National Agriculture Research Council NARC and the International Centre for Integrated Mountain Development ICIMOD to deal with questions on soil science in the Kathmandu Valley. Although detailed soil fertility data is only available for very specific sites in Nepal, the overall experience shows that farmers try to remedy nutrient deficiency by adding synthetic fertilizer.

Urea enjoys the priority of most local farmers for its comparably cheap price and directly visible effects (N being an essential component for chlorophyll, high N inputs bring on shiny green leaves in plants). As a negative side-effect, the remaining nutrients in the soil are depleted and soil acidity raises.

In the matter of micro-nutrients, boron, molybdenum and zinc are deficient in Nepalese soils [Rajbhandari, N.].

Low fertilizer quality and informal fertilizer trade

Few farmers are aware of the complex nutrient balance; consequently consumption of fertilizers containing other elements than N is relatively low. Research from the National Department for Agriculture has also shown that most compound fertilizers are of poor quality, some of them containing far less nutrients than indicated [Mandal, S.N., report to be published].

Given that Nepal does not operate any mineral fertilizer production facility, all fertilizers sold in the country are imported from India. The Indian government froze official fertilizer prices in 2002. Present fertilizer prices are kept at this low level through heavy subsidies from the government [Gautam, P.].

As a result, Indian fertilizer is sold informally to Nepal. Obviously, the official imports cannot compete with these artificially low prices. According to the responsible at the National Department for Agriculture the fertilizer import into Nepal is completely 'out of government control' [Mandal, S.N.].

The Agricultural Inputs Company AIC, the Nepalese government agency charged with keeping sufficient fertilizer stocks for eventual shortages, estimates the informal imports to $100'000 \text{ t}\cdot\text{a}^{-1}$ [Gautam, AIC]. As an instance, the subsidized Indian urea is sold at $8 \text{ NRs}\cdot\text{kg}^{-1}$ (0.08 €) at the Nepalese border crossing points. By the time it has reached the Kathmandu Valley, its retail price has augmented to $24 \text{ NRs}\cdot\text{kg}^{-1}$ (0.24 €). If the initial fertilizer sale did not receive any subsidies, the price at the border would attain an estimated $57 \text{ NRs}\cdot\text{kg}^{-1}$ (0.57 €) [Mandal, S.N.].

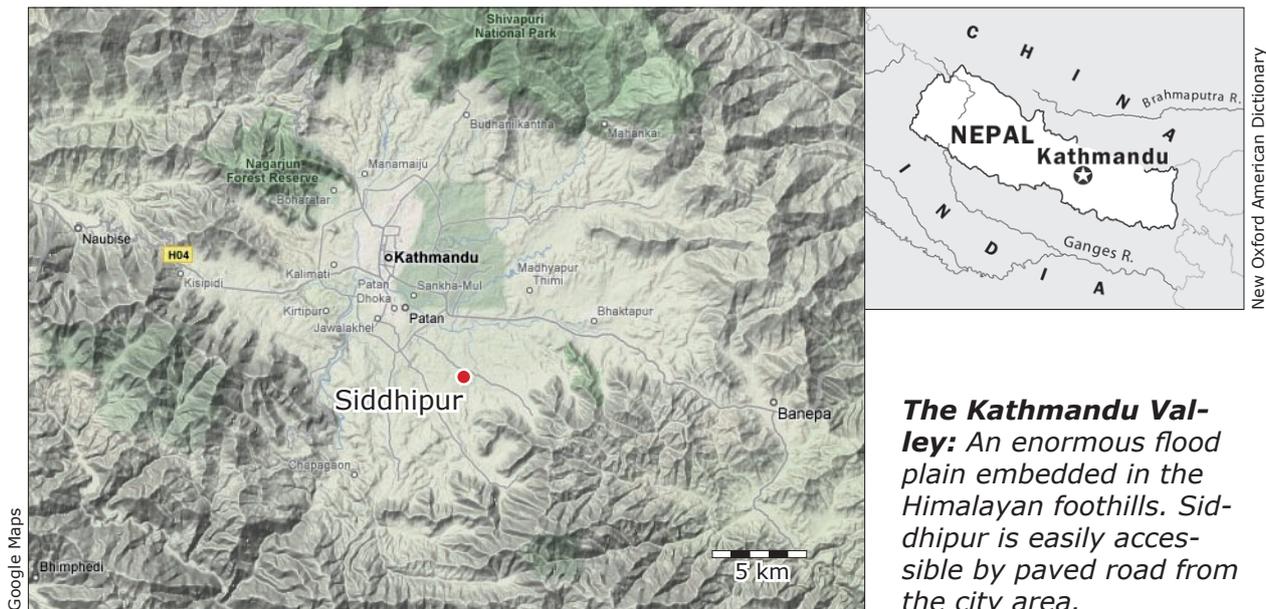
2.6 Siddhipur – farming in the peri-urban area

The town of Siddhipur (also known as Sangaon) at approximately 5 km distance from Lalitpur Sub-Metropolitan City is a traditional Newar settlement with about 6000 inhabitants. 90% of the inhabitants are engaged in agriculture, although numerous persons have a secondary occupation (e.g. small business, handicrafts such as weaving sukul, commuter to the city etc.) [Gantenbein & Khadka, 2008].

Most families in Siddhipur practice agriculture for self-subsistence following the traditional alternating crop cycle: Paddy/rice is planted during the monsoon season, when sufficient water for irrigation

is available. After the rice harvest at the end of the monsoon in Asoj (Nepali month lasting from mid September to mid October), the same fields are used to cultivate wheat. Small plots in the backyards serve as vegetable garden.

At an average of 4.6 family members per household, every family grows its food supplies on roughly 1 to 2 ropani (500 to 1000 m²) of land. As in many traditional Newar communities, tall houses gather snugly around the core area, leaving little space for agricultural surface. Thus, villagers often have to endeavour to long walks before reaching their fields.



2.7 Administrative structures in Siddhipur

In Nepal, villages are governed by the so-called Village Development Committees VDC. The local VDC of Siddhipur is momentarily out of function, as elections have not been held for the replacement of the former committee members. Although these administrative structures are not operable at the moment, some of the community's facilities are well managed by specific user committees.

For instance, the Siddhipur Water Supply and Sanitation User Committee administers the town's drinking water supply and

sanitation issues. Within the User Committee, a special sub-committee deals with sanitation, especially the construction of EcoSan toilets in collaboration with different NGOs, such as ENPHO or CIUD.

Starting in 2006, an extensive water supply and sanitation programme was carried out in Siddhipur by a joint collaboration between the community, ENPHO and the Water for Asian Cities WAC Programme by UN-Habitat. The programme provided access to safe drinking water for a majority of the households.

3

Objectives

Set up an integrated struvite production process in Nepal

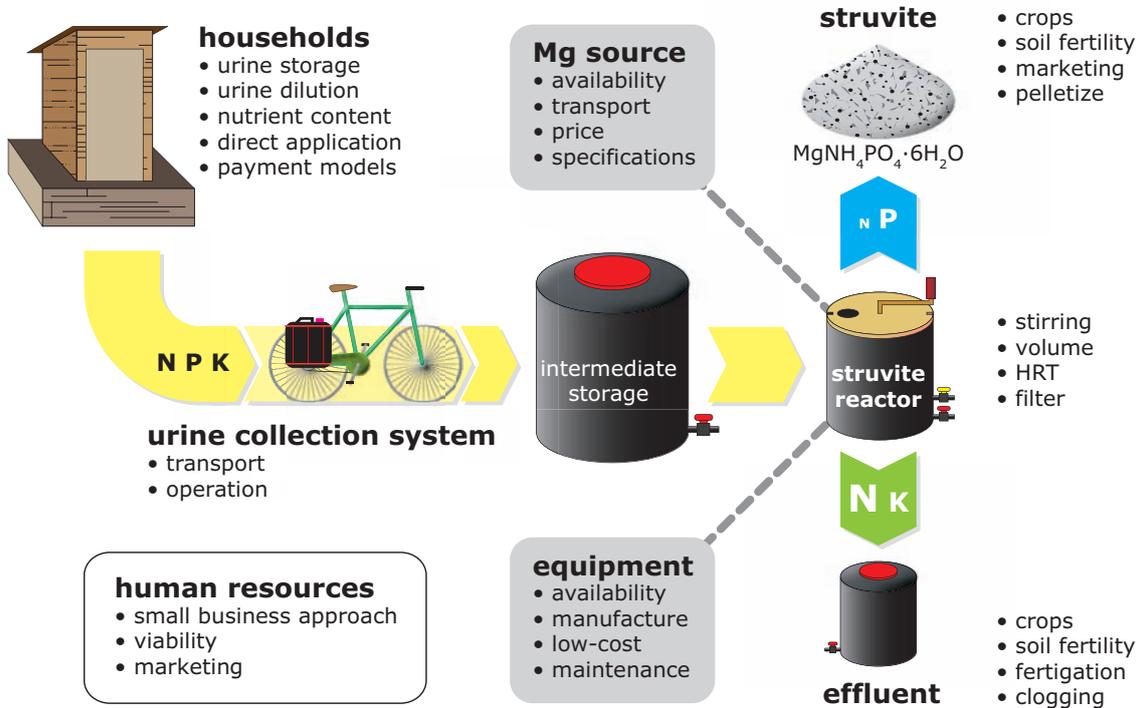
Within the framework of the project *Struvite recovery from urine at community scale in Nepal STUN*, the present report examines the practical aspects of struvite production from urine collected in EcoSan toilets in Siddhipur. The main focus lies on the struvite precipitation reactor as central element of the production process. In order to achieve viability in struvite production, the following steps need to be studied in detail:

1. Process inputs: The process requires various inputs, from urine over magnesium to labour. Their availability is substantial for the operation of the process.
2. Process operation: From the set-up to the optimized procedure, the production process plays the key role in the struvite recovery.
3. Process outputs: The management of the outputs from struvite to the N-rich effluent will finally decide upon the success of the project.

