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Struvite Recovery from Urine at Community Scale in Nepal

Final Project Report Phase I

March 2009

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Struvite Recovery from Urine at Community Scale in Nepal (STUN) - Final Project Report Phase I

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STUN is a joint collaboration project of Eawag (Swiss Federal Institute of Aquatic Science and Technology) and UN-Habitat Water for Asian Cities Programme Nepal (The United Nations Human Settlement Programme).

March 2009

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Abstract

- Struvite production at a community scale within a peri-urban settlement of Kathmandu is possible.

Urine

- Approx. 350 liters of urine can be collected per adult household member and year with an EcoSan toilet.
- The collected urine shows nutrient concentrations at the lower range of expected values.
- The presently available usage options for source separated urine are suboptimal. It is estimated that for approx. 60% of the collected urine the utility value could be improved.

Magnesium

- Magnesium products are scarce in Nepal. Sourcing is difficult but possible. Due to the nonexistent demand prices are comparably high.
- At present magnesium sulphate is the product of choice. Bittern and locally quarried magnesite might have a potential for the future.

Agriculture

- The present availability of industrially produced mineral fertilizer is good. Organic fertilizers are sparse as cattle are rare and composting and EcoSan toilets are the only available sources.
- Whereas nitrogen is applied sufficiently phosphorous and potassium are assumed to be deficient.
- Struvite, having a phosphate content of 29%, could become a welcome additional source of phosphorous.

Community

- Social acceptance of struvite is high in the Newar community. Concerns are indicated about the acceptance in other, higher casts (Brahmins, Chetris).
- Observed interest and enthusiasm for struvite within the community of Siddhipur are remarkable.
- The rural character of the community poses questions whether promotion of direct application is preferable over struvite precipitation. Whereas half of the farmers prefer struvite precipitation others prefer direct application

Economics

- The current local nutrient value of urine is estimated to approx. 250 NRp·m^{-3} (3.70 CHF). 20% of this value can be fixed as struvite, 80% remain in the processing effluent.
- The effluent it of major concern as the major part of nutrients cannot be precipitated as struvite. It is unlikely that struvite production becomes economically feasible unless viable and efficient usage/treatment options are available for the effluent.
- The present magnesium input costs are of the same order as the likely price struvite can achieve on the market. Additional labour and processing costs are not included yet.
- A full-scale community wide struvite production scheme could at present generate approx. 170 kg struvite per year with an estimated value of 5’000-7’000 NRp (75-100 CHF).

- The practical reactor set-up and operation as well as further research in project phase II will bring additional and more assured results.

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Abbreviations

AS	Ammonium sulphate $(NH_4)_2SO_4$
CIUD	Centre for Integrated Urban Development, local NGO
DAP	Diammonium phosphate $(NH_4)_2HPO_4$
DNET	Development Network Pvt. Ltd., local consulting company
DWSS	Department of Water Supply and Sewerage, Nepal
Eawag	Swiss Federal Institute of Aquatic Science and Technology
EcoSan	Ecological Sanitation, in the context of Nepal often used for UDDTs referred to as EcoSan toilets
ENPHO	Environment and Public Health Organization, local NGO
FGD	Focus Group Discussion
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation)
Lumanti	Lumanti Support Group for Shelter, local NGO
MAP	Metal Ammonium Phosphates ($MeNH_4P0_4 \cdot xH_20$), a group of ammonium phosphate compounds formed with divalent metals, can be used as fertilizers; Struvite ($Mg\ NH_4P0_4 \cdot 6H_20$) is the most commonly used MAP and in the literature MAP is often used as a synonym for struvite (Magnesium Ammonium Phosphate); in this context not to be confused with Mono-Ammonium Phosphate, another common fertilizer product
MOAC	Ministry of Agriculture and Cooperatives, Nepal
MOP	Myriate of Potash (K_2O)
NARC	Nepal Agricultural Research Council
NEWAH	Nepal Water for Health, local NGO
NPK	Nitrogen (N), Phosphorous (P) and Potassium (K)
NRp	Nepalese Rupees (at the time of writing 100 Nepalese Rupees have a value of approximately 1 Euro or 1.50 Swiss Franc)
STUN	Recovery of STruvite from Urine at community scale in Nepal
UDDT	Urine diverting dry toilet
UN-HABITAT	United Nations Human Settlements Programme
V.D.C.	Village Development Committee, institutional and organisational entity of a village which is too small to form a municipality
WAC	Water for Asian Cities Programme
WAN	WaterAid Nepal
WSSUC	Siddhipur Water Supply and Sanitation User Committee

1 Introduction

The concept of ecological sanitation[1] (further referred to as EcoSan) and its worldwide promotion to ameliorate the sanitary situation of people and communities in developing countries has been a success story in many aspects. For the people who could profit the toilets built have brought comfort and dignity into their lives which they have both severely been missing in their often desolate sanitary conditions. Further the proper collection and treatment of the human waste has helped to improve the environmental situation as well as to decrease the proliferation of vector diseases thus largely helping to establish better living conditions among the poor.

The stated achievements can be expected from any improved sanitary technology and might be considered as standard. In contrast to the conventional systems EcoSan toilets do not only provide a standard solution though, they outmatch these achievements by providing the users a very valuable extra. Whereas the logic of conventional toilets ends with the above mentioned accomplishments and leaves the users with recurring costs for getting rid of what they excrete by making them pay for emptying of pits, connection to sewer systems or dislocation of the whole toilet, EcoSan toilets even generate value for their users. The human waste in the form of faeces and urine that is collected with these toilets serves as perfectly conditioned fertilizer and enables the users to engage in high yielding organic agriculture or saving at least some of the burden oppressed on them by the ever rising costs of chemical fertilizers.

But of course there is not all pure gold what comes with EcoSan and the approach has also its stumbling blocks and shortcomings. Of many of such that might be identified by critics one of them is definitely the proper and entire reuse of the collected human waste. Undoubtedly this is dependent on the actual EcoSan technology used, the local context, the user awareness, training and experience and other factors but the fact that human waste handling is something considered as unclean and something that it is rather uncommon to big parts of the world confirms this point. Winblad and Simpson (2004) identify a widespread 'faecophobia' among people. In theory the reuse of composted or dehydrated faeces and collected urine is superb and permits not only the much propagated closure of nutrient cycles, it even permits it within the very premises of nutrient removal just as nature has provisioned it. But what works in theory is not always as easily achieved in practice. The usage and upkeep of an EcoSan toilet needs training and it is sometimes a long and strenuous process to make people value the recycled goods the way they deserve it. Not valuating the collected waste leads to inappropriate use (often non-use) and like this the very link is missing which distinguishes EcoSan from other conventional sanitary technologies. It is in a way easy to built EcoSan toilets but it is much harder to make the people understand the concept behind it.

Regarding the reuse of the collected human excreta in the case of Nepal, for most of the users it makes sense that the dehydrated, compost-like faeces is a good fertilizer and beneficial for their soil. But whereas its usage can be considered as good, urine on the contrary is often considered as of not much use. For a good share of people urine still does not have a value. And even if it is does, many are discouraged to use it because of its inconvenient odour and liquid form (Thapa 2004). The result is that the recycling of urine and the nutrients it

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[1] For further information on ecological sanitation please refer for example to ESREY, S. A., *et al.* (1998) *Ecological sanitation*, SIDA, Stockholm. or WINBLAD, U., and SIMPSON-HÉBERT, M. (2004) Ecological sanitation – revised and enlarged edition. SEI, Stockholm. A lot of information, further reading material and references can also be found on the EcoSan portal of GTZ (http://www.gtz.de/ecosan).

contains is often poor. Partly this is due to a lack of awareness of the people but partly this is just because urine does have properties which make its use less convenient. In the following work it is hypothesized therefore that these properties (liquid urine handling, difficult storage and transportation as well as bad odour, just to name the most important ones) are essential and inherent barriers for widespread acceptance of liquid urine as fertilizer. This project consequently tries to establish whether the conversion of urine into struvite (magnesium ammonium phosphate hexahydrate or $MgNH_4PO_4 \cdot 6H_2O$), a white odourless powder derived from source separated urine by the addition of magnesium, is an option to convert urine into a more desirable form and thereby to further promote and optimize the usage of urine. Whereas the precipitation of struvite has been examined and tested in laboratory scale, real life in-situ production of struvite in a developing context has never been studied so far. With this work hence a feasibility study shall be conducted in which the process of struvite recovery is investigated under site-specific conditions and a possible context determined in which struvite recovery could be successful.

For the targeted research the village of Siddhipur has been chosen, a peri-urban community in Nepal. The village is located approx. 8 km southwest of the capital Kathmandu. It is largely a farming community but the influence of the close and ever growing capital is sensible. To improve the poor sanitary conditions different organisations have been installing a total number of 100 EcoSan toilets in the last years and the people have been using them with a high degree of satisfaction (Manandhar *et al.* 2008).

1.1 Project Design

The goal of the STUN project is a feasibility assessment of the conversion of urine into struvite powder as a viable means for capturing the nutrients contained in source separated urine. As such the research scope of this project is very broad and ranging from technical aspects over economic considerations to socio-cultural issues. For practical means the work has been divided into two separate phases: a more theoretical socio-economic part which assesses the project environment and resource availability (Phase I) and a more practical technical part which comprises the setup and operation of a pilot reactor based on the findings of the preceding work (Phase II).

As a local partner for both parts of the research UN-HABITAT Nepal could be gained, the local branch office of the United Nations Human Settlements Programme. Under the Water for Asian Cities Programme (WAC) UN-HABITAT has been acting as a promoter, coordinator and funder of EcoSan projects in Nepal since after the pilot projects started in 2003 have been completed successfully (Manandhar Sherpa *et al.* 2006). UN-Habitat provided not only facilities for this research but also valuable support and practical knowledge.

This report details the findings made in Phase I of the STUN project. The first phase is concerned with a range of different objectives (see Figure 1) but mainly consists of the following activities:

- An overview of the general sanitary situation in the communities of the Kathmandu Valley having EcoSan toilets installed
- A quantitative and qualitative analysis of the needed input resources for struvite precipitation (urine and magnesium)
- An assessment of struvite which comprised mainly an evaluation of
    - the local agriculture environment and practies
    - the local availability and demand for fertilizer
    - the cultural and social acceptance of struvite
- A more general analysis of the fertilizer market and
- An economic feasibility assessment

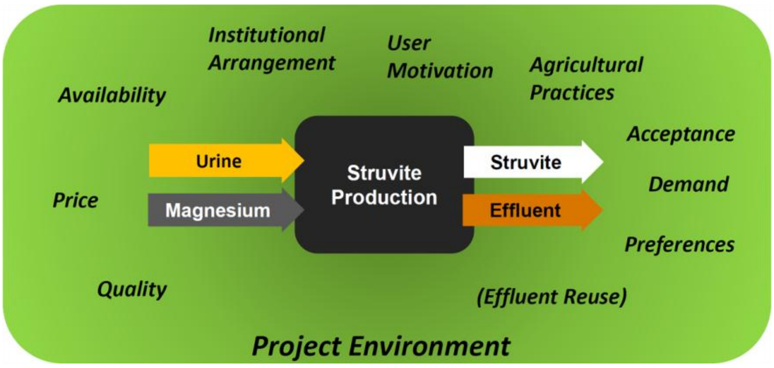


Figure 1: Overview of topics of interest STUN Phase I

2 Study Area

As Figure 1 shows, the production of struvite is influenced by a number of different factors. Among these are many which are dependent on the locally encountered project setting. The selection of an appropriate study area is therefore a vital part for the outcome of the targeted feasibility assessment. As the most fundamental factors which are largely dependant on the study area chosen could be identified: i) the total number of EcoSan toilets in the community; ii) the user motivation; iii) the institutional arrangement. Regarding the installed EcoSan toilets, these should have an appropriate and working urine collection system. Furthermore communities which already successfully practice direct urine application to a high degree have a small volume of excess urine and are therefore less interesting.

Section 0 will give a short overview of our findings from various visits to EcoSan communities in the Kathmandu Valley. First however, a general overview of the state of EcoSan development in the Kathmandu Valley follows.