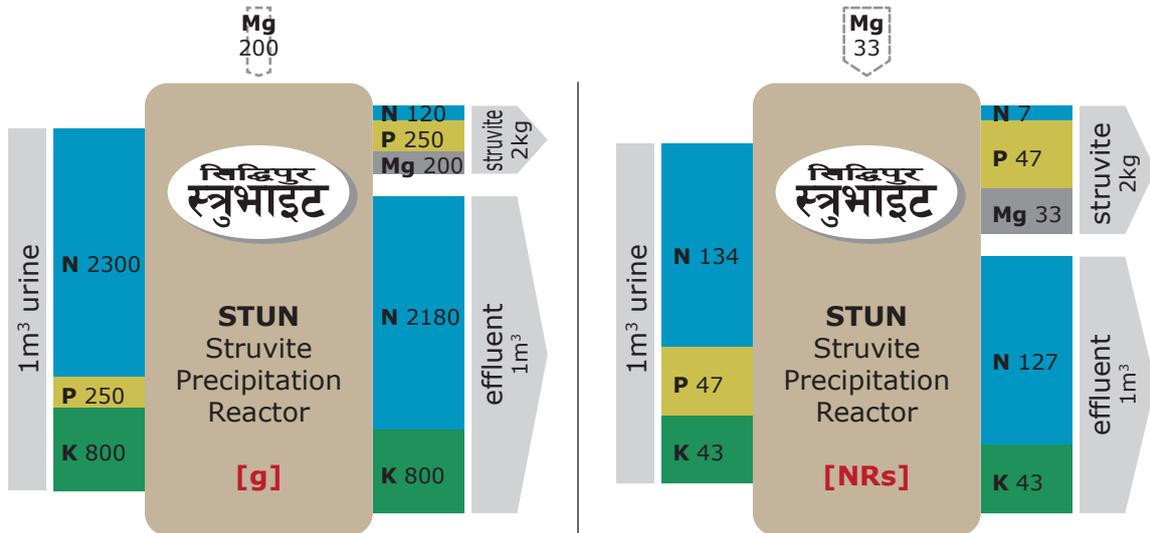
With regards on these steps, the goal of the STUN project lies in the establishment of a struvite production process matching the following criteria:

1. Simplicity in operation and low-maintenance, using locally available materials.
2. Reproducibility to assure that similar installations can be set up locally without specific technical knowledge.
3. The process has to be economically viable to make struvite an interesting option to mineral fertilizer.

STUN struvite production – process implications



STUN struvite production – nutrient monetary and mass flow



Nutrient mass flow

For processing 1 m³ stored urine.
According to reference concentration proposed for Siddhipur.

Nutrient monetary value flow

For processing 1 m³ stored urine.
According to fertilizer prices on the Nepalese market (August 2008).

4 Methodology overview

*From the selection of
the study site to the
optimization of the
reactor*

The STUN project is split into a preliminary feasibility study (stage I) and the succeeding implementation part including the operation of a pilot scale struvite precipitation reactor in Siddhipur.

The present chapter will first present a brief overview on the outcomes of the feasibility study and thereafter examine the detailed approach to the pilot scale field study. An outlook on the continuation of the STUN project shall be given at the end of this report.

4.1 Preliminary feasibility study in Siddhipur

During the first stage of the STUN project lasting from May to August 2008, a preliminary feasibility study was carried out. The research team formed of Raju Khadka and Basil Gantenbein visited several communities in the Kathmandu Valley, to select an appropriate study site. The village of Siddhipur was chosen due to the high number of EcoSan toilets and the supportive organizational structures.

Urine quality and quantity in Siddhipur

At a first point, the quantity and quality of available urine in Siddhipur was analyzed. 14 samples taken randomly from different EcoSan urine containers were mixed and tested for their nutrient contents by the laboratory of ENPHO in Kathmandu.

Average nutrient concentration in stored urine from EcoSan toilets in Siddhipur: [Gantenbein & Khadka, 2008]

pH	EC	N	P	K
-	<i>mS·cm⁻¹</i>	<i>mg·L⁻¹</i>	<i>mg·L⁻¹</i>	<i>mg·L⁻¹</i>
8.67	38.2	2352	259	802

The research team conducted various household surveys and focus group discussions at the Siddhipur Drinking Water and Sanitation User Committee to determine the available quantity of collected urine. Annually, 122 m³ of urine are estimated to be collected in Siddhipur's EcoSan toilets.

One of the focus group discussions at the Siddhipur Drinking Water and Sanitation User Committee. EcoSan users share their experience and visions about urine diversion.

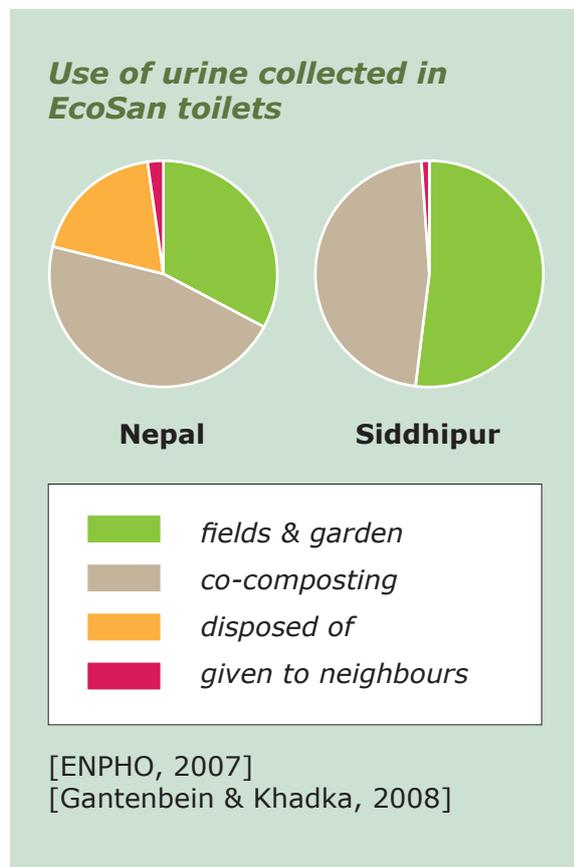


Urine used for direct application and co-composting

Compared to the general data on EcoSan usage gathered by ENPHO, the EcoSan users in Siddhipur stated that there is no excess urine, which would have to be dumped. About half of the collected urine is used on crops, whereas the other half is mixed with compost. The transfer from households with excess urine to households with increased urine demand is negligible at present. As priority has to be given to direct application, only half of the total collected urine volume can potentially be used for struvite production.

Fertilizer demand and supply – attributing a value to nutrients

By assessing the present fertilizer availability and prices on the Nepalese market, the study tried to attribute a monetary value to every nutrient contained in urine. Based on the current prices of N, P, K, Mg, S, and Ca in Nepal, urine would have a monetary value of 233 NRs·m⁻³ (2.33 €) [Khadka & Gantenbein, 2008]. However, this value does not take into account micro-nutrients, nor does it account for the pesticidal properties of urine applied on crops. And, last but not least, according to economic logics, the final retail price may differ greatly from the intrinsic value of a product.



Using the same calculation scheme based on actual nutrient prices, struvite may be sold for 27 NRs·kg⁻¹, if the nutritional value of magnesium is not considered, and 43 NRs·kg⁻¹, if the magnesium's value is added to the value of N and P. The prices of the magnesium source used for precipitation vary greatly, refer to chapter 5.2 for detailed information.

The market price for P is likely to increase, since phosphate rock deposits are depleting at a frightening velocity. To counter this evolution the nutrient recovery from waste streams is a necessary alternative.

The STUN project has received broad attention in the Kathmandu Valley. The recycling of human excreta for fertilizer production seems to be widely accepted by the local population. This attitude has been confirmed during the numerous household surveys and focus group discussions in Siddhipur. We may assume that there is a large target group for a struvite fertilizer product.

4.2 Collaboration with local organizations

We have experienced a very cooperative atmosphere at all of our partner institutions. Throughout our work we have collaborated with the following institutions:

Siddhipur drinking water and sanitation user committee

The inhabitants of Siddhipur manage their drinking water supply system and the sanitation issues in their community through a user committee UC. Stage I of the STUN project (feasibility study) was carried out in close collaboration with the UC.

From the beginning, the UC has been very interested and supportive towards our research. They provided logistical support in the selection of the urine contributing households, as well as the selection of the study site.

UN-Habitat – The United Nations Human Settlement Programme

We pitched our 'base camp' at the UN-Habitat office in Kathmandu. The UN-Habitat staff provided us with great advice, thanks to their long experience in fieldwork throughout Nepal, local contacts, and considerable logistical support with the entire office infrastructure.

National Agriculture Research Council NARC

The Soil Division at the NARC analyzed the soil samples for STUN and provided background information on local agriculture and soil conditions.

Partners for the future implementation of struvite recovery

An enormous diversity of NGOs is found in Kathmandu. We have had numerous contacts with institutions dealing with agriculture or sanitation. Upon completion of the STUN project, they will help to further spread the knowledge on struvite recovery.

During our work, we have received valuable advice from many specialists in the field. Some of the institutions, we have worked with:

- *ICIMOD*: International Centre for Integrated Mountain Development
- *SSMP*: Sustainable Soil Management Programme, Helvetas Nepal
- *ENPHO*: Environmental and Public Health Organization
- *KU*: Kathmandu University
- *SDC*: Swiss Agency for Development and Cooperation Nepal

Creation of a local identity

As STUN or Eawag as brand names are probably not familiar to any Nepalese, we decided to create a more memorable brand name. In order to establish a local identification with struvite production, we simply named our product 'Siddhipur Struvite', and we designed a corresponding logo using Devanagari script.



The Siddhipur Struvite Logo.

4.3 Assessment of magnesium sources

The second ingredient for struvite besides urine, magnesium, is available in various forms. As mentioned previously, struvite precipitation at laboratory scale employs mostly MgO or MgCl₂ as precipitating agent.

Yet, for a real scale installation, a more sustainable source than laboratory chemicals has to be found. Stage I of the project searched the local market for industrial grade products and alternatives. Based on the effectuated assessment the most eco-

nomically and easily available Mg source was chosen. Nevertheless, the selection has not been definitive, as the market situation changes rapidly, and alternative suppliers may arise in the future.

Our goal is to reduce external inputs to a strict minimum. Thus, magnesium should, if possible, be processed locally or be recovered from another industrial process to lessen environmental impact. Refer to chapter 5.2 for a detailed analysis of the different Mg sources.

4.4 Organization of urine collection service

With a decentralized sanitation approach, urine has to be transported from the households to the struvite production site. Different models for the collection system were discussed with the UC in Siddhipur.

The urine collection system's extension and organization had to be closely coordinated with the dimensioning of the reactor. In order to keep a maximum of flexibility for possible adaptations in the treatment

process, we chose to start with a rather small scale in both processing and collection. The UC selected the urine-contributing households, according to the criteria of proximity and urine availability.

Based on the pilot scale installation's capacity, the volume of the collected urine, the frequency of collection, the means of transport and the necessary human resources had to be determined.

4.5 Selection of study site

To minimize transport of the urine, a mobile struvite treatment plant would be an interesting option. Nevertheless, the focus being on the experimental aspects, a fixed reactor site was chosen, with the idea of potentially developing a comparable mobile reactor in the future.

The UC offered us to provide land for the set-up of our study site. Finally, we found the ideal site in the backyard of a local family of EcoSan enthusiasts. They use, whenever possible, urine as a fertilizer, knowing that they will be rewarded with higher sale

prices for their high quality products.

The farmer has also carried out experiments by himself, comparing the effect of commercial fertilizers and urine application on crops. To meet increased fertilizer demand of his cultures, he would be willing to buy other people's excess urine, as he stated. When he heard about our project, he was immediately interested in testing the effects of struvite on his vegetable crops. Thanks to his great support, we have benefited from knowledgeable counselling on agricultural issues.

4.6 Experimental layout of the precipitation reactor

We aim to develop a low-cost, simple and robust struvite production process for the conditions encountered in the Kathmandu Valley. Therefore, the reactor had to be built with locally available materials, employing local craftspeople. For the optimization of the struvite precipitation,

we examined the parameters below. The process parameters were adapted continuously according to the findings made during the reactor operation. The reactor is currently in operation and we plan to further improve the filtering efficiency using new filtering techniques.

<i>Process variable</i>	<i>Involved mechanisms</i>	<i>Influenced factors</i>	<i>Optimization indicator</i>
Stirring time	Thorough mixing of Mg and urine	Precipitation and settling speed	Rapid and complete precipitation
Filter materials	Varying mesh size and arrays of filter for liquid-solid separation	Filtering efficiency	Struvite retained in the reactor's filter and struvite flushed out through the reactor's outlet ($m_{\text{filtered}} - m_{\text{flushed}}$)
Mg source	Precipitation reaction	P removal efficiency	P removal ($[P_{\text{in}}] - [P_{\text{out}}]$)

4.7 Analysis

All samples for N and P analysis were filtered by two filtering steps prior to analysis, to reduce interferences to a strict minimum (as recommended by Tilley [2007]):

- 0.7 μm pore size paper filter
- 0.45 μm pore size membrane filter

After determination of pH, electric conductivity and temperature, all reactor influent and effluent samples were analyzed on the site using a portable HACH DR 2000 photo-spectrometer according to the methods and procedures described below.

A series of fresh urine samples from villagers was transported to Switzerland for analysis at the Eawag laboratory. The samples were acidified following the collection, using 1 mL of 1 mol·L⁻¹ nitric acid (HNO₃) solution per sample of 50 mL (decreasing pH to below 4). Despite of the acidification, a precipitate was formed during the transport. As this precipitate had certainly changed the samples' composition, they were not analyzed.

The second series of fresh urine samples was treated by filtering immediately after collection. No precipitate was formed during the travel, thus the samples were analyzed as planned.

N – salicylate and Nessler method

All samples for ammonium analysis were diluted 1:8'000 to 1:10'000 with distilled water (as recommended by Tilley [2007]) to minimize interferences and to match the measurement range comprehended between 0.01 to 0.5 mg N·L⁻¹ (salicylate) respectively 0.01 to 2.5 mg N·L⁻¹ (Nessler). Dilution was made in two steps by diluting 1 mL of the sample in 100 mL, respectively 80 mL deionized water.

For a long time, we struggled with relatively high ammonium concentration in the local 'deionized' water. Testing different water from different local research laboratories, as well as water sold for injection purpose in hospital pharmacies, the ammonium concentrations in the deionized water used for sample dilution

were frequently above the measurement range of the photo-spectrometer. As most of Kathmandu's tap water is drawn from groundwater, which probably contains a high nitrate concentration, special care has to be exercised, when distilling water for analytical purposes.

The HACH salicylate method (HACH method # 8155) using reagent powder pillows was used, as it gives high precision results. Standard addition with a 1000 mg NH₄⁺·L⁻¹ standard solution (Merck) was carried out for verification of the measurements' accuracy. As the laboratory was operated outside, the reaction times for sample preparation recommended for room temperature had to be doubled to allow sufficient time for reaction (winter daytime temperature in the Kathmandu Valley: ~ 15°C).

The disadvantage of the salicylate method consists in its relatively high price (~ 2.50 € per sample) and its long reaction times (considering the low temperatures in the Nepalese winter, sample preparation lasted approximately 1 hour.

As an alternative with very short reaction time (1 minute) and implying low costs, we also examined the Nessler method (HACH method # 8038) using a locally available Nessler reagent. The standard addition conducted with the same 1000 mg NH₄⁺·L⁻¹ standard solution (Merck) showed rather doubtful results; the increment slope was only 0.85 and standard deviation was 0.06 mg N·L⁻¹ for a sample containing approximately 0.5 mg N·L⁻¹. A standard adjustment curve had previously been established, showing a fair standard deviation of 0.025 mg N·L⁻¹ and correlation of 0.9985 on the measurement range from 0.25 to 2.5 mg N·L⁻¹. To a certain degree, this might be due to the missing mineral stabilizer and polyvinyl alcohol dispersing agent recommended by HACH.

In Standard methods for the examination of water and wastewater [Greenberg, 1985], the Nessler method is only recommended for purified drinking water, natural water and highly purified wastewater, as any coloration might interfere with the colorimetric measurements.

P – molybdovanadate method

Phosphate was analyzed using the molybdovanadate method (HACH method # 8114) with a single liquid reagent. Analogously to the ammonium analysis, reaction times had to be increased twofold, to compensate the low ambient temperatures in the Himalayan foothills.

After filtering, samples were diluted 1:100 (for stored urine) or 1:10 (for the reactor effluent) down to the photo-spectrometer's measurements range from 0.1 to 45.0 mg P·L⁻¹. Accuracy check by standard addition (1000 mg PO₄³⁻·L⁻¹ Merck standard solution), revealed a standard deviation of 9.7 mg P·L⁻¹ for a sample containing 277 mg P·L⁻¹ (comparable to the concentrations found in stored urine in Siddhipur).

pH

pH was measured using a WTW pH315i pH-meter calibrated before each series of measurements with pH = 4.01 and pH = 7.00 buffering solution (manufacturer HACH or Merck).

A SensoTix 31 electrode was used for the field and laboratory measurements. The electrode was rinsed with deionized water before and after every measurement.

Electric conductivity EC

EC was measured with a LF340 by WTW. The uncorrected EC and temperature (measured by the EC electrode) were reported separately. The measured EC was temperature compensated during data processing by the following formula:

$$EC' = EC / (1 + \alpha(T - T'))$$

with:

- EC' compensated EC
- EC measured EC
- α temperature correction coefficient (0.02 for water samples)
- T' reference temperature (25°C)
- T measured temperature

Correlation EC versus phosphate in stored urine

With the idea of developing a simple and cheap indicator for nutrient content in stored urine, we always measured electric conductivity and temperature in parallel to the P concentration. A correlation factor was later calculated.



Above: the entire lab on two wheels.

Below: a curious audience observes our lab work in the field.



4.8 Outlook on struvite use

Handling of struvite has to be as easy as possible to increase its marketability. With the operation of a struvite precipitation reactor, the final form of struvite must also be examined. Struvite can only compete with commercially available mineral fertilizers, when the user accepts it as an equivalent product. Special attention has to be paid to the appearance. A simple powder might

not fulfil the criteria for easy handling. In addition, it might be blown away by the wind, and its nutrient will not reach the soil at the desired site.

As an alternative, the struvite would have to be pelletized using a pellet mill. Pellets can easily be spread onto a field and are not as easily shifted around by the wind.



Peri-urban agriculture near Patan, Latitpur

4.9 Manual for struvite production

If struvite recovery from urine proves to be a successful treatment technology for the Kathmandu Valley or Nepal in general, a manual for an easy reactor set-up shall be developed. The STUN project aims to make struvite production accessible to any interested public. As a consequence, the knowledge about the 'Siddhipur Struvite' reactor has to be spread as widely as possible.