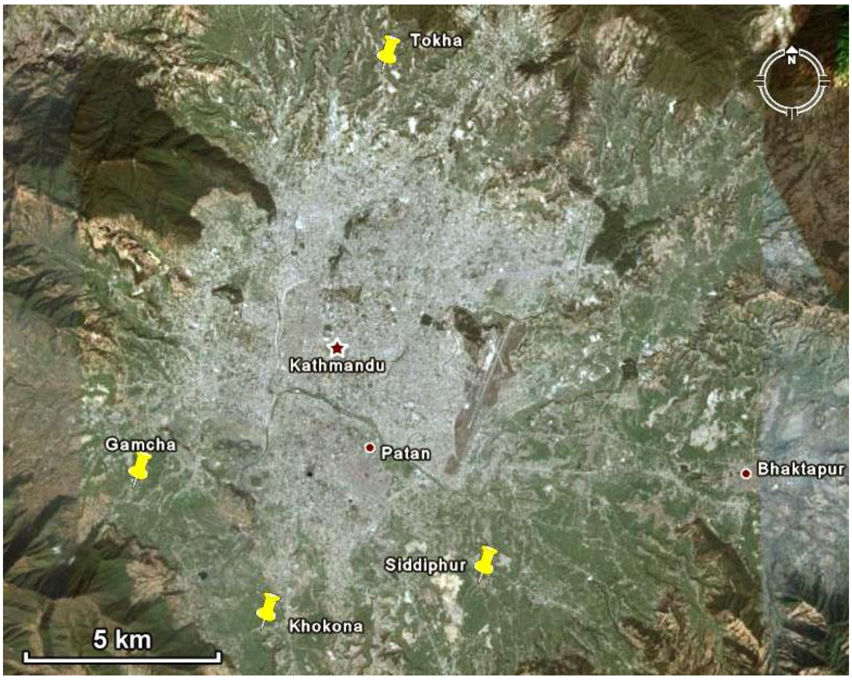
2.1 EcoSan Overview Kathmandu Valley

EcoSan is still a new concept for Nepal though farmers are using human excreta with their own way. Few Nepali professionals are already got training on ECOSAN from Sweden and China. ENPHO organized a talk program on 15 January 2002 to sensitize this issue within major stakeholders working in water and sanitation sector. In Nepal, the ecological sanitation toilet concept was first introduced in 2002/2003 by ENPHO under the support of Water Aid Nepal in Khokana. As part of the pilot programme, ENPHO constructed 10 EcoSan units in Khokana. In the same year the Department of Water Supply and Sewerage (DWSS) under the support of WHO also constructed 10 EcoSan units as a pilot project in Siddhipur. Hence both the programmes in these communities were successful and well received locally. After the success of these pilot projects, the EcoSan concept was extensively expanded to other peri-urban areas of Kathmandu by WaterAid Nepal, ENPHO, Lumanti, NEWAH and DWSS in some villages around the Kathmandu valley. Also the EcoSan toilet is also under construction at newly built house in Kathmandu inside urban area as a demonstration unit. It has great potential in country like Nepal where only 27 % of total population is accessed by sanitation.

At the moment Kathmandu valley peri-urban area like Siddhipur, Khokana, Lubhu, Imadol, Thecho Gamcha, Sankhamul, Tokha, Bode, Thimi, Tigani, Duwakot have EcoSan toilet. However according to ENPHO report large number of EcoSan toilets is built within the peri-urban area of Kathmandu valley (WAN and ENPHO 2007). Among 517 EcoSan toilets, 481 toilets are built in this area. Except two EcoSan toilets in urban area one in Dr. Roshan Shrestha's house and one in ENPHO office. Most of the EcoSan Toilet built in Newari community area. But according to field visit different area with discussion different people number of EcoSan toilet probably more than 800 all over the Nepal out of this more than 600 might be inside Kathmandu Valley.

The project was implemented in the community in association with partner organisations most of the toilet funding by different Organization like Water Aid UN-HABITAT, ENPHO, CIUD and Lumanti provided both technical and Financial support to construct EcoSan toilet. When construct the toilet 50 to 80% funding provide by funding agency and 20 to 50% funding by people themselves.

Handling of excreta especially urine of EcoSan toilet in different region have different practice. In Siddhipur we found some people used urine to the composing and some people used directly to the backyard vegetable crop but most of the people used urine to the composting.



Source: Google Earth

Figure 2: Overview of Kathmandu Valley and the visited communities

Which community is most suitable for a successful implementation of a community scale struvite production? Different villages within the rural area of the Kathmandu Valley have been visited. Among the villages with a larger number of EcoSan toilets it was agreed upon with the local partners that Siddhipur V.D.C is the most promising and suitable place for this research. During the last 5-10 years a total number of 100 EcoSan toilets has been built within the community and used with great success.

2.2 Visited Sites

Totally we have visited four different communities in the peri-urban area of Kathmandu: Siddhipur, Khokana, Gamcha and Tokha with 95, 57, 8 and 136 built toilets according to the latest assessment done by ENPHO (2007). Siddhipur, Khokana and Tokha are together with Thecho, which we have not visited, the four villages with by far the biggest number of built EcoSan toilets in Nepal. However, it has to be considered that these figures of built toilets are almost two years old by now and to a certain degree outdated. Additional construction programmes have been realised in the meantime. Despite some efforts it has proved hard to obtain updated figures and the numbers subsequently mentioned in the text have to be considered as estimations.

Next to the number of EcoSan toilets, the different implementing NGOs have been a factor for choosing the stated villages. In the four visited villages different local NGOs have been introducing the EcoSan toilets and as such we also found different practices, knowledge and attitudes regarding the implementation of the EcoSan concept.

Siddhipur

Siddhipur VDC of Lalitpur district lies in the close vicinity of the capital city of Kathmandu. Siddhipur is one of old Newar settlements in Kathmandu Valley. It is in Lalitpur district and located some 5 km east of Lalitpur. The main ethnic groups of the area are Newar and more than 90% of them are engaged in agriculture occupation. Its 1.9 square kilometer area in home to 6046 people in 1308 household.

UN-HABITAT is now extensively implementing EcoSan in Siddhipur which is peri-urban area. There, 10 toilets are already implementing by D-Net and about 90 are implementing whit joint collaboration by UN-HABITAT and ENPHO.

Khokana

Khokana VDC situated in Lalitpur district and is 12 km south of Kathmandu. Wards No. 1 to 8 are concentrated within the same location which is known as Thulo Khokana where as ward 9 is isolated from the other wards and is locally known as Sano Khokana. There are altogether 692 households with a population of 4152 dominated by the indigenous community of ethnic Newars. Khokana Village Development Committee (VDC) is dominated by the ethnic inhabitants of Newars.

Till date ENPHO has constructed 65 Eco-san toilets in local partnership of Khokana Janakalyan Sangh. Since Khokana is the farmer community, ECOSAN is gaining popularity day to day.

According to Agronomist Harikrishna Upreti from Nepal Agriculture Research Centre(NARC) already did urine application study there and it was found people use urine very well all most all urine use in different way to the crop what they have collected they used about 25% urine to the composting. But during our visit and discussion with people of Khokana it was found composting is common practice in this community. Most of the farmers are adopting pile composting in open place. After the construction of ECOSAN, many farmers are applying urine in composting because of bad smell of stored urine and difficult to transport to field they use urine very less amount directly to the field.

Gamcha

Gamcha is also one of Newari poor community area which is inside Kirtipur Municipality wards no 7. Located 8 Km south of Kathmandu and west of Lalitpur. Till date CIUD has constructed 25 Eco-san toilets with local partnership of Gamcha user community other some also under construction. They use only few urine and faeces as fertilizer to the backyard because of the people doesn't have more agriculture land .

Tokha

Tokha is also another per-urban area of Kathmandu valley. Tokha is Located 6 km north from the Gongabu new bus park of Kathmandu. Till date Lumanti has constructed 86 EcoSan toilets in the local partnership of Tokha user community other 20 will start to construct very soon. We found toilet design is completely different from other place Lumanti doesn't provide urine collection tank. Most of the People put themselves locally made clay pot size about 20 to 30 litres for urine collection. Majority of the community is from Newar ethnic group. The culture, tradition and life style of the people are very similar to that of Siddhipur and Khokana. They are also used urine to backyard garden to the vegetable and also some of urine used to the composting but when visit there they are not using very well because we saw they don't have good collection system of urine.

Discussion of Findings

For selection of suitability for our struvite project area are compare to different place of EcoSan urine management practice place, like Khokana have already done some analysis by NARC they are using urine very well as good fertilizer. Another place Gamcha there has good urine collection system and also they don't have much more agriculture land. Good option to the excess urine suitable for making struvite powder but they have very limited number of EcoSan toilets. Similarly when we visited the Tokha Lumanti constructed the number of EcoSan toilet but they have very poor urine collection system they don't have any fixed urine collection mechanisms even in some toilet directly discharge to ground. Still we did not visit yet Techno any way we already discuss with Lumanti staff there is also very worst condition of urine collection system.

According to comparing different area of EcoSan project are in Kathmandu valley. As we visit in different location of EcoSan toilet there are different practice and behaviour we found most of the area people use urine directly to the composting as compare to the other area Siddhipur have high number of EcoSan toilet. Siddhipur might be good option for struvite project as we visit so many times in Siddhipur there are already very well functioning user committee. Number of EcoSan toilet also very high and they don't use urine as properly they have excess urine which could be use for making struvite and also found people are very much interesting to make struvite. Most of the people those who have EcoSan toilet they are farmer and they need fertilizer and they know urine also very useful fertilizer but most of the people have far way of land fields and they feel due to bad smell stored urine difficult to transport liquid urine to the field. People think if we able to produce struvite powder it can easily stored and easily transport whenever when they need. In this way Siddhipur might be good option among other peri-urban area because of people have very good approach to the struvite project and they have already very well functioning user committee.

What does the local community and study area like? Siddhipur V.D.C. is a peri-urban settlement at the fringe of Kathmandu City. It is part of the local Newar communities and counts ca. 6000 inhabitants. Despite the vicinity to the city the village has kept a very rural character. A majority of its population is engaged in agriculture. Important sources of income are besides agriculture the the production of straw mats (sukul) and beaten rice.

2.3 Siddhipur

Siddhipur is a peri-urban settlement with the status of a village Development committee (VDC). It is situated in Lalitpur District at a distance of about 4 km southeast of Lalitpur. Siddhipur has a mild climate most of the year summer temperatures range from 19-27°C. In winter temperatures are between 2-20°C. During the rainy monsoon season between June and August, there is an average rainfall of between 200-375mm in Siddhipur.

Source: Google Earth

Figure 3: Arial view of Siddhipur V.D.C

Legend:
1 Siddhipur Water Supply and Sanitation User Committee Office
2 House of Jiban Maharjan (field reactor site for Phase II)
F Fertilizer shop

The total population of Siddhipur is 6046 with 1308 households. The average household size in Siddhipur is 4.6. The total area of Siddhipur VDC is 1.9 km^2. Major occupation is agriculture followed by service, own enterprises and wages/labour. If there is no any agriculture work most of the women were involved in making straw mats (sukul).

The socio economic status of the community is comparatively better. Although agriculture is the traditional occupation of the community but now it is practiced only at subsistent level.

2.3.1 Historical Use of Urine and Faeces

Historically the Kathmandu Valley had been an agriculture based area with few industries and most of the waste was biodegradable. Composting played a very important role. In the past people of the ethnic communities in the Kathmandu Valley area were practising the use of raw human excreta on their agricultural fields. In some places of the valley the collection of human excreta and its use for agricultural purposes still exists today but after modernisation the access to this resource was limited and the introduction of chemical fertilizers often replaced local nutrient recovery. Additionally these current practices are liable to threaten human health as the personal and community hygiene is not taken into account when collecting and using human waste on the farms.

Traditionally, there are two types of domestic composting pits mainly practiced by the Newar communities, the main ethic group populating the Kathmandu valley. Saaga is a pit located in the backyard of the house where kitchen waste is dumped and composted. The pit is emptied three to four times a year. Naugal on the other hand is a small pit dug under the staircase on the ground floor in which ash and rice husk mixed with urine and certain other materials were composted. Mostly elderly and children are used to urinate in this pit out of convenience. The composted material of saaga and naugal is later used as fertilizer in agriculture. Besides these pits, some settlements also dispose of public open defecation areas, called Nalas.

Figure 4: A traditional saaga composting pit

Almost all the people of Siddhipur belong to the Newari cast with about 90% of the population being involved in agriculture (WAN and ENPHO 2007). Many practice naugal and shaaga. Additionally, the drained water from the public open defecation area is used for field irrigation. There are six main areas used for open defection out of which four designed for females only. Due to high ground water table those who have septic tank and pit latrine using open defection because of fear of quick filling of septic tank and pits and there are no any conventional sewage system so most people like to install EcoSan toilet. But this community public toilet looks no any secure just surrounding wall with open drain which is directly goes to irrigate land and it shows to need proper maintenances and operation.

3 Production and Market Environment

Besides the determining factors looked at for the evaluation of the different possible study sites a range of other factors is of considerable importance as well for a positive feasibility assessment of a community scale struvite production. What is the production and market environment that struvite would have to compete on? Is there a demand for fertilizer products? How do the local agricultural practices look like? What is the price range for fertilizers? Would there be a demand for struvite? What would be the effect of struvite introduction on soil fertility? These and other questions shall be assessed in the following main section. First some considerations about predominant soil types are given followed by an overview of the local fertilizer market and the agricultural practices including fertilizer application and nutrient cycles.

What characteristics do the predominant soils show? In general Nepalese soils are slightly acidic and show low to medium organic matter, medium nitrogen, very high phosphorous and medium potassium concentrations. A local soil test conducted earlier in Siddhipur showed a low pH value, medium nitrogen, deficient phosphorous and excessive potassium concentrations. High lime application was advised. Secondary macro- and micronutrients have not been studied so far in Nepal. Theoretical considerations suggest however that magnesium application might have a positive effect.

3.1 Predominant Soil Types and Soil Fertility

Soil is the most important natural resources because it is the medium which supports the growth of all plants. Soil offers mechanical anchorage as well as water and essential plant food elements (nutrients) for plant growth. According to a Nepal wide study conducted in 2006/07 by NARCs Soil Science Division a total number of 1015 samples from various study areas covering 11 districts and additionally 283 samples from farmers covering 17 districts have been analyzed (NARC 2007). These sample have been tested for organic matter, pH value, total and available nitrogen, available P_2O_5 and available K_2O. According to the data the Nepalese soils can generally be qualified as slightly acidic, low to medium in organic matter, medium in nitrogen, high in phosphorous and medium in potassium content (see Figure 5).

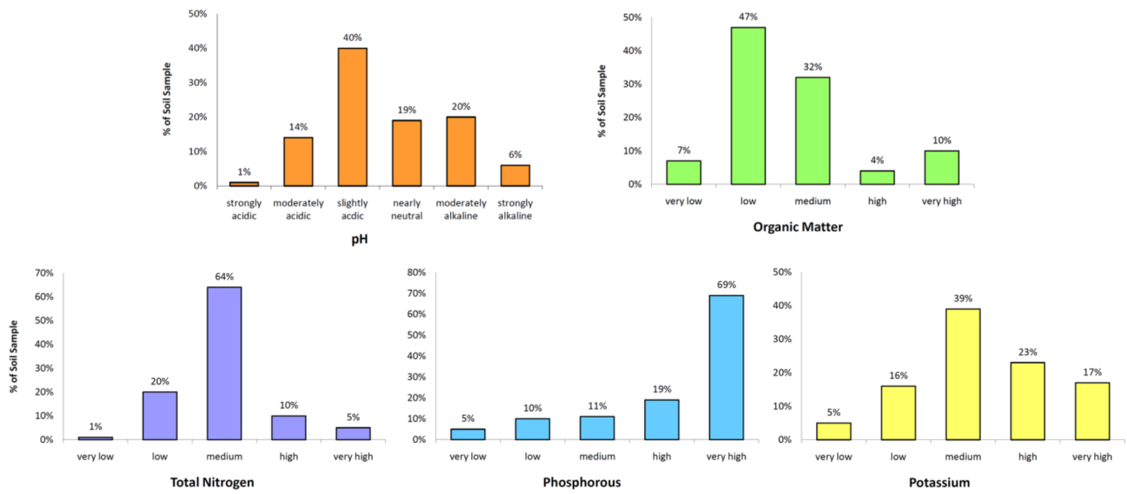
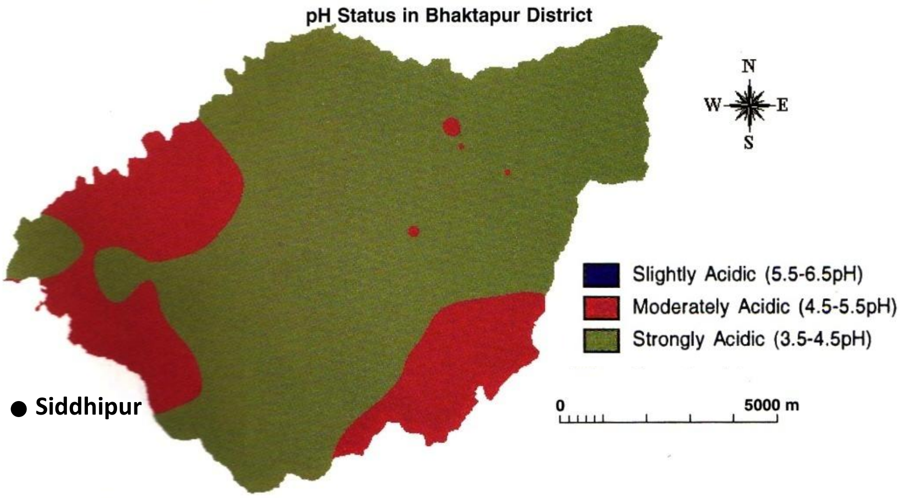


Figure 5: Nepalese soil analysis results (pH, organic matter, nitrogen, phosphorous, potassium)

Another research done by the Soil Science Division of NARC identifies mainly two different types of soils with distinct characteristics in the Kathmandu Valley (NARC 1995): Soils of irrigated lowland (*khet*) with sandy loam in surface soil and sandy clay loam in subsurface soil and soils of upland (*bari*) with gravelly sandy loam. Siddhipur comprises almost completely khet land. A number of samples were analysed from the Kathmandu Valley (Kathmandu, Lalitpur and Bhaktapur). During the last few years it was found that the soil pH value of almost all areas indicated strongly acidic soils which would require liming for correcting the soil pH. The report includes a soil map of Bhaktpur (*Figure 6*) which shows that almost the whole area is strongly acidic. This area is very close to Kathmandu and Siddhipur and of more less the same topography and soil conditions.



Source: NARC (1995)

Figure 6: Soil acidity map of Bhaktapur District

DNET (2003) commissioned a soil analysis at the time of EcoSan toilet introduction in Siddhipur. The laboratory analysis showed that the local soils resemble the ones in the whole Kathmandu valley. The following parameters were measured: ph 5.4, nitrogen 0.19% (medium), phosphorous 16.07 kg·ha^{-1} (deficient), potassium 467.4 kg·ha^{-1} (excess). Because of the low pH value liming was advices by the laboratory in a ratio of 188 kg·ropani^{-1} (3'700 kg·ha^{-1})

Soil Fertility

Soil fertility is the capacity of soil to supply plant nutrients in adequate amounts to facilitate optimum growth. Mainly there are 10 nutrient elements that are necessary for plant growth. These elements can be divided into major nutrients and micro nutrients (*Table 1*). When these element are not available to the plant in quantities optimal for growth the quantity and quality of yield is affected.

Table 1 Major and micro plant nutrients

Major Nutrients	Primary nutrients	Nitrogen (N) Phosphorus (P) Potassium (K)
	Secondary Nutrients	Calcium (Ca) Magnesium (Mg) Sulphur (S)
Micro Nutrients		Copper (Cu) Zinc (Zn) Manganese (Mn) Molybdenum (Mo)

Source: MOAC (2003)

Every nutrient has different major functions. Table 2 shows some major nutrients and their functions and role for the crop.

Table 2 Functions and deficiency symptoms of various plant nutrients

Nutrient	Major functions	Deficiency symptoms of crop
Nitrogen	Necessary in large quantity for all growing crops to promote growth of leaf and stem, increase plant vigour, improve succulence in leafy crops and improve their quality, increase protein content of food and fodder crops.	Yellowing of old leaves, reduced tillering of cereals, if deficiency is serve the whole crop appears yellowish and growth is stunted
Phosphorus	Needed for flowering, fruiting, seed formation, root development and early plant development, strength-ens straw and decreases loading	Stunted growth, purple orange colour of older leaves, new leaves dark green, cereals' tillering is drastically reduced
Potassium	Imparts increased vigor, makes plant stalks healthy and strong and is very important in reducing the effect of drought	Deficiency symptoms are seen in older leave first. Overall slow growth, increased susceptibility to decreased loading
Calcium	More important in alkaline and acidic soils, necessary for normal cell division, helps in the development of the terminal buds	New Leaves become white, growing points curl and die
Sulphur	Required for the formation of chlorophyll, esp. impor-tant for soy bean	Pronounced retarding effect on plant growth, results in uniformly chlorotic plants, first chlorosis of younger leaves, under severe deficiency the whole plan shows symptoms
Magnesium	More important in acidic soils, key element in chloro-phyll molecule without which photosynthesis cannot occur	Marginal of interveinal chlorosis with pinkish colour of older leaves, sometimes leaf rolling like drought effect, plant susceptible to winter injury

Source: MOAC (2003)

According to information received from soil scientists at NARC until now only research about the primary plant nutrients has been completed and very few studies have done so far regarding secondary nutrients. Because of this there have been no recommended values about secondary nutrients established so far for Nepal. However, as Figure 6 shows and in accordance with information received at NARC the soils in the Kathmandu Valley are mostly acidic. As Table 2 shows this may be a point which might render the usage of a magnesium fertilizer more interesting. Possibly this could mean that struvite, which contains about 10% magnesium, might be especially good for soil fertility under the local conditions.

What is the availability of fertilizers on the market? The present availability of mineral fertilizers on the Nepalese market is good. Within Siddhipur five shops were found selling well over 2000 pieces of 50 kg bags per year. Prices range from 20 to 50 $NRp \cdot kg^{-1}$ depending on the product. By far the most popular product is urea, a straight nitrogen fertilizer. Due to comparatively high official prices and heavy Indian fertilizer market subsidies over 70% of the total Nepalese fertilizer demand is illegally imported from India. The lack of control has raised concerns about fertilizer quality.

3.2 Fertilizer Market Overview

A reliable supply of fertilizers is of immanent interest to every state in order to assure proper alimentation of its population. For meeting agricultural output targets today's intensive and high-yield targeting agriculture is dependent on a significant and steady supply with industrially produced mineral fertilizers. Yet, in many developing countries shortages of fertilizers occur due to their high price and/or a lack of funds for adequate state subsidies. In order to get an overview about the local conditions under which struvite would have to compete the local fertilizer market within Siddhipur and as well in general is looked at in the following subsections.

3.2.1 Fertilizer Survey Siddhipur

Within the community of Siddhipur four shops have been identified selling fertilizer products to local farmers (see Figure 3). Whereas one can be considered as considerably big with a wide variety of different fertilizer products and even a branch shop, two are mainly selling other products next to a handful of fertilizers. One shop at last is actually a grocery store with just one or two fertilizers on sale. The larger shops stated that they are open throughout the year and are always able to supply fertilizer to the market. In accordance, within the shops and in storerooms larger amount of fertilizer could be observed. According to information received the reliability of supply with Indian fertilizers is sometimes hampered due to shortages. However, during recent years Nepalese fertilizers have always been available. The largest shopkeeper states an annual average sales volume of 1500 - 2000 bags of fertilizer per year (50kg bags) whereas the second largest estimates a number of 400 - 500 bags per year. However, since both of them state that a not neglectable amount of these bags is sold to people from other communities and also because it is difficult for them to tell the percentage of local customers these figures cannot be applied for Siddhipur. From a seasonal perspective the biggest demand for fertilizer is reported to be in the time of June/July when the paddy fields are planted and in Nov/Dec, the time of winter crop planting (normally wheat).

To assess the local availability of fertilizer products a small survey in the four bigger shops has been conducted and samples of the major products have been taken for further analysis. The found products and prices are listed in Table 3. Additionally Annex C.1 gives a more detailed overview of the available fertilizer products, the importers / manufacturers, the fertilizer composition and prices.

Table 3 Available fertilizers in Siddhipur

Fertilizer	Nutrients (% of weight) N	P_2O_5	K_2O	Price smaller amounts [$NRp \cdot kg^{-1}$]	Price whole bag [$NRp \cdot kg^{-1}$]	Avg. discount [%]
Urea $(NH_2)_2CO$	46	0	0	22 - 32 [1)]	20 - 30 [1)]	9%
NPK 20:20:0	20	20	0	30 - 32	27 - 30	6%
NPK 20:20:10	20	20	10	36	32	11%
Diammonium phosphate $(NH_4)_2HPO_4$	18	46	0	42 - 48	38 - 44	9%
Ammonium sulphate $(NH_4)_2SO_4$	20.6	0	0	26 - 28	24 - 25	9%
Myriate of Potash (KCl)	0	0	60	25 - 26	22 - 24	10%

[1)] large price difference due to products of different quality (mainly granule size)

The survey shows that at the time of research the normal fertilizer prices in Siddhipur vary from around NRp 20-25 to 40-50 per kg depending on the composition of the fertilizer. The cheapest fertilizers on the market are urea and myriate of potash (MOP), both single-nutrient or straight fertilizer with 46% nitrogen and 60% K_2O respectively. On the other side of the price scale ranges diammonium phosphate (DAP) with 40-50 NRp/kg having a nutrient content of 18% N and 46% P_2O_5. 12 of totally 18 examined products are imported products with the main share being supplied from India. The remaining 6 products are labelled with the name of one of the three fertilizer companies of Nepal but it is difficult to establish whether they have actually been domestically produced or are also imported products. An interesting fact is that there is actually no fertilizer product containing magnesium available. Whereas in western agriculture magnesium is, after N, P and K, the forth most important nutrient supplied to the fields there seems not to be any demand for magnesium within the observed community so far.

3.2.2 The Nepalese Fertilizer Market

After a long period of state regulated and concerted fertilizer supply in Nepal the fertilizer market has been completely liberalized by the government in 1997. Whereas in earlier times fertilizer prices were directly subsidized and indirectly kept low through transport subsidies since the liberalisation the fertilizer prices are subject to the demand and supply conditions on the market. After many years of a major undersupply of the market and reportedly kilometre long lines in front of fertilizer shops the state had embarked on this significant change in policies in order to overcome the eminent shortages and let the market solve the problem. Unsurprisingly the liberalization had a big influence on the availability of fertilizer. But when looking at the official statistics a significant drop in fertilizer imports can be detected after the liberalization (MOAC 2009) and it has hence to be concluded that despite the actual plans the supply further cut down. Interestingly this fact cannot be observed when visiting local fertilizer shops as the supply is steady.