Up to know, we have identified a few channels for distribution of a brief manual:

- Manual as a brochure distributed by different institutions, e.g. UN-Habitat, ENPHO etc.
- Integration into the NEPCAT fact sheets for conservation approaches and technologies (4 page format based on WOCAT fact sheets, www.wocat.org).
- Description of the struvite reactor on a 'Technology information sheet' in the newly published Compendium of Sanitation Systems and Technologies [Tilley, 2008c] by the Sandec department at Eawag.

At present, the STUN struvite reactor needs some further improvements, before its technology can be passed on to future users.

5 Outcomes

*Operating and
improving the pilot
scale reactor*

5.1 Urine collection

Urine undergoes some changes in its properties from excretion to final use for struvite production. The liquid collected from the urine container of the EcoSan toilets in Siddhipur does actually contain urine plus an unknown quantity of flushing water. To specify this dilution, fresh urine samples were collected from villagers and compared to the nutrient concentration measured in the stored urine collected for struvite production.

Transport

According to suggestions from UN-Habitat and to local traditions, we chose to collect the urine from the different households using a bicycle, which was dubbed the 'pee-cycle'. Throughout Nepal, bicycles can be seen ferrying around a variety of liquid cargo; from 20 L PET drinking water containers to 15 kg net weight butane gas cylinders, which are transported one on each side of the baggage rack.



The 'pee-cycle' used for urine collection from about a dozen households in Siddhipur

For the urine hauling, two welded metal trays, holding a 20 L PP jerry can each, were attached to either side of a traditional heavy duty Indian bicycle's baggage rack. As the STUN pilot reactor was designed with a volume of 50 L, weekly urine need was estimated at maximum 200 L. The urine-contributing households selected by the Siddhipur UC are all situated within a 2 km radius of the reactor site and the terrain is mostly levelled with only few slopes to climb.

To collect the weekly 200 L of urine, the operator worked for 4 to 6 hours and was paid 400 NRs (4 €) as proposed by the Siddhipur UC. In the future, when struvite production will be up-scaled, the UC would prefer to hire a person on a monthly basis, to provide full employment.

Viability

The economic viability of a collection system operated as described will still have to be examined. Obviously, at the present pilot scale, the struvite production does not cover the cost for urine collection. At a larger scale, the process steps can further be coordinated and one person may be able to handle the entire process from collection to production and marketing.

The urine collector on his way through Siddhipur, collecting the urine from the EcoSan toilet's storage tank.



Payment model

We proposed three different payment models for urine collection to the UC:

1. Attribute a value to urine: the contributors would be reimbursed the nutrients' or part of the nutrients' value contained in the urine.
2. Urine collection as sanitation service: the households would cover for collection as an emptying service for their storage tanks (as for septic tanks).
3. Collection free of cost: as an intermediate way, urine would be collected free of cost for the households, nor any money would be paid for its nutritional values.

The Siddhipur UC opted for the free-of-cost model, endorsing the following arguments:

- Reimbursing the families for the urine they contribute would create discrepancies between EcoSan users.
- There is not enough value in the urine that would make it worth paying for its transport or handling.
- The collected urine is the village's contribution to our research project.
- The collection system operator should provide basic storage tank maintenance, such as repair of leakages in the storage tank or outlet tap, rather than pay money to the EcoSan users.

Average chemical properties of fresh urine samples ($n=14$)

Parameter	NH ₄ -N	Urea	N _{total}	PO ₄ -P	K	SO ₄	Mg
Method	FIA	FIA	Ganimed	IC	IC	IC	ICP
Unit	mg·L ⁻¹						
Average	438	4454	6030	388	1869	878	45
CV%	47	39	42	65	52	43	50
Median	418	4422	5961	383	1939	822	37
Average _{lit}	480	7700	-	740	2200	1500	100
Minimum	179	2309	2758	95	608	347	18
Maximum	902	6941	10942	973	3680	1759	106

Parameter	Cl	Ca	Na	pH	EC (25°C)	TIC	COD
Method	IC	ICP	ICP	electrode	electrode		Dr. Lange
Unit	mg·L ⁻¹	mg·L ⁻¹	mg·L ⁻¹	-	mS·cm ⁻¹	mg·L ⁻¹	mg·L ⁻¹
Average	6617	89	3238	5.63	22.8	-	7656
CV%	36	64	38	8	30	-	60
Median	6406	74	3275	5.46	23.7	-	6340
Average _{lit}	3800	190	2800	6.2	-	-	-
Minimum	2384	14	1266	4.95	10.8	7	3240
Maximum	10766	221	5530	6.54	34.2	11	18280

Average_{lit}: comparison to literature values compiled by Udert et al. [2003].

Average chemical properties of stored urine samples ($n=4$)

Parameter	pH	EC (25°C)	PO ₄ -P
Method	electrode	electrode	HACH
Unit	-	mS·cm ⁻¹	mg P·L ⁻¹
Average	9.0	29.9	264
CV%	1	7	14
Median	9.0	29.7	255
Minimum	8.9	27.5	230
Maximum	9.1	32.7	315

Urine characterization throughout the pathway

Fresh urine collected from 14 Siddhipur villagers of different age groups and gender were analyzed in the Eawag laboratory in Dübendorf for nutrient content (see annex p. 47 for detailed lab report).

The results show relative low nutrient contents in urine from Siddhipur compared to literature values. The low concentrations found in stored urine during the preliminary study led to the conclusion that the urine is diluted by flushing water by a ratio of roughly 40% urine to 60% water. Regarding the low concentrations in fresh urine, this assumption has to be revised. It has to be concluded that the low nutrient concentrations in stored urine do not, or at least only to limited extent, result from dilution, but from low initial values.

In general, variations between the individuals are high. The results do not show an uniformly distributed mineral pattern in urine. On the contrary, every individual seems to excrete minerals in varying proportions. Regarding P, the variations seem to be extremely high ranging from 95 to 973 mg P·L⁻¹.

The measurements of stored urine used for the urine collection system confirmed that the pH in the storage tank increases to 9, due to urea degradation and ammonium production by urease. The ideal conditions

Urine sampling in front of the Siddhipur User Committee's office.



for struvite precipitation by Mg addition are thus given. It can be assumed that the stored urine in Siddhipur is sufficiently hydrogenized by this increase in pH.

The P from fresh to stored urine diminishes by 32% or 124 mg P·L⁻¹. Assuming that the Mg present in fresh urine (average 45 mg Mg·L⁻¹) reacts completely to form struvite in the storage tank, an estimated 57 mg P·L⁻¹ is precipitated from stored urine. To reach the concentration found in the storage tanks, the urine has to be diluted by approximately 20% water (to 80% urine). These calculations do not take into consideration eventual Mg content in the flush water.

During collection, organic sludge was found floating in storage tanks. It is thus important to filter the collected urine through a coarse cloth filter before pouring it into the tank, to prevent clogging of fittings and to guarantee a smooth operation of the struvite precipitation reactor.

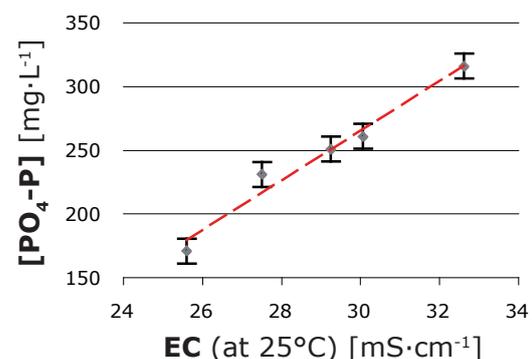
EC as quality indicator

As tested, EC measurements can be used as a reliable indicator of P concentration in urine. To avoid repeated P measurements in up-scaled installations, reaction calculations can be based on EC values. Nevertheless, the formula will have to be verified in different settings.

Correlation EC vs. P concentration measured in the collected urine.

Formula: $[\text{PO}_4\text{-P}] = 19.5 \cdot \text{EC} - 321$

Correlation: $\rho = 0.986$



5.2 Magnesium source

As assessed during the first stage of the STUN project, various Mg sources are available in Nepal. The adequacy of a Mg source may be summarized as follows:

- *Solubility:* For an efficient struvite precipitation, the Mg salts should readily dissolve when added to the urine or the Mg should be available as a solution. If solubility is too low, pre-treatment of the Mg source will be necessary.
- *Price:* For competitive production, the input costs have to be minimized.
- *Concentration:* High Mg concentration decreases weight and therefore transportation energy and cost.
- *Side products:* If the Mg source has to be pre-processed (e.g. with acids) to adapt its solubility to the struvite production, the arising waste-products should not have a negative impact.
- *Sustainability:* All mineral resources are non-renewable, availability and prices are thus likely to change.
- *Handling:* For a simple struvite production process, the Mg dosage to the reactor should not involve any special preparation (if possible use Mg source directly as powder or solution).

Up to present, we have conducted experiments with two substances: magnesium sulphate MgSO_4 and bittern, the Mg-rich waste-product from sea salt production:

Magnesium sulphate MgSO_4

Magnesium sulphate is available on the market as a fertilizer in its hydrates form $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ containing typically 9.9% (mass) of Mg. The substance is highly

soluble in water ($710 \text{ g}\cdot\text{L}^{-1}$). As the fertilizer users in Nepal focus primarily on urea and to a reduced extent on DAP or other compound fertilizers, the import of MgSO_4 is not common. One of the most important chemical suppliers, Rohit Chemicals, located in Birganj in the southern lowlands, provided a quotation for MgSO_4 in August 2008 stating its retail price at 21 NRs $\cdot\text{kg}^{-1}$.