What seems like a paradox has an obvious explanation however. After 1997 the state liberalized legislation and installed some hidden state subsidies. In order to give the market a boost the Nepalese government removed import duties and VAT on fertilizer products and granted other tax reductions. These decreases were not significant enough however to compensate for the increase of prices that happened after the liberalisation. Because of this a new source of fertilizer supply was taped: black market imports from India. Since India continues to subsidize its fertilizer market heavily up to the present the fertilizer prices across the border are considerably cheaper. A comparison shows that identical products cost 40-100% more on the Nepalese market. Thus a lucrative business has developed by smuggling Indian fertilizers into Nepal. As of 2006 roughly 70% of the total amount of fertilizer sold in Nepal is estimated to be from informal sources and almost all of this share can be attributed to India (Thapa 2006). Based on this figures it can be estimated that illegal import of subsidised Indian fertilizer leads to a cross-subvention of the Nepalese market in an order of 40-50 Mio. US$. This is about 7'000 $NRp \cdot ton^{-1}$ or 7 $NRp \cdot kg^{-1}$ fertilizer. The result of these practices is that the official suppliers are more and more pushed out of the market since they are not capable of competing with vendors of Indian-subsidized informally imported fertilizers.

Due to the often obscure sources of the major share of available fertilizers repeated complaints were heard about low fertilizer quality. Since the state cannot control imports at the border and the trade is going through illegal channels chances are high that tampering and cutting with other substances may occur. When asked about their perceptions local farmer showed awareness of the issue. Yet, they did not utter too much concerns and were of the opinion that the general quality is acceptable. Investigations at the Soil Management Directorate, the branch of the MOAC responsible for fertilizer quality control, showed that the quality of the tested fertilizer actually is assumed to better than expected. According to the information received sampling showed that the fertilizers composed of one single chemical compound like urea, diammonium phosphate, ammonium sulphate and myriate of potash were almost to 100% pure. However, certain problems were reported with compound NP(K) fertilizers of which a few did not contain nearly the specified nutrient rations.

3.3 Local Agricultural Practices

The local agriculture in Siddhipur is characterized by paddy cultivation. However, the climatic conditions and the low availability of irrigation infrastructure only allow one harvest per year. During the rainy season literally all fields are planted with rice. For the reminder of the year different suitable crops are cultivated like wheat, maize, potato or vegetables. The following topics will be covered in this subsection: local farm characteristics, crop cultivation patterns and fertilizer application. Additionally a comparison between field nutrient removal and supply is done based on the estimated crop yield and fertilizer application.

How does a typical local farm look like? The typical local farm in Siddhipur is adhering to a paddy-wheat cropping system and does not have any cattle. The available land is with 2.2 ropani (0.11 hectares) of land very small and thus normally 40% of the farm income comes from other income sources.

3.3.1 Farm Characteristics

Agriculture is mainly practiced on the level of individual family units. With a found average of 2.2 Ropani per family (approx. 0.11 ha) the cultivation area available to each household is very low (see Table 4). It is not surprising therefore that agriculture is in average only providing 60% of the household incomes and other sources like remittances and wage labour are needed to sustain livelihood (see Table 5). Out of 27 EcoSan households studied only 3 generate 90% or more of their income with agriculture alone.

Table 4 Basic farm characteristics

Parameter	Unit	Average	CV%	Median	Min	Max
Average cultivation area	[ropani]	2.2	73%	2.0	0.1	10
	[ha]	0.11	73%	0.10	0.04	0.51
Distance to closest field [2)]	[km]	1.1	109%	0.75	0	4.5
Distance to most distant field [2)]	[km]	2.63	61%	2.25	0	4.5
Agriculture	[%]	100	0	-	-	-
Cattle	[%]	0	0	-	-	-

Source: Household baseline survey and Farming Questionnaire data (n=52), 38 households with EcoSan toilet, 14 with conventional toilets; [1)] only Farming Questionnaire (n=25)

Table 5 Farm income sources

Parameter	Unit	Average	CV%	Median	Min	Max
Agriculture	[%]	59	35	60	25	100
Private business	[%]	9	215	0	0	70
Wage labour	[%]	11	130	10	0	50
Government / Authorities	[%]	7	226	0	0	60
Remittances	[%]	15	150	0	0	70

Source: Household baseline survey (n=27)

What crops are cultivated? The most common crop regime found in Siddhipur is paddy-wheat. The average obtained yield is estimated to approx. 7 $t{\cdot}ha^{-1}$ for rice and 3 $t{\cdot}ha^{-1}$ for wheat. An average household thus can harvest roughly 750 kg of rice and 350 kg of wheat. The expected plant nutrient removal per household and year is approx. 30 kg N, 10 kg P_2O_5, 40 kg K_2O and 3 kg Mg.

3.3.2 Crop Cultivation and Nutrient Removal

To identify the different main crops that are cultivated in Siddhipur throughout the year a FGD with 8 farmers was held and a Farming Questionnaire Survey with totally 11 EcoSan households and 14 non-EcoSan households was conducted. All farmers stated that during the rainy season rice is the only crop cultivated. After the rice harvest different crops are planted. According to the agriculture survey the main crop in the winter season is wheat (75% of cultivation area) followed by vegetables (12%). The remaining land is divided among beans, potatoes and mustard (see Table 6).

Table 6 Major crops cultivated throughout the year

Crop	J	F	M	A	M	J	J	A	S	O	N	D	Rainy Season [%]	Winter [2] [%]	Yield [kg·ropani^{-1}]	Yield [kg·ha^{-1}]
Rice													100	0	360	7100
Wheat													0	75	140	2700
Beans													0	5	- [1]	- [1]
Potato													0	3	800	15'700
Mustard													0	3	- [1]	- [1]
Vegetables													0	12	- [1]	- [1]

[1] no data obtained; [2] remaining 2% of cultivation area were found to be used as clay quarry during winter

At the FGD the farmers were also questioned about the average yield that is obtained with the popular crop varieties on local soils. The received figures can be found in Table 6. The average yield stated by the MOAC for Lalitpur district and the year 2007/08 is for paddy 4870kg/ha, wheat 2237 kg/ha and potato 18'400 kg/ha (MOAC 2009). Compared to these published values the stated yield in Siddhipur is considerably higher for paddy, slightly higher for wheat and a little bit lower for potato. However, the stated 7.1 tonnes of rice per hectare are not special and in the range of modern high yielding varieties (Wichmann 2001).

Typical plant nutrient removal figures for a rice-wheat cropping system can be found in Wichmann (2001). Based on this data it can be estimated that in average 265 kg N, 100 kg P_2O_5, 370 kg K_2O and 30 kg Mg are removed from the local fields per hectare and year (see Table 7)

Table 7 Typical yearly nutrient uptake by a rice-wheat cropping system

Cropping system	**Grain yield [t·ha^{-1}]**	**N [kg·ha^{-1}]**	**P_2O_5 [kg·ha^{-1}]**	**K_2O [kg·ha^{-1}]**	**Mg [kg·ha^{-1}]**
Rice-wheat (India)	1.0 [1]	27	10	38	3
Estimation rice-wheat Siddhipur	9.8	265	98	372	29

Source: Wichmann (2001), data based on a study from India; [1] normalized

On the basis of a single average household the nutrient uptake from cultivated fields can be estimated to be approx. 30 kg N, 10 kg P_2O_5, 40 kg K_2O and 3 kg Mg per year (see Table 8, base on figures shown in Table 7). Thus these amounts of nutrients should in average be restored to the field by application of organic or mineral fertilizer or through planting of legumes in order to sustain soil fertility over time.

Table 8 Estimated yearly field nutrient removal per household

Cropping system	**Grain yield [t·ha^{-1}]**	**N [kg·ha^{-1}]**	**P_2O_5 [kg·ha^{-1}]**	**K_2O [kg·ha^{-1}]**	**Mg [kg·ha^{-1}]**
Rice-wheat Siddhipur	1.1	29	11	41	3

Which fertilizers are commonly used in Siddhipur? What amounts are applied? With an estimated average urea demand of approx. 70 kg per household and year nitrogen is by far the nutrient applied in biggest quantities. The avg. demand per household for DAP is estimated to 12 $kg \cdot y^{-1}$, that of myriate of potash (K_2O) to 6 $kg \cdot y^{-1}$. This suggests that the fertilizer application and soil nutrient restoration is highly imbalanced. In comparison to application recommendations an oversupply of nitrogen and a lack of phosphorous and potassium has to be assumed. Due to high cost of multi-nutrient fertilizers the typical farmer does only apply urea (nitrogen).

3.3.3 Fertilizer Application

In the past farmers have been using different indigenous sources of manure to manage the soil fertility of their land. However, the use of indigenous manures may not be enough for satisfactory crop yield and soil fertility restoration anymore today due to high yielding varieties and more intensified crop production (MOAC 2003). As only very few households in Siddhipur have cattle in order to use cattle manure as organic fertilizer the farmers mainly rely on mineral fertilizers to compensate for the nutrient removal from their soils. These fertilizers are increasingly used by Nepalese farmers as they intensify cropping systems and expect greater yields on per hectare basis. Because of their high nutrient content they can readily supply the nutrients on the desired scale. While a 50kg bag of urea supplies 23 kg pure nitrogen, a farmer would need about 2'000 kg of organic material to supply this much nitrogen (MOAC 2003).

Fertilizing Recommendations: The general ratio of N:P:K in fertilizing recommendations varies with the type of crop, soil characteristic and physiographic situation but the general national guideline is 1.0 : 0.5 : 0.3 parts. Individual crop recommendations published by the MOAC can be found in Table 9 whereby the recommendations are either for organic fertilizer or for mineral fertilizers.

Table 9 Recommended nutrient application rates

Crop		Organic Fertilizer (manure)			N	P_2O_5	K_2O	N	P_2O_5	K_2O
		[$kg \cdot ha^{-1}$]	[$kg \cdot ropani^{-1}$]	[$kg \cdot m^{-2}$]	[$kg \cdot ha^{-1}$]	[$kg \cdot ha^{-1}$]	[$kg \cdot ha^{-1}$]	[$kg \cdot ropani^{-1}$]	[$kg \cdot ropani^{-1}$]	[$kg \cdot ropani^{-1}$]
Rice	irrigated	6'000	305	0.6	100	30	30	5.1	1.5	1.5
	non-irrigated	6'000	305	0.6	60	20	20	3.1	1.0	1.0
Wheat	irrigated	6'000	305	0.6	100	50	25	5.1	2.5	1.3
	non-irrigated	6'000	305	0.6	50	50	20	2.5	2.5	1.0
Maize		6'000	305	0.6	60	30	30	3.1	1.5	1.5
Potato		30'000	1527	3	70	50	40	3.6	2.5	2.0
Beans		4'000-6'000	204-305	0.4-0.6	10	40	30	0.5	2.0	1.5
Mustard		6'000	305	0.6	60	40	20	3.1	2.0	1.0

Source: MOAC (2003)

Methodology

The actual fertilizer application in Siddhipur has been studied in both the household baseline as well as the agriculture questionnaire survey. To get some additional information about the common application regimes a question block has also been integrated into a FGD about agricultural practices with 8 local farmers. Additionally informal interviews with local fertilizer merchants have been conducted.

Results

Interviews with Fertilizer Shopkeepers: From informal talks with farmers in the field it was already known that potassium and phosphorus application is extremely low. Most of the farmers in Siddhipur rely on urea as primary nutrient provider. In accordance all fertilizer shopkeeper in the village agreed that urea is by far the most popular and top-selling fertilizer product in their outlay. The main reasons they can identify for this are that urea is the cheapest product available on the market and that it shows immediate and high increases in yield like all nitrogen fertilizer do. As another good selling product one retailer also mentioned a 20:20:0 NP compound fertilizer. But all the merchants agreed that most of the farmers actually are not really aware of the different characteristics the offered fertilizers have but merely go for the price and their past experiences.

Questionnaire Surveys: In the two questionnaire surveys the farmers were asked about their annual demand for mineral fertilizers. According to the received data only urea and DAP were stated to be used. The average amount of mineral fertilizer bought yearly per household is found to be roughly 70kg of urea and 12kg of DAP. In relation to the area cultivated this leads to average nutrient application rates of 345 kg nitrogen and 45 kg phosphate per hectare and year (see Table 10).

Table 10 Mineral fertilizer demand rates per average household and year

Fertilizer	Unit	Total	CV%	Median	Min	Max
Urea	[$kg \cdot y^{-1}$]	71.8	71	63.5	1.0	250
DAP	[$kg \cdot y^{-1}$]	11.8	186	0	0	100
Urea	[$kg \cdot ha^{-1} y^{-1}$]	712	58	655	79	1965
DAP	[$kg \cdot ha^{-1} y^{-1}$]	99	166%	0	0	491
Nitrogen (N)	[$kg \cdot ha^{-1} y^{-1}$]	345	53	301	36	904
Phosphate (P_2O_5)	[$kg \cdot ha^{-1} y^{-1}$]	45	166	0	0	226
Potash (K_2O)	[$kg \cdot ha^{-1} y^{-1}$]	0	0	0	0	0

Source: Household baseline and agriculture questionnaire survey (n=52, of which 38 EcoSan and 14 Non-EcoSan households)

The data also indicates a remarkable difference in the mineral fertilizer usage between EcoSan and non-EcoSan household: -11% nitrogen and -53% phosphorous for EcoSan households compared to non-EcoSan households (see Table 11). The data has not been tested for significance however.

Table 11 Differences in mineral fertilizer application rates EcoSan and Non-EcoSan households

Fertilizer	EcoSan	Unit	Total	CV%	Median	Min	Max
N	yes	[$kg \cdot ha^{-1} y^{-1}$]	336	57	301	36	904
N	no	[$kg \cdot ha^{-1} y^{-1}$]	371	44	362	76	753
P_2O_5	yes	[$kg \cdot ha^{-1} y^{-1}$]	35	195	0	0	226
P_2O_5	no	[$kg \cdot ha^{-1} y^{-1}$]	74	119	27	0	211

Source: Household baseline and agriculture questionnaire survey (n=52, of which 38 EcoSan and 14 Non-EcoSan households)

Focus Group Discussion: To complement the data received from the questionnaire surveys a FGD was held with 8 well established farmers from Siddhipur. These were questioned about commonly applied fertilizer rates among local farmers. According to their information the following fertilizer regimes are common (all figures per Ropani of land ≈0.05 ha):

- *Rice:* 21 kg of urea-DAP mix in a ratio of 2:1 at planting time with additionally 2.5 kg myriate of potash; 25 days later another 3.5 kg of urea-DAP mix with same ratio; no compost applied, however usually the harvest residues of the winter crop are burnt on the fields before tillage; some farmers are used to add 100kg of fertilizer grade lime before cultivation.
- *Wheat:* approx. 19 kg of urea at planting time together with 5 kg of DAP-MOP mix in 1:1 ratio; no compost applied.
- *Potato:* approx. 800 kg of compost applied at field preparation; at sowing planting time approx. 65 kg of urea.

- *Mustard:* same as rice.
- *Beans:* no fertilizer application.

Based on the application regimes described above the application rats have been calculated for the major locally grown crops (see Table 12).

Table 12 Commonly applied fertilizer rates per crop

		Crops				
Fertilizer	Unit	Paddy	Wheat	Potato	Mustard	Bean
Urea	[kg·ropani^{-1}]	16.4	19.25	67.5	16.4	0
DAP	[kg·ropani^{-1}]	8.2	2.5	0	8.2	0
Myriate of Potash	[kg·ropani^{-1}]	2.5	2.5	0	2.5	0
Compost	[kg·ropani^{-1}]	0	0	800	0	0
Urea	[kg·ha^{-1}]	322	378	1326	322	0
DAP	[kg·ha^{-1}]	161	49	0	161	0
Myriate of Potash	[kg·ha^{-1}]	49	49	0	49	0
Compost	[kg·ha^{-1}]	0	0	15720	0	0
N	[kg·ha^{-1}]	177	183	610	177	0
P_2O_5	[kg·ha^{-1}]	74	23	0	74	0
K_2O	[kg·ha^{-1}]	29	29	0	29	0
Compost	[kg·ha^{-1}]	0	0	15720	0	0

Source: FGD

Additionally to the fertilizer application practices the farmers have been asked as well about their knowledge of plant nutrients and their link to fertilizer products. However, despite their detailed knowledge about fertilizer application practices the farmers did not really have a concept of the different plant nutrients contained by the single products. Their knowledge seems to be largely base on their personal experiences and occasional training / advice by field consultants of the Ministry of Agriculture and Cooperatives (MAOC). Nonetheless, they know that urea fertilization should be complemented with DAP. Due to the high price of DAP this is not always followed.

Discussion

A comparison between the different fertilizer application rates obtained through the questionnaire survey and from the FGD for urea reveals that the congruence is quite high (see Table 13). According to the described fertilizer and crop regime (FGD) an average farm needs 78 kg of urea per year. The found value according to the survey on the other hand is 72 kg. This leads to the assumption that the practices the farmers described at the FGD and their resulting application rates are approx. what most of the local farmers actually adhere to. However, whereas the figures for urea show a high correspondence the actually found value for DAP is remarkably lower. This is an interesting fact and supports other statements that in cases of monetary constraints DAP is frequently left aside due to its high price.

A question remains about the lack of data received about the usage of myriate of potash from the questionnaire surveys. According to information obtained from shopkeepers and personal observations some people also apply MOP. It has to be assumed thus that most likely the small amounts applied were not stated by the interviewees. The same must hold for the other compound fertilizers available on the market. Even if the demand is low there must be some otherwise the shops would not have it in the assortment. It has to be assumed therefore that the figures received are to some degree underestimating the actual application of P and K.

Table 13 Comparison of the yearly fertilizer demand of an avg. farm for the most common crop regime (paddy-wheat)

Fertilizer	Unit	According to FGD data [1)]	According to quest. data	Ratio [%]
Urea	[kg·y^{-1}]	78	71.8	92%
DAP	[kg·y^{-1}]	24	11.8	49%
Myriate of Potash	[kg·y^{-1}]	11	0	0%

[1)] calculated for an average farm size of 2.2 ropani

Based on the considerations made above the nutrient application rates for the primary crops rice and wheat shown in Table 14 shall be assumed for further interpretations. For Siddhipur, both paddy and wheat fall mostly in the category of rainfed non-irrigated cultivation. Comparison with the recommendations of MAOC (2003) and with figures published in the IFA World Fertilizer Use Manual (Wichmann 2001) lead to the conclusion that in general the all over amount of fertilizer applied is high. However, in Siddhipur most of the fertilizer is applied in the form of urea which almost leads, according to the present data, to an oversupply of nitrogen. In average phosphorus seems to be applied in an adequate to high ratio for paddy and a rather low amount for wheat. Potassium on the other hand is both lower for paddy as well as for wheat.

Table 14 Comparison of nutrient application rates

	Crop:	Paddy				Wheat			
		Estimated	Recommended			Estimated	Recommended		
	Source:	Siddhipur	MOAC (2003)	MOAC (2003)	Wichmann (2001)	Siddhipur	MOAC (2003)	MOAC (2003)	Wichmann (2001)
Fertilizer	Unit		Non-irrig.	Irrig.	(Non-)Irrig.		Non-irrig.		
N	[kg·ha^{-1}]	170	60	100	40-150	180	50	100	60-150
P_2O_5	[kg·ha^{-1}]	40*	20	30	40-60	10*	50	50	30-90
K_2O	[kg·ha^{-1}]	15*	20	30	0-60	15*	20	25	- [1)]

* due to low popularity of fertilizers containing P and K (price) the obtained values from FGD data have been halved (see Table 13); [1)] no data

The obtained results are surprising in the way that in average it rather has to be spoken of an oversupply than of a lack of mineral fertilizers. This is unusual given that in general a sometimes significant nutrient undersupply is assumed for developing country regions. It has to be interpreted therefore that, in average, sufficient funds are available (or the fertilizers are sufficiently cheap) for adequate mineral fertilizer application. However, it also seems that the ratio on which the different fertilizers / nutrients are applied is not optimal. Whereas nitrogen seems applied (over-) sufficiently phosphorus and potassium are rather low.

Nevertheless, when judging the obtained results the following considerations have to taken serious: Firstly, the given figures are based on qualitative interrogations. In order to make assured conclusions further detailed quantitative assessments would become necessary. These results should therefore rather be taken as indications than facts. Secondly, these results are aggregations and average values. However, the variations in fertilizer practices vary widely among the different farmers. Out of 52 farmers interviewed all stated to apply urea but only 16 or 31% also stated to apply DAP. This means that in accordance with the information received from informal interviews a clear majority is not applying phosphorus (and likely potassium) at all. This can be attributed on one side to the comparably much higher cost of the compound fertilizers and on the other side to a general lack of awareness about the different plant nutrients necessary for optimal plant growth. At the FGD the farmers where interviewed about their knowledge of plant nutrients and their occurrence in mineral fertilizer products. However, it was found that there was almost no concept of individual nutrient elements present.

Hence it is difficult to conceive the necessity and benefit of compound or multi-nutrient fertilizers and it seems coherent that the high price of these fertilizers has a deterrent effect on their application.

3.3.4 Nutrient Cycling

A comparison of the estimated nutrient removal and the estimated nutrient supply through mineral fertilizer application leads to conclusions highly coherent with the findings of the precedent section. According to Table 15 more nitrogen is supplied to the soil than is actually taken out by the crops (+32%). On the other hand only 51% of the actually needed phosphate and 8% of the potassium is restored to the soils. However, these results have to be interpreted with care since the chosen assessment approach is not very accurate. Besides mineral fertilizer applications all visited households were also practicing composting. A further source of nutrients are crop residues left on the fields after harvest. Thus it has to be estimated that the nutrient supply is higher than estimated and likely the nutrient outtake lower. The calculations were done based on the assumption that all superficial plant matter is removed. Whereas this is true for paddy it was not established for the other crops.

Table 15 Comparison of estimated nutrient removal and supply (Siddhipur)

Fertilizer	**Unit**	N	P_2O_5	K_2O	Mg
Nutrient removal [1)]	$[kg \cdot ha^{-1} y^{-1}]$	265	98	372	29
Mineral fertilizer supply	$[kg \cdot ha^{-1} y^{-1}]$	350	50	30	0
Ratio	[%]	132%	51%	8%	0%

[1)] calculated for the most common crop regime paddy-wheat

4 Struvite Production Process Inputs

The basic and single most important resource for the proposed production method of struvite is *urine*. Straight source separated urine is needed as it is collected by waterless urinals and urine diverting toilets such as the EcoSan toilets built in Nepal. In the following subsection an estimation of the qualitative and quantitative properties of the urine collected in Siddhipur is conducted. Besides urine, the second important process input for struvite production is *magnesium*, more precisely magnesium cations (Mg^{2+}). These can be obtained from different magnesium sources, especially salts and carbonates. In section 1.1 different sources are identified and their suitability for the proposed production method assessed. Furthermore cost estimations are calculated based on present magnesium prices found in Nepal.

4.1 Urine

The amount of struvite that can be produced within the community is primarily dependent on the *quantity of urine* that is available. Thus, it is important to have an estimation of the average amount of urine generated and collected within the community. Further the *nutrient content* of the available urine is a major factor since it has a direct influence on the amount of struvite that can be precipitated. The nutrient content may vary considerably depending on the local diet and because a certain dilution with water is unavoidable due to the construction of the toilets. However, it has to be considered that for an estimation of the possible struvite production volume of the community not all the collected urine will or should be used for the production of struvite. That is why the different *present utilizations* of the urine have to be taken into account as well by considering their benefit and comparing it to the benefit of struvite.

In the following subsections the qualitative and quantitative parameters of urine collected in Siddhipur are assessed. This is done through the means of questionnaire surveys among EcoSan users, field measurements and theoretical calculations. The parameters are compared to available literature data and reference values are established to serve as a basis for further calculations.

Preliminary Considerations

A point to clarify here is the fact that it is important to be specific about what is actually meant when talking of urine. Especially in regards of the nutrient content of urine it is important to distinguish between different types of urine. *Fresh urine* has not the same properties as stored urine due to different processes starting after its excretion (cf. Udert 2002; Udert *et al.* 2006). *Stored urine* in turn can be kept airtight or in an open container which entails a not negligible loss of nitrogen. Source separated urine collected by EcoSan toilets on the other hand is normally diluted to a certain degree with flushing or toilet cleaning water and may contain other side products such as ash which is used in dry EcoSan toilets for treating the faeces. Table 16 gives an overview of the different types of urine that can be encountered and some of their properties. It is important that these distinctions are respected in the considerations that follow.

Table 16 Different urine types of concern

Typ of urine		Dilution	Nitrogen loss	Nutrient precipitation (P, Ca, Mg)
Fresh urine		no	no	no
Stored urine	airtight	(no)	no	yes
	open container	(no)	yes	yes
	EcoSan toilet	yes	yes	Yes

Another important point regarding the subsequent observations is the fact that the qualitative parameters (nutrient content) and the quantitative parameters (amount of urine collected) of the analysed urine are connected via the degree of dilution. Urine is excreted in a certain amount and with a certain nutrient concentration. However, if the urine subsequently is diluted through flushing and cleaning the amount of urine increases whereas the concentration of the urine decreases. Since the dilution can be assessed from a qualitative side (urine nutrient concentrations) as well as from quantitative considerations it can serve as a link to assess whether the results from the different approaches fit together.

What are the qualitative characteristics of locally with EcoSan toilets collected urine? Urine analysis data of both fresh and stored urine of local origin could be obtained. The data shows that the nutrient concentrations of fresh and consequently as well of stored urine are at the lower end of the expected range. For the collected urine a water content of approx. 15% is assumed. However, a very low potassium concentration and an estimated ammonia loss of 50% still pose questions. Struvite precipitation tests with magnesium chloride showed a very high process efficiency of over 90%. A struvite precipitation of approx. 1.9 $g \cdot l^{-1}$ urine can be expected.

4.1.1 Qualitative Analysis

The nutrient content of the collected urine is a crucial factor in assessing the amount of struvite that can be produced within the community. It may vary to a considerable degree depending on the variety of the local diet, the climate and the lifestyle of the local people (Esrey *et al.* 2001). Hence, it is important to establish the qualitative properties of the locally collected urine for further calculations. Average nutrient concentration figures for urine can be obtained from the literature and are listed in Annex A.1.