However, after our order in September, the chemical was not imported into Nepal for more than one month. Apparently, the minuscule quantity of our ordered 50 kg, compared to the everyday fertilizer import, did not awake the company's business instinct. We had to insist several times, explaining that we will soon transfer our production to a larger scale and thus need big quantities of MgSO_4 in the future.

By the time, the MgSO_4 reached Kathmandu (November 2008), its retail price had increased to 40 NRs $\cdot\text{kg}^{-1}$. The granule size of the delivered product was quite big, with some aggregates reaching the size of more than 1 cm. As a consequence, the dissolution in water or urine required some more patience than expected and the big MgSO_4 chunks had to be crushed manually using a mortar.

Bittern

Besides sodium and chlorine, seawater contains a variety of other dissolved ions, as described below. After industrial extraction of NaCl, the residual minerals remain in a highly concentrated salt brine, called bittern. Bittern has been used as P and N precipitating agent in various wastewater streams, such as landfill leachate or animal slurry [Lee, 2003 & El Diwani, 2007]. The cited Mg contents in bittern range from 16 to 32 mg Mg $\cdot\text{L}^{-1}$.

Average mineral composition of seawater

Ion	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Si ⁴⁺	Cl ⁻	SO ₄ ²⁻
Concentration [mg $\cdot\text{L}^{-1}$]	412.3	1291.8	10768	399.1	4.28	19353	2712

[PHREEQC database for seawater]

We obtained a bittern sample of 5 L from the Jakhau Salt Company (Most important sea salt producer in Asia) located in the state of Gujarat in northwestern India. The Mg content was measured at $26.2 \text{ mg}\cdot\text{L}^{-1}$ by titration method at the ENPHO laboratory in Kathmandu. As bittern is a waste-product at present, the chief executive of marine chemicals at the Archean Group of Companies (head company of Jakhau Salt Company) expressed his interest in our research on bittern reuse [Venkataraman, V.R.]. In this sense, the combination of two waste-products, urine and bittern, to a fertilizer seems to be an ideal process from an ecological point of view.

The shipment of bittern from India to Nepal turned out to be a rather difficult enterprise. All consulted couriers in Kathmandu refused to carry liquid goods across the Indian-Nepalese border, especially those of unknown composition. At last, the sample was transported by UN staff from New Delhi to Kathmandu, after reaching the UN-Habitat branch office in New Delhi by Indian courier.

If the need for Mg sources increases with struvite production, a more viable alternative for transportation has to be found. We plan to further collaborate with the Jakhau Salt Company to create a long-term link between bittern and struvite production.

*Impressions from the abandoned **magnesite mine** near Charikot (80 km east of Kathmandu).*



Outlook on potential local Mg sources – magnesite from Charikot

Mg is found in different minerals, one of which is magnesite MgCO_3 . Magnesite is mined commercially and processed to a number of Mg products at many places in the world. The Nepalese government used to operate its own magnesite mine close to Charikot in the Dolakha district, approximately 80 km to the east of Kathmandu.

Due to complications during the maoist conflict time over the past decade, the mine was shut down a few years ago. Its infrastructure remains intact, and with a comparably low investment, the mine could return back into operation. The present Nepalese government uniting communists, maoists and democrats is planning to reopen the mine in the near future, as announced in the national press in September 2008. If magnesite would become available locally, this would be an interesting option for struvite production, and its efficiency would have to be tested in the STUN pilot reactor.

As magnesite is only slightly soluble in water, it has to be treated with acid before using it for struvite precipitation. Gunay et al. [2008] obtained maximum solution by using a ratio of 2 M HCl to 1 M MgCO_3 . The Mg solution was tested as precipitating agent for P recovery from landfill leachate in Turkey. Compared to a treatment with MgCl_2 , the MgCO_3 dissolved in acid achieved 18% reduction in treatment costs.



5.3 Reactor set-up

As described previously, the struvite precipitation reactor was set up on the premises of a farmer's family in Siddhipur. The farmer constructed a shelter with bamboo posts and a thatched roof measuring 3 by 4 metres adjacent to his building.

Within the struvite production process from urine collection over Mg sources to struvite application to crops, the struvite precipitation reactor is the central element. The success of the entire process lies to high degree upon the reactor's functioning. This means, in terms of constraints for the reactor:

- All materials used for the reactor must be available locally.
- Assembly must be done by local craftspeople.
- The reactor must not require any particular maintenance besides the operations required for struvite production.
- Efficient reactor operations must be reduced to a few clear steps.

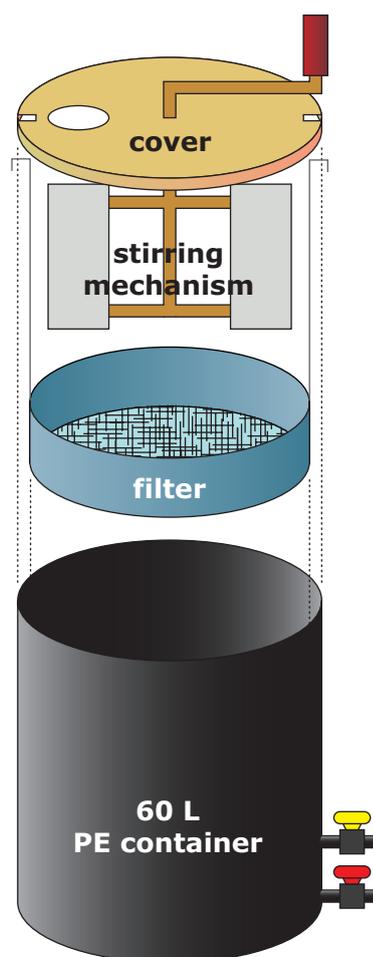
Design options – focus on liquid-solid separation

Based on literature, previous reactor models, and our imagination, we designed two basic options for the reactor:

1. Stirred tank reactor in the shape of a welded PP or PE tank with a tapered bottom leading to a filter bag.
2. Stirred tank reactor using a cylindrical shape PP tank and a removable filter tray.

Although the first option would probably increase user-friendliness of the process, it soon had to be rejected, as there are no facilities for welding PP or PE in Nepal. We opted for the second option, somehow inspired by the liquid-solid separation between whey and curd in the process of cheese making.

As we had decided on a reactor volume of 50 L, we purchased a cylindrical PP tank,



Above: the reactor assembly

Below: the STUN field study site



easily available in Nepal. The top part was cut off, to have a full size opening to access the reactor's interior. A local welder constructed the reactor's lid including the stirring system according to our drawings. All elements were assembled using only 1.5 and 3 mm steel sheets, 8 mm steel rods ($\frac{3}{8}$ " reinforcement bars) and 1.25 mm ($\frac{1}{2}$ " steel pipe. The raw steel was rustproofed with paint and some grease was added to the main axle bearing.

The first prototype of the filter tray consisted of a wire mesh with a 5 cm high rim made of metal plates. As a filter cloth, we used a densely woven (mesh size $< 200 \mu\text{m}$) cotton, as we were not able to find nylon cloth at the local tailor stores.

The filter tray was later adapted to a simpler version using a circle-shaped 8 mm

steel rod and a mono-filament nylon fabric (mesh size $< 100 \mu\text{m}$), which was found at a mountain equipment store in Kathmandu. To our surprise, the two filter types showed similar filtration efficiency. Some further investigations must be made to determine, whether the height of the filter tray's rim plays an important role in solid retention.

At the bottom of a tank and at a height of 5 cm from the bottom two plastic taps were added for decantation of the supernatant and purging the remaining liquor. The connection between these taps and the reactor wall, respectively bottom, was shown to be prone to leakages, as the plastic is of poor quality, and the tap's thread does not suit well with the plastic nut. We realized that plastic is not really an option despite of its lower cost, thus we recommend to use metal fittings.

Filter fabric

Recommendations for filters used in struvite production process range from specific fleece to non-woven polyethylene fabrics. We tested locally available densely woven cotton and mono-filament nylon fabrics.

Filter tray 1:

cotton
 $d_{\text{pore}} < 200 \mu\text{m}$



Filter tray 2:

nylon
 $d_{\text{pore}} < 100 \mu\text{m}$



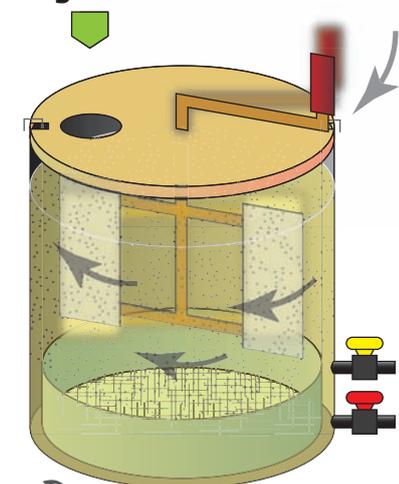
The STUN reactor

Struvite production process in the STUN pilot scale precipitation reactor.

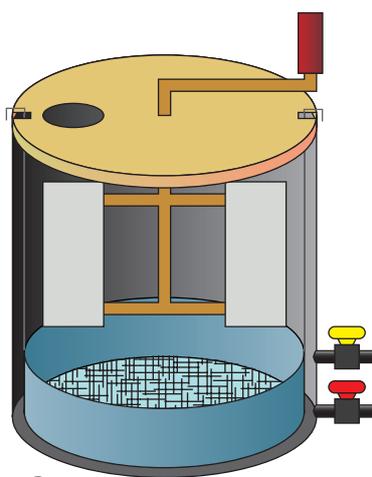
Tank volume: 50 L

Struvite produced per run (ideal conditions with average urine from Siddhipur): 100 g

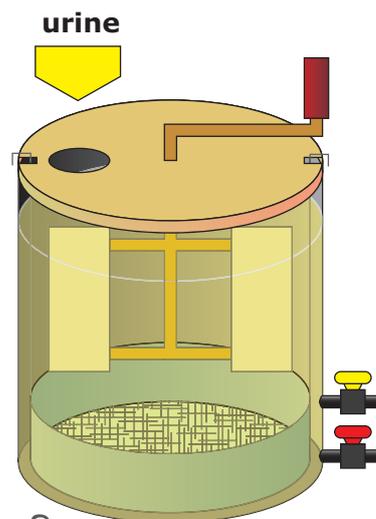
magnesium



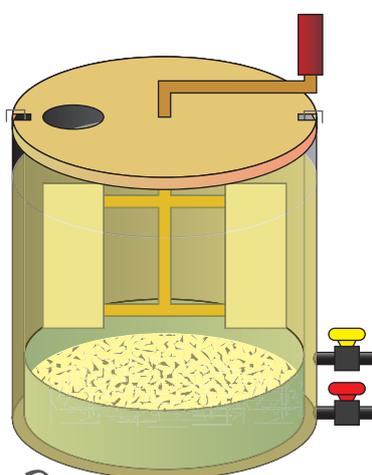
2 add magnesium and stir
> struvite precipitates



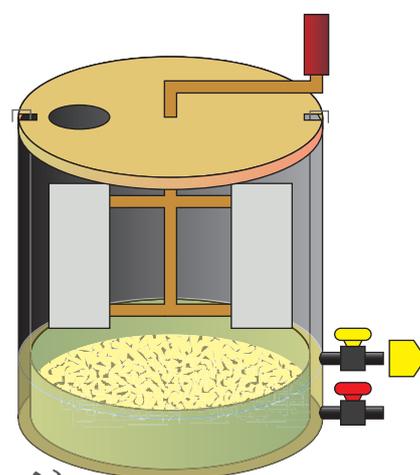
0 empty reactor



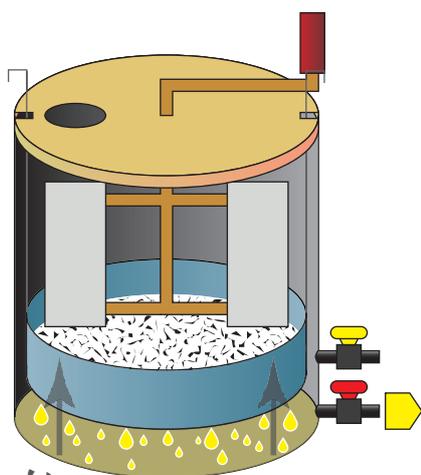
1 fill with urine



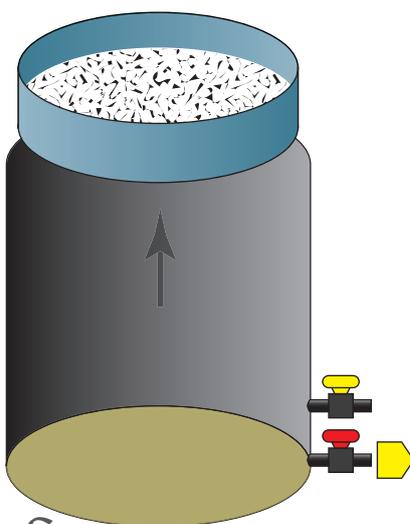
3 struvite settles



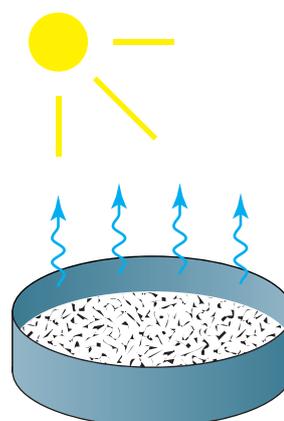
8 open upper outlet
> urine decantates



4 lift filter partly
> remaining urine drains



5 remove filter



6 sundry struvite

The set-up of the STUN pilot scale installation; with the reactor to the left and the urine storage tank to the right.



Reactor feeding and purge

A cylindrical 100 L PP tank was installed at 1 m above the ground. The tank serves as intermediate storage for the collected urine and feeding reservoir for the reactor. A simple rubber hose directs the urine from the tank's outlet to the reactor inlet.

On the other side of the reactor, 2 PP tanks of 50 L capacity each are used to store the effluent prior to direct application or use in the irrigation system.

An appropriate array of the feeding tank, the reactor and the effluent tank makes gravity do the work that pumps would have to do otherwise. Obviously, the possibility for an entirely gravity driven process depends on the reactor's dimensions and the local terrain.

However, at the moment, electricity is only available 12 hours per day (by alternating 6 hours power supply and 6 hours power cut according to a fixed schedule) in Nepal. The process must thus be as electricity-independent as possible.

Operating parameters

With the present reactor design, one can influence the struvite production process by the following parameters.

- Stirring time
- Mg source
- Alternative filters or new mechanisms for liquid-solid separation

Process optimization – stirring time and Mg dosage

The first experimental series were run dissolving the MgSO_4 powder or granules directly in the urine in the reactor. To compare the precipitation efficiency, MgSO_4 was also added as solution, using distilled water to dissolve the powder or granules. The means of MgSO_4 dosage did not have any influence on the precipitation efficiency, the attained P removal achieved 85 to 88% in any case.

On the opposite, stirring time and thus mixing did have a direct influence on precipitation. For the first batch of struvite, the mixing time was only 3 minutes. The resulting P removal achieved only 77%. In addition, the struvite had not completely settled after more than 24 hours. Nevertheless, even at low stirring time, when mixing cannot be assumed to be complete, no MgSO_4 granules were found in the filter and the recovered struvite had an even texture.

Because of the delayed start of our experimental series, due to the late Mg delivery, we did not repeat any experiment with such low stirring times. On the rest of the experimental series, we applied stirring times of 10 and 15 minutes, using both MgSO_4 and bittern as Mg source. The increase from 10 to 15 minutes did not affect the precipitation.

The issue of dosage is considerably simplified, if bittern plays the role of the Mg source. As it is already in liquid form, it can easily be dosed using a graduated plastic beaker found in every household. Weighing goods is already a bit more tricky. The good old balance with 100 g weights has to be used.

Mg sources – bittern as efficient P precipitating agent

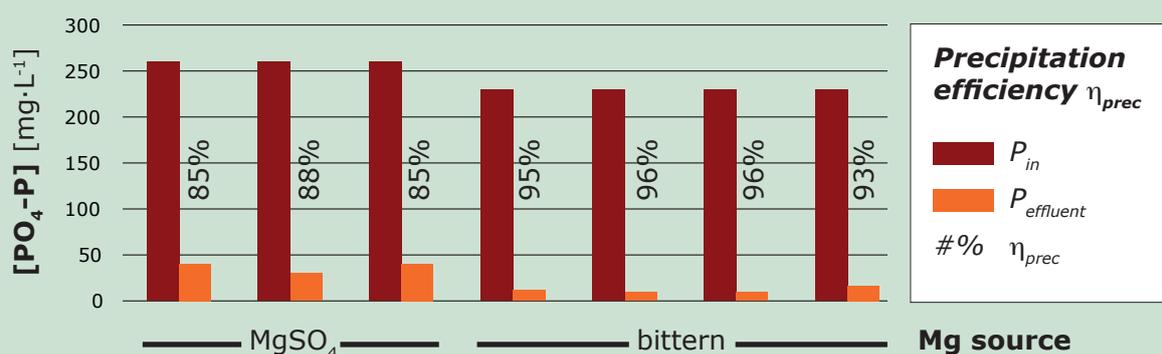
Bittern was proved to be an efficient precipitating agent achieving P removal rates above 93% at any case. On the other hand, we can only partly explain the comparably low (85 to 88%) P removal rates, when MgSO_4 is used. The analysis of the exact Mg content in the powder shipped as MgSO_4 is pending. Simultaneously, the substance would also have to be analyzed for heavy metal content; being an industrial mineral product, it is prone to heavy metal contamination.

Determining settling speed

To determine the effective time required for the complete struvite settling, we had planned to observe the settling front using a glass capillary tube. However, precipitation was very heterogeneous and crystals formed of a wide range of size. Although bigger crystals were observed to settle within minutes from Mg addition. It was thus optically impossible to distinguish the exact settling front in the liquid (high fraction of small size particles).

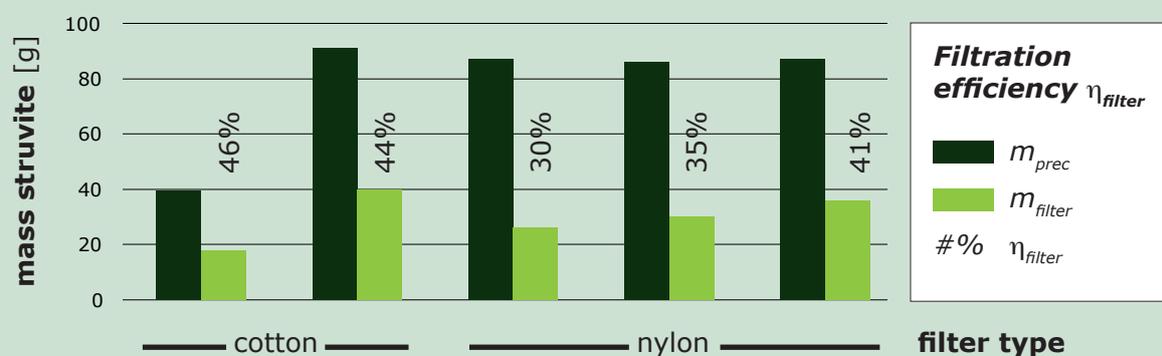
Precipitation efficiency η_{prec}

Ratio of effluent P concentration (P_{eff}) versus influent P concentration (P_{in}). Values based on photo-spectrometric measurements.