Methodology

Stored Urine from EcoSan toilets

To investigate the quality of the urine which is collected by EcoSan toilets and which will be used for the production of struvite a chemical analysis of the urine has been performed. Random samples have been taken from totally 14 containers (see Annex A.2). Before taking a sample the urine content has been thoroughly stirred and if not possible urine has been tabbed and poured back to the container until a clear and homogenous sample was acquired. Since the interest lies more on the average nutrient contents and in order to safe analysis costs 10 samples have been mixed and analysed for the total amount of nitrogen (N), phosphorus (P) and potassium (K). The remaining 4 samples have been tested individually for the total amount of phosphorus. Additionally, with one part of the mixed sample struvite has been produced and the processing effluent has subsequently been analysed for total N, P and K as well.

The actual analysis of the samples has been conducted by laboratory staff of ENPHO (see Annex A.3). According to the information received from the laboratory responsible person the samples have been stored at 4°C until they could be stabilized with acid, for which sulphuric acid has been used. After stabilisation the samples were stored at room temperature. The test methods are as described in the report: for Nitrogen a Kjeldah digestion and titration; for P Ammonium molybdate, spectrophotometric; and for K AAS flame emission. It has to be mentioned however that the urine samples were not filtered by us or the laboratory before the analysis because the laboratory responsible person was of the opinion that this was not needed.

Fresh Urine

For comparison with the stored urine fresh urine samples have been taken from Siddhipur inhabitants in a later stage of the project. Totally 14 samples were obtained from different age groups and gender. For stabilization purposes the samples have been filtered with a 0.7μm and 0.45μm filter kit and were later analyzed at the Eawag laboratories in Switzerland.

Results

The laboratory analysis of the *fresh urine* results in an average rounded nutrient content of 6000 mg N, 400 mg P and 1900 mg K per litre of fresh urine. On the other hand the testing of the *stored urine* samples shows concentrations of approx. 2400 mg of N, 260 mg of P and 800 mg of K per litre of urine. Detailed results are displayed in Table 17 and can also be found in Annex A.3, A.4 and A.5.

Table 17 Qualitative urine analysis based on samples from Siddhipur

Sample	pH	EC_{25} [mS/cm]	N_{total} [mg·l^{-1}]	PO_4-P [mg·l^{-1}]	K [mg·l^{-1}]	Mg [mg·l^{-1}]	SO_4 [mg·l^{-1}]	Ca [mg·l^{-1}]
Fresh urine	5.63	22.8	6030	388	1869	45	878	89
Stored urine (diluted)	8.67	37.5	2352	259	802	-	-	-
Struvite prod effluent	8.59	3837.7	2240	16.47	744	-	-	-

Based on the measured results for fresh urine it is possible to theoretically calculate the corresponding nutrient values for airtight stored undiluted urine. This allows a comparison with the obtained values for stored diluted urine collected by EcoSan toilets and thus an estimation of the dilution ratio and the loss of nitrogen that has occurred during storage time.

According to findings of Udert (2002) and Udert et al. (2006) it can be assumed that during the storage process the available magnesium and calcium will precipitate completely. This takes place principally through the formation of struvite ($MgNH_4PO_4 \cdot 6\ H_2O$) and hydroxylapatite ($Ca_5(PO_4)_3(OH)$). During this process parts of the available N and P are fixed as well. Table 18 shows the results of these theoretical estimations. The calculations can be found in Annex A.6.

Table 18 Theoretical quantification of storage processes and dilution

Sample	N_{total} [mg·l^{-1}]	PO_4-P [mg·l^{-1}]	K [mg·l^{-1}]	Mg [mg·l^{-1}]	Ca [mg·l^{-1}]	Struvite [mg·l^{-1}]	Hydroxylapatite [mg·l^{-1}]
Fresh urine	6030	388	1869	45	89	0	0
Undiluted stored urine (closed container, incl. precipitates)	6004	290	1869	0	0	454	1115
Diluted stored urine (open container, precipitates removed)	2352	259	802	0	0	0	0
Estimated dilution and N evaporation	**N_{lost}**	**dilution**					
Based on P ratio	48%	87%					
Based on K ratio	4%		43%				

The theoretical calculations suggest that average undiluted stored urine from Siddhipur has nutrient concentrations of approx. 6000 mg N, 290 mg P and 1900 mg K after roughly 450 mg of struvite and 1100 mg of hydroxylapatite have precipitated. Based on the ratio of phosphorous (undiluted stored urine to diluted stored urine) a dilution ratio of 87% urine to 13% water can be estimated. This would suggest that consequently 48% of the total nitrogen present must have been lost through evaporation. If the calculation is based on the concentration change of potassium (K) the theoretical dilution ratio would be considerably higher, namely 43% urine to 57% water resulting in a nitrogen loss of only 4%.

Discussion

Compared to available literature data it can generally be said that the obtained urine analysis results are lower than expected. The literature review in Annex *A.1* gives a compilation of different nutrient concentrations for fresh and stored urine from various places. It has to be acknowledged however that it is difficult to compare the obtained figures with the different literature values since the exact conditions of measurements are seldom completely clear.

Fresh urine: In comparison to a literature compilation done by Udert et al. (2006) the values obtained in Siddhipur are throughout 30-50% lower for all constituents except for K. According to personal communication with K. Udert further analysis conducted at Eawag suggests however that the stated values are at the upper limit and that actual average values might be lower. Other fresh urine analysis test conducted in Siddhipur in 2003 by a local environmental consultancy show a similar concentration of P, a higher concentration of N and a lower concentration of K (Development Network 2003). Based on these findings it can be concluded that the received figures seem possible (taking into account natural varying of urine composition) but are at the lower end of nutrient concentration values.

Stored urine: The low nutrient content of fresh urine is inevitably reflected in low concentrations measured in stored urine. Compared to the obtained figures however, Ek et al. (2006) mention only slightly bigger "normal" average N, P and K values of 3600, 310 and 900 for urine collected in urine diverting toilets. This suggests that the obtained results are reasonable. Regarding this qualitative analysis it has to be considered however that both the measurements in Siddhipur as well as these of Ek et al. result from a considerable degree of dilution. The water content however has a significant effect both on the resulting quantity of collected urine and the precipitation potential of struvite (cf. Tilley *et al.* 2008a; Tilley *et al.* 2008b; Udert *et al.* 2003a; Udert *et al.* 2003b).

Estimation of Dilution: The results obtained for fresh urine and the urine taken from the EcoSan toilets allow an estimation of the dilution by comparing the respective nutrient concentrations. However, since nitrogen is lost during storage by transformation to ammonia only the phosphorus and potassium concentrations must be considered when assessing the dilution. Additionally care has to be given when comparing P values since a not negligible amount of phosphorous precipitates in the form of struvite and hydroxilapatite during urine storage. The amount of P that precipitates is determined by the presence of magnesium and calcium.

The figures shown in Table 18 suggest a urine concentration of 87% based on the P ratio and 43% based on the K ratio. Assumed that the former is right the K value for stored diluted urine from EcoSan toilets would theoretically be 1626 mg per litre, resulting in a concentration which is 824 mg higher than measured. However, given that the latter is true the theoretically calculated P value would be 124mg per litre or 128 mg lower than actually measured. This suggests that either some of the potassium (K) is lost through dilution or that additional phosphorus is added to the urine through flushing water. Since the latter is highly unlikely in such a high amount it has to be assumed that an estimation based on the P ratio is closer to reality. Therefore the water content of stored urine obtained from EcoSan toilets can be estimated to be around 15%. However, it remains unclear through which processes the remaining potassium is lost and further investigations to resolve this issue are indicated.

Estimation of Nitrogen Loss through Evaporation: Based on the above established dilution ratio it is also possible to estimate the loss of nitrogen that occurs during storage through evaporation as ammonia. Assumed that the collected urine has a water content of 13% the difference of N which has to be attributed to evaporation results to 2872 mg per litre (Annex A.6). This means that 48% of the nitrogen (present after storage precipitation has happened) is lost. This value is unexpectedly high. To some degree it can be ascribed to the observed bad condition of the storage tank lids. Most of them are broken because they are not made of UV-resistant plastic. However, this high value still has to be questioned and further research into this issue would be appropriate.

Based on the results from the performed analysis the urine values displayed in Table 19 are proposed as reference values for urine quality in Siddhipur.

Table 19 Proposed reference values for urine quality (Siddhipur)

Type of Urine			Fresh undiluted urine	Stored diluted urine (EcoSan toilet)
Dilution			no	yes
Nitrogen loss			no	yes
Water content		[%]	0	15%
pH			5.6	8.6
Nitrogen	N_{total}	[mg·l^{-1}]	6000	2400
Phosphorous	PO_4-P	[mg·l^{-1}]	400	250
Potassium	K	[mg·l^{-1}]	1900	800
Magnesium	Mg	[mg·l^{-1}]	45	0
Sulfate	SO_4	[mg·l^{-1}]	875	875
Calcium	Ca	[mg·l^{-1}]	90	0
N:P:K ratio	N		100	100
	P		7	10
	K		32	33

* airtight container, estimations based on the measurement of fresh urine

Struvite Precipitation

The occasion of urine sampling and analysis has also been used to produce some struvite with locally collected urine and to establish some reference values for struvite precipitation (see Annex A.4). Half a litre of the mixed urine sample has been taken and magnesium chloride has been added in a molar concentration of 108% compared to the urine's phosphorus content. In this way a phosphorus fixation efficiency of 93.6% could be achieved and 0.960g of struvite has been obtained. The values shown in Table 20 shall therefore serve as reference values for further calculations.

Table 20 Struvite precipitation reference values

Magnesium product	Struvite precipitation [g·l^{-1}]	Phosphorus fixation efficiency
Magnesium chloride	1.9	93%

How much urine is collected with EcoSan toilets in Siddhipur? The establishment of assured estimations has proven to be difficult even though different approaches have been taken. It is expected that approx. 350 l of urine (incl. dilution) are collected per person and year. This leads to roughly 1'700 l per household and a total of 150'000 l·y^{-1} for all EcoSan toilets in Siddhipur. The water content is estimated to 17% which correlates well with the qualitative analysis.

4.1.2 Quantitative Analysis

The quantity of urine that is collected by EcoSan toilets in Siddhipur is dependent on various different parameters. Table 21 gives an overview of the identified parameters together with short remarks and information about the degree this factor is considered to be manipulable so as to influence the quantity collected.

Table 21 Parameters influencing the quantity of urine collected with EcoSan toilets.

Parameter	Remark	Influencability
Number of EcoSan toilets installed	The number of installed toilets has a direct linear influence on the amount of urine collected.	High
Number of users per EcoSan toilet	Depending on the family size.	Low
Age distribution of EcoSan users	It is assumed that a child only excretes about half the amount of urine of an adult person. Because of this the age distribution of the users can have a significant influence on the amount of urine collected.	Low
Usage frequency of toilet by users and year	The usage frequency of the EcoSan toilet depends on different parameters but the main factor is surely the time spent at home or in the vicinity of the toilet. Other factors can be the usage comfort and the availability of other toilets in the surrounding area especially if the user motivation is moderate.	Medium
Amount of urine excreted per user	The amount of urine excreted per user is dependent on various factors like age, intake of liquids, physical exertion and climate (Esrey *et al.* 2001).	Low
Dilution of urine	Depending on the proper usage of the toilet and in particular the method of cleaning there might be a significant amount of water added to the urine.	Medium

Methodology and Results

In order to establish an estimation of the amount of urine that is collected by the EcoSan toilets in Siddhipur three different approaches have been taken:

- a *questionnaire survey* asking EcoSan users about their experiences regarding urine collection (partly done at FGDs and as part of the household baseline survey)
- *toilet usage statistics* logging in detail frequency of toilet usage and corresponding urine collection for six EcoSan households during 5 days
- an *analytical calculation* based on theoretical estimations for the parameters listed in Table 21

Since the two latter estimations done on the basis of the toilet usage statistics and analytical calculations are largely dependent on the amount of water added to the tank, considerations also have to be given to the dilution ratio of the collected urine. These considerations are based on data received from the household and the toilet usage statistics.

Questionnaire Survey

As a first mean to assess of the amount of urine collected with the EcoSan toilets in Siddhipur a questionnaire survey with 26 EcoSan users has been conducted during two FGDs in June 2008. The users have been asked about their family size, the size of their urine storage container, average emptying periods and the normal level to which the container is filled when being emptied (see Annex A.7). Based on the acquired data the average amount of urine collected per household and per person can be calculated (see Annex A.8). If all data is included into the calculation an amount of approximately 160 litres per person and year or a total of roughly 80'000 litres per year for whole Siddhipur results. However, if only data from persons emptying the urine containers is used and extreme values are discarded slightly smaller numbers are received (see *Table 22*).

Additionally to the small surveys done at the FGDs some questions about the urine generations have also been included into the baseline household survey which was conducted with 27 households in August and September (see Annex D.2). The average urine collected per person is with approx. 150 litres per person and year a little bit lower but very similar to the results obtained at the FGDs. Since regular absences of household members have been included into the household survey the average family size is with 4.8 members slightly lower. This and the lower collection per person lead to an estimated total of roughly 70'000 litres per year for whole Siddhipur. Details can be found in Annex A.9.