Filtration efficiency η_{filter}

Ratio of struvite mass retained in filter (m_{filter}) versus precipitated struvite mass (m_{prec}) calculated stoichiometrically from P concentration in the reactor.



If the reactor's effluent was filtered using a paper coffee filter, we were able to retain the remaining fraction of solids almost completely ($\eta_{filter} > 90\%$).

Struvite harvest

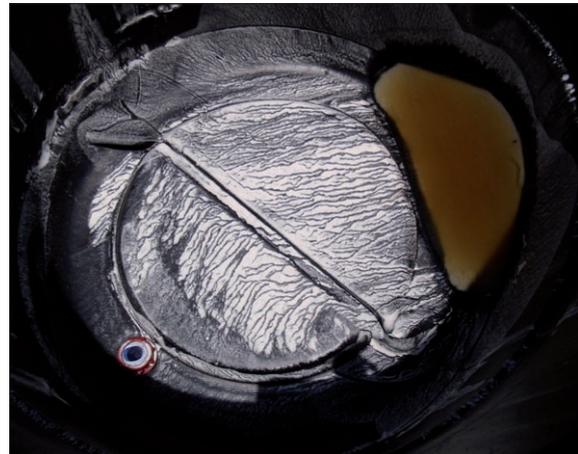
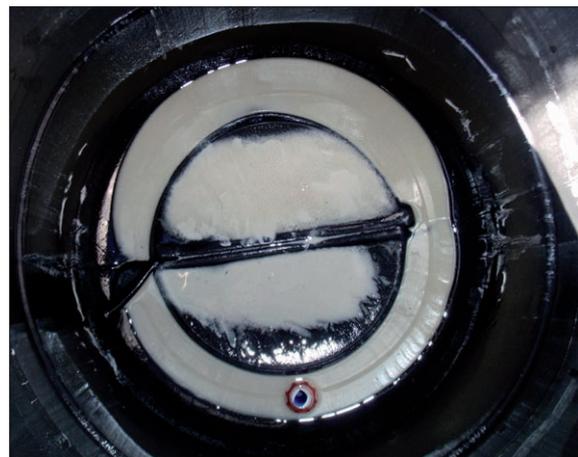
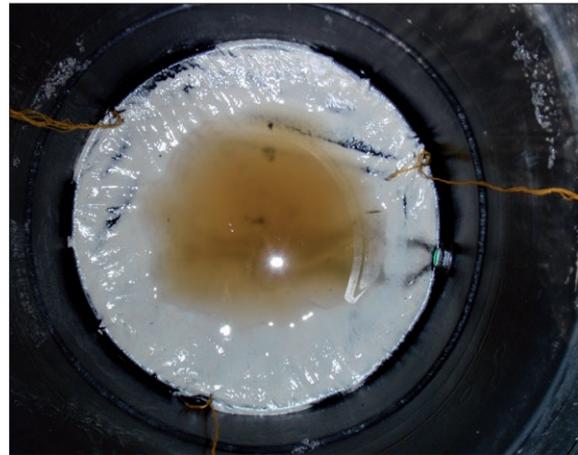
After decantation of the supernatant, the filter is gently lifted upwards, taking care not to tilt it sideward. Since cloudy skies or even rain are very scarce during the Himalayan winter (the annual rainfall being concentrated during the monsoon season from Asaar to Bhadau - mid-June to mid-September), the struvite can easily be dried in the sunlight. For this purpose, we lay the filter tray upon the roof during 1 to 2 days.

The precipitated struvite formed a relatively compact layer on the filters surface. It was easily removed by shaking the filter cloth and finally by scraping it off using a knife. The second filter tray with an only 8 mm high rounded rim (compared to 5 cm steel plate in the first filter) facilitated the struvite removal. The wire mesh sustaining the filter cloth is not necessary, as at this size (filter diameter $d = 38$ cm), the filter cloth is sufficiently strong to bear the struvite load by itself.

Due to the limited struvite retention in the filter, a considerable amount of struvite reached the bottom of the tank remaining in suspension in the stagnant liquor. Thanks to its small size, the reactor can easily be tilted or moved to the sun to dry the struvite sludge at the bottom, which is later scraped off using a knife. In larger scale installations, moving the reactor will not be an option anymore; hence the filter must guarantee maximum removal efficiency. Some further improvements need to be made at this level to make the process ready for up-scaling.

Adding polymers to the reactor, as described by Szögi et al. [2006], will have to be tested. Furthermore, we would like to look more deeply into other liquid-solid separation techniques.

1. The remaining liquid is drained through the cloth filter in the reactor's lower part.
2. Below the filter, the struvite sludge can be seen at the reactor's bottom.
3. Struvite sludge after drying, by leaving the entire reactor at the sun for 1 day.
4. The influent and effluent can be easily distinguished by their colours.



Lessons learned from the operation of the pilot scale reactor

Summarizing the above mentioned points on reactor operation, we may give the following recommendations for a future struvite precipitation reactors:

- Critical point in the struvite production process: liquid-solid separation.
- Special attention must be paid to the filter.
- Optimum stirring time: about 10 minutes.
- Fittings must be metal (plastic causes frequent leakages).
- A minimum settling time of 24 hours has to be observed (for bigger reactors, this time has to be extended accordingly).
- Bottom and walls of the reactor have to be cleaned periodically from remaining struvite.
- Achieving a high P removal from the liquid is not difficult, whereas separating the precipitated struvite from the liquid is the key problem.

From all experiences made with the precipitation reactor up to present, we may deduce that the improvement of the liquid-solid separation is the prime concern.

5.4 Economic aspects

As studied during the first stage of the STUN project, there are several management approaches to producing struvite and selling it as a fertilizer:

- Community operated urine collection system and struvite production facility.
- Independent small scale business, providing employment for one person.
- Struvite production integrated into another institution (e.g. public toilet operator).

The present experience of a pilot scale installation, has shown the approximate cost for the set-up of the reactor and the urine collection system. Based on these expenses, the cost of an up-scaled version of a struvite production facility may be calculated.

Urine collection system

	CHF	NRs
transport tanks (2 x 40L L) & trays	23	1'500
bicycle	53	3'500
total	76	5'000

Struvite precipitation reactor

The STUN struvite precipitation reactor cost 5'000 NRs, or 100 NRs per litre treatment capacity or 50'000 per kg struvite production capacity per day. These expenses can further be brought down, by selecting lighter materials for the stirring

Urine collection system

The urine collection system could easily be up-scaled, if the collection area is not extended beyond cycling distance. If the average distance to a household is 3 km, the 2-way trip takes roughly 40 minutes. Calculating another 20 minutes for filling and emptying the tanks, 40 L can be collected in 1 hour, or 320 L per working day. At a daily wage of 400 NRs, this would mean 1.25 NRs per litre of urine collected or 625 NRs per kg of struvite produced.

If the economic breakdown concentrates on the effective value of struvite only, the collection system by 'pee-cycle' is will hardly be viable. Nonetheless, if the struvite production is linked to an 'urine bank', the collection by bicycle might become more interesting. An 'urine bank' would provide an exchange platform between EcoSan users producing excess urine and farmers in need of additional fertilizer. Within this framework, the struvite production would facilitate the storage of excess nutrients for more nutrient demanding periods.

system (the current system is made of thick metal plates). For an up-scaled reactor of 500 L volume, we estimate 37'000 NRs set-up cost. On a per-volume-base, the price would be reduced to 74 NRs per litre treatment capacity. A 500 L reactor could produce 1 kg of struvite daily, if the settling time is not too high.

Reactor set-up	50 L (expenses)		500 L (budget)	
	CHF	NRs	CHF	NRs
50 / 500 L tank for reactor	4	250	61	4'000
stirring system & filter tray	48	3'200	227	15'000
100 / 1000 L tank for intermediate storage	8	550	121	8'000
pipes & fittings	8	500	30	2'000
effluent storage tanks 2 x 50 / 500 L	8	500	121	8'000
total	76	5'000	561	37'000

Struvite on the fertilizer market

Based on the nutrient value contained in struvite, the retail price of 1 kg struvite should not exceed 43 NRs (fertilizer market prices as of summer 2008) [Gantenbein & Khadka, 2008]. However, fertilizer prices have increased drastically, and the price hike is very likely to continue, due to:

- Depletion of minerals.
- Energy shortage for extraction, process and transport of minerals and fertilizers.
- Increased demand in agriculture.

For 2008, first estimations show an increase of 300 to 500% on fertilizer prices in Nepal [ENPHO, 2008].

Therefore, the development of low-cost struvite precipitation in Nepal can be seen as a precautionary measure for the near future, when the local fertilizer market will be struck by supply shortfalls and exorbitant prices.

Simultaneously to the struvite powder, the process' effluent also has to be marketed or used in further processing to transfer it into a more appropriate form. If N, K and the remaining nutrients can also be trapped in solid or highly concentrated aqueous form, the production's overall benefit will grow considerably.

At present, a parallel research project at Eawag investigates the potential of such treatment on the reactor's effluent. We hope to implement it in Nepal in the near future.

Increasing viability – reducing production costs

To bring down struvite production costs, several options exist:

- Install struvite facility at sites with high urine output, such as public toilets or large public buildings, markets etcetera. The transportation by vehicle could be replaced by direct feed lines.