Table 22 Estimated collection of urine in Siddhipur (questionnaire data)

Calculation based on	Nr. of EcoSan toilets	Household members	Avg. urine collected per person [1] [$l \cdot y^{-1}$]	Total collected urine Siddhipur [$l \cdot y^{-1}$]
FGD all data	100	5.1	155.6	78'995
FGD selected data [2]	100	5.1	138.5	69'237
Household survey	100	4.8	147.1	70'286

[1] No distinction made between adults and children
[2] Only data from persons actually emptying the urine container included and extreme values deleted (top and bottom 10%)

Toilet Usage Statistics

To get some more detailed information about the urine quantity that is collected with the EcoSan toilets in depth toilet usage statistics were conducted with six randomly selected households of Siddhipur. During five days the household members and guests were asked to record in a table each time they were using the toilet. Alongside the user statistics the level of urine in the tanks was taken to measure the amount of urine that was collected during the survey.

All together the statistics include data from 117 person days. The analysis of the recorded data shows that an adult person excretes approx. 275ml of urine per urination in an EcoSan toilet with averagely 3.6 urinations per day. This leads to a total of roundly 360 litres of undiluted urine per adult person and year that is collected by an EcoSan toilet (see Annex A.10).

Table 23 Estimated collection of urine for an ***adult person*** (toilet usage statistics)

Parameter	Unit	Amount
Excretion per urination	[l]	0.274
Number of urinations per day in private EcoSan toilet		3.6
Amount of undiluted urine collected per day	[$l \cdot d^{-1}$]	0.98
Amount of undiluted urine collected per year	[$l \cdot y^{-1}$]	358

Whereas by chance all of the six randomly for the toilet usage statistics selected households stated not to flush urine with water, data from the household survey shows that approx. 25% of the people in Siddhipur are used to so. It is therefore necessary to consider dilution as well in order to extrapolate the data of Table 23 for whole Siddhipur (see Box "Estimation of Dilution"). If the considerations about water dilution are integrated into the calculations an adult person produces roughly 410 litres of diluted urine per year. When the household age distribution is considered approx. 350 litres are collected per member of an EcoSan household. This leads to an estimated amount of approx. 165'000 litres of urine per year for whole Siddhipur (see Table 24).

Table 24 Estimated collection of urine in Siddhipur (toilet usage statistics)

Calculation based on	Nr. of EcoSan Toilets	Household members	Urine collected per household member [$l \cdot y^{-1}$]	Total collected urine Siddhipur [$l \cdot y^{-1}$]
Toilet usage statistics	100	4.8	346	166'288

Estimation of Dilution

To better appraise the dilution ratio which the analysis of the urine nutrient values suggests the user habits have been assessed during the household survey with a number of questions (see Annex D.2). The main issue of concern is if the people artificially add water when using the toilet, especially for flushing after urination or when cleaning the toilet bowl.

The analysis of the survey data shows that 26% of the EcoSan users flush the toilet after urinating and by doing this add an average of 140 ml of water to the tank per urination. 96% of the households additionally use water for periodically cleaning the toilet bowl. In average they clean the toilet approx. 5 times per month each time adding roughly 750 ml of water to the urine tank.

In combination with the detailed toilet usage survey which was conducted, the amount of water that is artificially added to the urine tank through flushing and toilet cleaning can be estimated. Calculations show that in an average household in Siddhipur approx. 7 litres of water are added to the tank per person and year for cleaning the toilet bowl. Additionally roughly 50 litres of water are added per person and year for flushing the urine. Added to the amount of undiluted urine this gives an estimated 410 litres of diluted urine that is collected with EcoSan toilets per adult person and year and a respectively smaller figure for children (see Table 25). When the age distribution of an average EcoSan household is considered the amount of diluted urine collected per household member comes to approx. 350 litres. The dilution ratio of such urine is estimated to be 17% water to 83% urine (see also Annex A.11).

Table 25 Averaged urine dilution data (based on household survey and toilet usage statistics)

Parameter	Unit	Adult	Child
Water added through toilet cleaning	[$l \cdot Pe^{-1} \cdot y^{-1}$]	7.1	
Water added by flushing urine	[$l \cdot Pe^{-1} \cdot y^{-1}$]	47.8	
Urine collected (undiluted)	[$l \cdot Pe^{-1} \cdot y^{-1}$]	358	179
Urine collected (diluted)	[$l \cdot Pe^{-1} \cdot y^{-1}$]	414	235
Water content of collected urine	[%]	13%	24%
Urine collected per average household member (diluted)	[$l \cdot Pe^{-1} \cdot y^{-1}$]	346	
Water content of average collected urine		17%	

Additionally to the actual data received through the household survey two more hypothetical scenarios have been calculated to better understand the possible range of dilution. Scenario A assumes that 75% of all users flush after urinations (140 ml). This leads to a water content of approx. 35%. Scenario B on the other hand assumes that 50% of the users flush with 400 ml water after urinations and this gives an estimated water content of roughly 50% (see Annex A.11).

Analytical Calculations

As a complement of the two above described methods a third theoretical approach based on literature and survey data as well as founded estimations is used to establish another set of data. This allows to critically compare the different results and gives a better estimate for the actually collected amount of urine in Siddhipur.

For the theoretical analytical approach a number of assumptions are made for the parameters listed in Table 21. Whenever possible the assumed values have been based on established literature or survey data and only if not possible on founded estimations (see Table 26).

Table 26 Parameter qualification for theoretical urine quantity analysis

Parameter	Remark	Value	Possible Range	Assessing Accuracy
Number of EcoSan toilets installed	The number of installed toilets is reported be 100 by the implementing NGO and assumed to be correct.	100	-	High
Number of users per EcoSan toilet	The number of users per EcoSan toilet is not easy to establish and is for subsequent purposes equalled with the average number of household members. It has to be considered that by doing so the visitors are not included. Since the family itself might visit in equal intervals other homes it can be argued however that this is a minor factor.	4.8 [1)]	4.6 – 5.2	High
Age distribution of EcoSan users	The age distribution has been established in the household baseline survey (regular absences are accounted for). The age distribution of all Siddhipur inhabitants is stated by CIUD (2006) to be 34% children, 56% adults and 10% elderly [2)] (not incl. regular absences).	children 36% [2)] adults 59% elderly 5%	-	High
Usage frequency of toilet by users	The usage frequency is assumed to be linearly correlated with the time spent at home and estimated for the different age groups. The total amount of urine collected with the EcoSan toilet is the product of the average amount of urine excreted by user and the time spent at home.	children 75% [3)] adults 69% elderly 80%	55 - 95% 49 - 89% 60 - 100%	medium
Amount of urine excreted per user and year	The amount of urine excreted per user is dependent on various factors like age, intake of liquids, physical exertion and climate and therefore difficult to establish. The literature normally states values from 0.7 to 1.5 litres per person and day.	child 180l adult 360l elderly 360l	135 - 275l 270 - 550l 270 - 550l	Low
Water content of urine	The water content can be estimated on the basis of the qualitative urine analysis and the calculations done in Annex A.11 and the comparison with literature data, but is highly speculative.	15% [4)]	10 - 50%	Low

[1)] according to household survey data and with regular absences accounted for; Development Network (2003) states a average household size of 5.2 for Siddhipur whereas CIUD (2006) finds a number of 4.6
[2)] Definitions: child < 20 years; adult 20 - 59; elderly >= 60 years
[3)] values based on estimations (see Annex A.12), an error of +/- 20% seems to be indicated; that the calculated values are still reasonable however shows data found in the literature (see Annex A.1)
[4)] according to estimations based on the qualitative urine analysis and the household / toilet usage survey

Using the adopted values found in Table 26 calculations can be made to analytically estimate the amount of urine collectable: Based on the most likely values on average 240 litres of urine would be collected in the EcoSan toilet per household member. This figure comprises age distribution and water dilution. When extrapolating this to whole Siddhipur a total of approx. 115'000 litres of collected urine per year results. Table 27 gives an overview of different figures calculated for the assumed parameter values as well as for some selected extreme values for the parameters identified with a low and medium assessing accuracy. For an example of the calculations refer to Annex A.13.

Table 27 Estimated collected urine Siddhipur (analytical approach)

Age group	Excreted urine $[l \cdot y^{-1}]$	Water content of collected urine [%]	Urine collected in EcoSan toilet per person (diluted) $[l \cdot y^{-1}]$	Total Urine collected in Siddhipur (diluted) $[l \cdot y^{-1}]$
Child Adult Elderly	135 270 270	15%	180	80'365
		40%	219	105'140
Child Adult Elderly	180 360 360	15%	**240**	**115'115**
		40%	292	140'140
Child Adult Elderly	275 550 550	15%	367	175'950
		40%	446	214'200
Minimum values for excreted urine, time at home and dilution			124	59'620

Maximum values for excreted urine, time at home and dilution	616	295'500

Discussion of Results and Establishment of Reference Values

The amount of collected urine that is received by analysing the questionnaire data is with approximately 150 litres per person and year very low. Considering that an average adult person excretes about 270-550 litres per year one would expect that roughly ⅔ or about 300 litres should actually be collected. Why the figures received by this approach are only half of what could be expected is difficult to establish and subject to speculations. Mainly two parameters are in question. The first is the average amount of urine excreted per person and year. The literature data could be too high for the local setting and therefore not appropriate. However, the amount would have to differ significantly and this seems not very likely. The second parameter which might have a big influence is the usage frequency. It might be possible that the people are still clinging to old habits of open defecation or do not assess the user comfort of the EcoSan toilets as high and therefore prefer to use different toilets. However, existing literature data from EcoSan toilet assessments in Nepal render this option very unlikely by stating that the user comfort and satisfaction is high (Manandhar *et al.* 2008; Rajbhandari 2008). This is supported by the personal impression of the authors from informal conversations with EcoSan users as well as by data received by the household survey showing that usage frequency and user satisfaction are high. Another more likely option might be that the information obtained in the questionnaire surveys is actually not very accurate. When asked some of the EcoSan users pointed out to have difficulties to give exact answers to the questions. The main reasons are that the urine collection containers are normally opaque and equipped with a tab which allows emptying without opening the tank. Additionally a number of users stated that they take out urine at irregular intervals just whenever there is need. Because of this many users have no direct mean of monitoring the amount of urine they collect and it has to be assumed therefore that the given answers are more based on estimations than on experience. As these observations suggest it seems likely that the established figures are not very accurate.

The data received from the toilet usage statistics on the other hand suggest that averagely 350 litres of urine are collected per year and household member. Based on this approach the water content of the collected urine is roughly 15%. Considering this dilution ratio an amount of 350 litres of collected urine seems to be very sensible. This is further supported by the fact that the estimated water content of 15% comes very close to the results obtained by the quantitative urine analysis. However, since the number of selected households for this toilet usage statistic is with six very small the results have to be taken with caution.

When calculating with the most likely parameter values the third analytical approach suggests that 240 litres of urine are collected per household member. This figure lies more or less precisely in between the two other values. However, what is interesting to observe from the analytical calculations is that the low value found by the questionnaire survey can only be reproduced by using minimum values for both the average amount of urine excreted as well as the urine concentration. Even though the minimum values are in the range of possible results it is very unlikely that both parameters tend towards the assumed minimum. It should therefore be justifiable to argue that the low figures obtained by the questionnaire approach are highly unlikely. The 350 litres received by the toilet usage statistics on the other hand can be modelled with an estimated water content of 15% and a urine excretion close to the possible maximum assumed. Further the estimated 350 litres lie almost exactly between the theoretical maximum and minimum of 620 and 120 litres. This suggests that the figure received by the second approach is much more likely. However, since the error bands assumed for the parameters are skewed the calculations indicate that the actual figure is more likely to be lower than higher as the 350 litres.

In order to be able to perform this feasibility study for struvite production in the local context a reference value has to be established on which further calculations can be based. Since the detailed toilet usage survey is the only of the three approaches relying on actual field data and the results obtained fit very well with the qualitative urine analysis it seems appropriate to establish 350 litres of collected urine per household member as reference. It has to be added however that this value is rather in the upper part of the band of urine amounts that can actually be expected. To support this decision for an upper range value rather than one which is too low it is argued that struvite production can be assumed to have a positive effect on urine collection performance since it gives users a new opportunity to use their urine. If the collection performance is going to be affected the amount of collected urine per household member rather increases therefore.

The figures shown in *Table 28* shall further be used as reference values for estimating the amount of urine that is collected by EcoSan toilets in Siddhipur.

Table 28 Urine availability Siddhipur reference values

Parameter	Unit	Value
EcoSan toilets installed in Siddhipur		100
Toilets working	[%]	90% [1)]
Average number of household members		4.8
Urine collected per household member	[$l \cdot y^{-1}$]	350
Urine collected per household	[$l \cdot y^{-1}$]	1680
Urine collected in Siddhipur	[$l \cdot y^{-1}$]	150’000

[1)] see Annex A.2

At this point is shall be mentioned that an extended field survey of the urine collection of a bigger number of EcoSan urine containers over a longer period of time would surely be an appropriate way to establish more reliable data in this area. This seems worthwhile especially when considering that not any useful information at all about the actual amount of urine collected with EcoSan toilets could be found in the present literature. All the references that could be found were using theoretical excretion figures and actually were seldom even thinking of the fact that some of the urine might not end up in the EcoSan urine container.