- Investigate further into a continuous flow reactor, able to treat larger urine volumes at a lower reactor volume, and reducing operation steps.
- Use locally produced Mg sources to reduce transport and process costs.

The most promising option, and probably also the next step in the STUN research will be the set-up of a reactor at a site with high urine output.

Environmental value of waste and wastewater treatment

If a value is attributed to waste and wastewater treatment, as well as to improvements in environmental quality, struvite production is of even higher interest. Especially, if urine in the urban area of Kathmandu can be treated before reaching Bagmati River, struvite production will contribute a small, but potentially growing part to the resurrection of the nowadays dead river.

6

Conclusion

At the present stage, the struvite production at community scale requires some further investigations. Before the technology can be disseminated, the process must be optimized and the recovery efficiency has to be extended.

Summing up our findings, the chemical mechanisms (struvite precipitation by Mg addition) were implemented without greater problems, whereas the physical mechanisms (liquid-solid separation) have not yet met our expectations. It is not surprising that this aspect is rarely treated in the literature.

For the upcoming research within the STUN project, four strategies are imaginable:

- Struvite reactor at a site with high urine output to examine and adapt the struvite production process at real scale.
- Testing of alternative liquid-solid separation methods, ranging from various filter textiles, to continuous flow reactors with settlement chamber.
- Study of Mg sources and corresponding channels of supply, with a focus both on local magnesite processing and bittern reuse.
- Emphasis on effluent treatment in order to additionally recover nutrients (principally N) and transfer them into a more convenient form.

In general, we have experienced an enormous interest for struvite precipitation in Nepal. Local organizations, media and individuals welcome this 'new' approach linking sanitation and fertilizer production. We may rely on widespread support for our further project stages.

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First off all, I would like to express my thanks to all my Nepali friends for their unlimited hospitality. They have made my stay in Nepal a most memorable experience far beyond working in another country. Especially, I would like to thank Raju, Jayanti, Yukee and Unesh Khadka for accepting me as a new family member.

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Annex

Fresh urine samples Siddhipur

Collected on 21st November 2008, filtered 0.7 μm and 0.45 μm , stored at appr. 4°C, analysis at Eawag laboratories, Dübendorf, Switzerland.

Lab #	NH ₄ -N FIA mg/l	Urea FIA mg/l	N _{total} Ganimed mg/l	PO ₄ -P IC mg/l	Cl IC mg/l	SO ₄ IC mg/l	TIC Dr. Lange mg/l	COD mg/l	Mg ICP mg/l	Ca ICP mg/l	K ICP mg/l	Na ICP mg/l	pH electrode	EC electrode mS/cm	Temp electrode °C	EC _{corr} mS/cm
ST08001	212	2478	3736	116	6025	347	<2	3380	28	70	608	3185	5.55	16.0	20.8	17.4
ST08002	429	2631	3413	303	6771	575	<2	3380	46	62	681	2113	5.41	-	-	-
ST08003	557	4521	6075	488	8083	788	<2	8060	30	78	3072	3481	5.33	25.5	21.0	27.7
ST08004	418	4323	10942	323	5976	855	<2	6260	38	102	1483	3188	6.04	18.8	20.7	20.6
ST08005	902	6370	8100	794	6041	1271	<2	17200	67	54	2983	2301	5.20	22.0	21.4	23.7
ST08006	418	6594	7241	425	8280	885	<2	7300	68	152	1850	4421	6.37	24.0	20.5	26.4
ST08007	658	6442	7552	157	8707	1201	<2	6320	45	115	2028	4109	4.95	25.7	20.5	28.2
ST08008	179	2762	3498	359	5575	725	7.6	6860	32	36	2153	3361	6.54	18.8	20.8	20.5
ST08009	334	3676	4690	434	7747	779	<2	6360	35	54	2572	4079	5.95	23.7	20.5	26.0
ST08010	651	6941	7814	406	10766	1201	<2	9400	106	221	2074	5530	5.47	31.2	20.6	34.2
ST08011	382	2555	3490	95	9206	655	11	5520	36	119	1452	4564	5.41	26.5	20.7	29.0
ST08012	541	5334	9263	973	4108	1759	<2	18280	57	29	3680	2073	5.44	19.0	20.8	20.7
ST08013	266	2309	2758	127	2968	369	7	3240	18	14	641	1666	5.78	9.9	20.8	10.8
ST08014	188	5422	5847	427	2384	876	<2	5620	29	142	893	1266	5.44	10.0	20.5	11.0
Average	438	4454	6030	388	6617	878	9	7656	45	89	1869	3238	5.63	20.9	20.7	22.8
CV%	47	39	42	65	36	43	25	60	50	64	52	38	7.95	30.2	1.2	30.3
Median	418	4422	5961	383	6406	822	8	6340	37	74	1939	3275	5.46	22.0	20.7	23.7
min	179	2309	2758	95	2384	347	7	3240	18	14	608	1266	4.95	9.9	20.5	10.8
max	902	6941	10942	973	10766	1759	11	18280	106	221	3680	5530	6.54	31.2	21.4	34.2

Stored urine samples Siddhipur

Filtered 0.7 and 0.45 μm , analyzed directly using a HACH DR 2000 photo-spectrometer.

Sample #	Date	EC mS/cm	Temp °C	EC _{comp} mS/cm	pH -	PO ₄ -P mg P/L
I	11/27/2008	27.1	16.5	32.7	9.0	315
II	11/27/2008	22.9	14.1	29.3	8.9	250
III	11/27/2008	25.4	17.2	30.1	9.1	260
IV	12/19/2008	20.1	11.5	27.5	8.9	230
V	1/6/2009	20.3	14.6	25.6	9.2	170
Average				29.0	9.0	245
CV%				7%	1%	15%
Median				29.7	9.0	255
Minimum				27.5	8.9	230
Maximum				32.7	9.1	315

Correlation EC versus PO4-P

Correlation ρ : 0.986 Slope α : 19.5 Intercept β : -321

Standard addition Nessler method for NH₄⁺ analysis

Date: 10 December 2008
 Instrument: HACH DR 2000
 Matrix: diluted urine (1:10'000)
 Wavelength: 380 nm
 Standard: Merck 1000 mg NH₄⁺/L

Lineare Eichkurve

Standard-Nr.	Messsignal y _i	Sollkonzentration x _i	Messwert
	-	mgN/L	mgN/L
1	1.35	1.94	1.92
2	1.19	1.70	1.69
3	1.03	1.46	1.46
4	0.87	1.22	1.22
5	0.72	0.97	1.01
6	0.54	0.73	0.75
7	0.36	0.49	0.48
8	0.17	0.24	0.21

Verfahrensstandardabweichung: $s_{x0} = 0.025$ [mgN/L]

Addition

Addition-Nr.	Messsignal Y	Messwert X _{gefunden}	Δ_{Soll}	$\Delta_{gefunden}$
	-	mg N/L	m gN/L	mg N/L
1				0.00
2	0.35	0.46		0.08
3	0.50	0.69		0.15
4	0.51	0.70		0.23
5	0.51	0.70		0.30
6	0.54	0.75		0.37
7	0.61	0.84		0.45
8	0.67	0.93		0.52

Koeffizienten der Wiederfindungsgeraden (95%-Vertrauensgrenzen)

b = 0.85 (0.45...1.24)

a = 0.51 (0.38...0.64)

Reststandardabweichung der Wiederfindungsfunktion $s_{yf} = 0.060$ [mg N/L]

Standard addition molybdovanadate method for P analysis

Date: 3 December 2008
 Instrument: HACH DR 2000
 Matrix: diluted urine (1:100)
 Wavelength: 430 nm
 Standard: Merck 1000 mg PO₄³⁻/L

Addition

Standard Volume mL	[PO ₄ ³⁻] theoretical mg/L	[PO ₄ ³⁻] actual mg/L	Difference mg/L
0.00	8.5	8.5	0
0.05	10.5	10.7	0.2
0.10	12.5	12.4	-0.1
0.15	14.5	14.6	0.1
0.20	16.5	17.2	0.7
0.25	18.5	18.7	0.2
0.30	20.5	20.7	0.2

Standard deviation: 0.3 [mg PO₄/L] or 0.098 [mg P/L]

Pipet test Socorex 100 - 1000 µL and 10 - 100 µL

Date: 5 December 2008
 Density 25°C: 0.997 g/ml

Pipet Socorex 06072637

100-1000µL

preset	1 [g]	0.5 [g]	0.1 [g]
1	0.990	0.496	0.098
2	0.989	0.496	0.099
3	0.987	0.497	0.099
4	0.989	0.495	0.100
5	0.990	0.497	0.100
6	0.989	0.495	0.099
7	0.991	0.500	0.100
8	0.991	0.500	0.100
9	0.991	0.496	0.100
10	0.995	0.497	0.100
average	0.990	0.497	0.099
st dev	0.002	0.002	0.001
CV [%]	0.21	0.39	0.72

Pipet Socorex 12081204

10 - 100 µL

preset	0.1 [g]	0.05 [g]	0.01 [g]
1	0.099	0.049	0.010
2	0.099	0.049	0.009
3	0.099	0.049	0.010
4	0.099	0.049	0.010
5	0.099	0.049	0.009
6	0.099	0.049	0.010
7	0.099	0.049	0.010
8	0.099	0.049	0.010
9	0.099	0.049	0.009
10	0.099	0.049	0.010
average	0.099	0.049	0.009
st dev	0.000	0.000	0.000
CV [%]	0.22	0.27	1.99



Struvite

recovery from urine
at community scale in
Nepal

Projet SIE

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