How is the urine collected with EcoSan toilets presently used? It is assumed that the present usage of collected urine is distributed as follows: 60% co-composting, 25% direct application (20% backyard garden, 5% crop fields), 10% draining and 5% giving to neighbours. The share of urine which is applied directly and which allows to take the fullest benefit of the nutrients is with 25% remarkably low. There are periods of the year (mostly during the rainy season) where some people have not any other more convenient option as to drain some of the collected urine somewhere on their private ground. The presently generated benefit out of the collected urine in Siddhipur is not optimal due to a lack of awareness, insufficient usage options and the general low comfort of handling liquid urine. Thus struvite production could be a viable complement to increase the benefit of urine collection and encourage local nutrient recycling.

4.1.3 Present Usage

The analysis done in the preceding subsection has been concerned about the *total amount* of urine that is collected in EcoSan toilets of Siddhipur. These estimations show that approx. 150’000 litres of urine each year end up in the collection tanks and are available to the owners to be used for various purposes. Since a future struvite production is dependent on a share of this total it is crucial to know what different purposes the collected urine is actually used for. It is unlikely and also unreasonable to assume that all the collected urine will and shall be used for struvite production and therefore the present applications not only determine how much of the total collected urine could be used for conversion into struvite but also how sustainable this would be compared to prior usage.

The following main applications for collected urine could be identified among the EcoSan community members of Siddhipur:

- ***Co-Composting:*** A major share of EcoSan owners state to put collected urine into their traditional composting pits (sagaa) which most of the Newar households have in their backyard (see section 2.3.1). According to the household survey data most of the people regularly put some urine onto the compost together with new waste or at least a few times a month. Some of the households visited even have a pipe installed which directly connects the urine tank with the compost pit. According to the users experience as well as local scientific assessments (Shrestha 2005) urine has a positive influence on the composting process and the composts nutrient content.
- ***Direct application:*** The most obvious way to use collected urine is as direct liquid fertilizer for plants. Urine is either directly taken from the toilet's urine tank or stored separately before usage. When looking at direct application it can be distinguished between application in the *household's backyard/vegetable garden* and in the main *crop fields*. Whereas in most cases the local households posses a vegetable garden just around the house the crop fields are typically outside of the village core area. When applied on plants the urine normally is diluted with water in a ratio of approx. 1 : 3 to 1 : 5 as it is advised by the local NGOs implementing EcoSan projects. However, it has to be mentioned that due to the toilet layout (cf. Spuhler 2008) the normally advised storage time of 1 month (Schönning and Stenström 2004) for urine hygienization is not adhered to.
- ***Draining:*** Since urine collection is equally distributed over the whole year but the need varies distinctive with the vegetation and harvesting periods of the plants there are times where people state to have too much urine available. In this case people mostly resort to draining the urine somewhere on their private land. According to our survey data the time of year with the biggest surplus of urine and thus draining is during the rainy season from May to September. Interestingly this is actually the main vegetation period with the biggest demand for fertilizer (paddy cultivation).
- ***Other uses:*** Next to the three main applications co-composting, direct application and draining a few households place their collected urine at their *neighbours'* disposal. However, this is commonly only done among nearby living kinship. One family surveyed also stated to use their urine for *co-composting with the dehydrated faeces* after emptying the toilets faeces vaults.

Methodology

The distribution of the collected urine among the above stated main applications has proved to be difficult to ascertain. According to a nationwide EcoSan assessment study done by WAN and ENPHO (2007), which has surveyed approx. 450 EcoSan households, 45% of the families put their collected urine on the compost for co-composting, 35% state to use the urine in their backyard garden or on their fields as a direct fertilizer and 19% pour the urine down the drain. A minor fraction of 1% on the other hand is used to share the urine with their neighbours according to the cited survey. However, the study did not mention any considerations about the fact that many families actually adapt the application to their varying needs throughout the year and use the urine for different purposes at the same time. It has to be assumed therefore that this statistic only reflects the distribution of the primary usage options of each household.

To account for this fact a specific "Urine Usage Distribution Play" has been developed for the present study which allows the people to apportion the total urine amount of one calendar year among the four above identified main applications (see Annex A.14). For the usage assessment the total collected urine of one year is represented by 20 beans which the person can distribute freely. This allows to account for seasonal variation as well as diverse usage at the same time. The described play was integrated into two FGDs and was also part of the baseline household survey. The results obtained are illustrated in Figure 7 and Figure 8.

Results

Relative distribution of different urine applications for Siddhipur

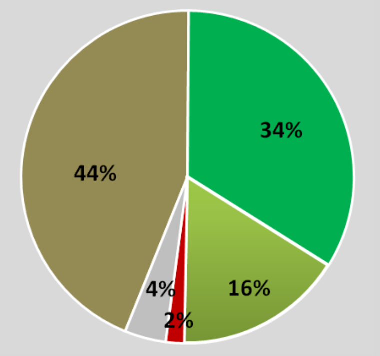


Figure 7: FGD Participants

Test persons: n = 25

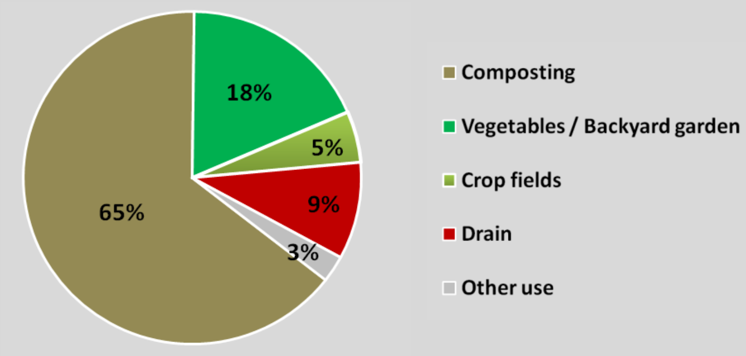


Figure 8: Household Survey

n = 27

As the diagrams show the results obtained at the FGDs vary significantly from the household survey data. FGD data suggests that approx. 45% of the urine is added to the compost; about 50% is used for direct application and the remaining share given to neighbours and poured out. Household survey data on the other hand estimates that roughly ⅔ of the urine is used for co-composting, ¼ for direct application and that the remainder is mainly poured out. The differences are stark considering that both datasets have been acquired with the same methodical approach. Two possible reasons can be identified to explain the discrepancy. During the FGDs the play was carried out in teams of 2-3 people for mutual assistance and improvement of understanding. Despite the fact that for each person a round was played individually it might be that the assistance and observation of the others has had a remarkable influence on the results. An indication therefore is the fact that “draining” has a considerably smaller nomination compared to household survey data where the interview was conducted in a private setting. Besides this it was also observed in later informal conversation that in some cases there has bee some misconception about the classification of the usage options. In a few cases people stated they use urine for fertilizing their crops (direct application) but actually put it onto the compost which is later brought out on the fields.

Discussion

In view of the above made considerations and the personal field observation that composting really is by far the most popular application it can be concluded that the data obtained during the household survey probably comes closer to the actual distribution of usage types than the FGD data. Therefore, for further considerations the following reference values shall be applicable.

Table 29 Urine application reference values

Application type	Percentage of total	Litre per household and year [$l \cdot y^{-1}$]
Compost	60%	1010
Direct application (backyard)	20%	340
Direct application (crop fields)	5%	80
Draining	10%	170
Giving neighbours	5%	80

The obtained results are interesting in various ways:

- *The share of urine which is actually applied directly as a liquid fertilizer and which allows to take the fullest benefit of the nutrients contained in urine is with 25% remarkably low.*

  According to information received from a FGD this can mainly be attributed to the bad handling properties which liquid urine fertilizer displays: its liquid form which implies heavy transportation weight as well as a storage and transportation problem (containers), the unpleasant smell and the additional effort for applying urine to the plants (dilution, spreading). A few farmers also have reported bad crop performance after the direct application of urine on their plants. That transportation does pose a hindrance for direct application can also be seen in fact that application in the backyard is four times higher compared to remote field application even though the field area commonly is many times bigger. As the household survey has shown the distances between the family homes and crop fields are considerable. According to received data the average distance between households and crop fields is 1-2.5 km.

  However, besides these obvious problems it has to be mentioned that the awareness about the fertilizer qualities of urine is not very well established too. Even though normally direct application is recommended by EcoSan implementing NGOs it is not an issue of primary importance and co-composting is pictured as an equally good but more convenient alternative.

- *With approx. 60% by far the biggest amount of collected urine is used for co-composting.*

  Considering that co-composting is promoted in the above mentioned way it is not remarkable that the biggest share of urine is used for co-composting. As in Section 2.3.1 described the addition of urine to the compost has a long tradition and still is very popular until today. When implementing EcoSan projects the NGOs thus normally take advantage of this experience and further promote it. The main advantage of co-composting with urine surely lies in the comfort it offers compared to direct application. Roughly ⅓ of the respondents of the household survey stated to favour co-composting over the other application options because of the positive effect of the urine on the composting process, the substantial need for compost material, the good all over result and the handling comfort. The other ⅔ see co-composting as a last resort before dumping urine somewhere else. However, because direct application on the remote fields is only for the least a viable choice it is still a popular option.

  An issue when reviewing co-composting is the question about its performance. It is commonly accepted that composting with urine does have a positive effect on the composting process (higher temperature, lower C:N ratio) and that some of the nutrients contained in the urine are fixed in the compost. However, it is also a fact that some nitrogen is lost by evaporation of ammonia and that only a part of the other nutrients remains in the compost (Pinsem and Vinnerås 2003; Shrestha 2005). Because of this it is crucial for efficient co-composting to take measures against nutrient loss (well dosed application, coverage of compost pile). In spite of this, data from the household survey shows that 11 out of 17 or roughly 65% do not take any measures at all against nutrient loss. Additionally the total amount of urine added to the compost is estimated to be around 1000 litres per year or 80 litres per month for an average household which is definitely far above the recommended 15% of wet compost weight (Pinsem and Vinnerås 2003).

  According to PAN (2008) the waste generation rate for Lalitpur Sub-Metropolitan City (main settlement of Lalitpur district to which Siddhipur belongs and which is neighbouring to Siddhipur V.D.C) is 0.37 kg per person and day with an organic fraction of 72%. ENPHO (2003) assessed the waste generation in Siddhipur to be 0.23 kg per person and day during rainy season and 0.12 kg during dry season. The content of organic waste is stated to be 80% and 64% respectively. Based on these data an average household in Siddhipur generates approx. 430 kg of organic waste. Thus it can be estimated that an amount of roughly 65 litres of urine per household and year would be sufficient for co-composting (see Annex A.17). Even when accounting for the popularity of co-composting by doubling these 65 litres to 130 litres per household and year an amount of approx. 1000 litres or 60% of the total (incl. drained urine) would be available for other usage options given that excess application of urine to for composting is of minor benefit.

- *There are periods of the year (mostly during the rainy season) where some people have not any other more convenient option as to drain some of the collected urine somewhere on their private ground.*

  In the household survey 30% of the families stated to sometimes pour away some urine. In line with the above made considerations the reason for this can be attributed to a lack of viable other usage options: direct application is too inconvenient and the amount of urine put on the compost already excessive. Additionally because of social and ethnical customs only in a few cases it is an option to give some of the urine to other households.

- *The presently generated benefit out of the collected urine in Siddhipur is not optimal due to a lack of awareness, insufficient usage options and the general low comfort of handling liquid urine. Thus struvite production could be a viable complement to increase the benefit of urine collection and encourage local nutrient recycling.*

  As the points above have shown a considerable part of the collected urine is not yielding its potential benefit. The main reason which can be identified for this circumstance is a missing choice of viable usage options readily available to the local farmers. Because direct application is regarded as too inconvenient and, as the estimations for optimal co-composting with urine have shown, the application of urine to local composts is excessive a need for additional usage options can be identified. It can be estimated that about 60% of the actually collected urine could be applied in a more benefitting way. Transformation of urine into struvite and thus the recovery of additional nutrients by producing a powder form and concentrated fertilizer might be a promising option.

4.2 Magnesium

Struvite is a naturally occurring precipitate in aged urine. It is formed from out of some of its compounds when the pH-level of the urine exceeds a distinctive level due to chemical changes happening during storage. The struvite molecules are formed through a combination of dissolved magnesium, ammonium and phosphate ions. Since the concentration level of magnesium is considerably lower than the concentration of the other compounds this natural process stops when all the magnesium ions in solution are fixed. However, this process can be stimulated again by artificially adding magnesium to the stored urine. By this the precipitation of struvite continues until one of the other in the process involved components (ammonium and phosphate) are depleted. In normal urine the concentration of phosphate is subsequently the limiting factor. The artificial addition of magnesium to urine is therefore a very convenient way of fixing the phosphorus and a part of the nitrogen that is contained in urine (Tilley *et al.* 2008b; Udert 2002; Udert *et al.* 2006).

As described above magnesium is needed to stimulate further precipitation of struvite from urine (more precisely magnesium ions). To achieve a fast and efficient reaction the magnesium ions should already be in solution or should dissolve well in alkaline conditions. Solubility is therefore one of the main factor that have to be taken into account when accessing different magnesium sources. Other factors are price, availability and handling comfort. Table 30 gives an overview of the factors that have been identified as important for assessing different magnesia sources.

Before continuing in this section a definition of thermology seems to be appropriate. It is important to distinguish between the chemical compounds which actually contain magnesium and the product as which this chemical compounds are shipped or within which they can be found. As a convention therefore, the magnesium compounds or components shall henceforth also be termed as magnesium sources whereas when speaking of magnesium products, substances available on the market are meant. In cases where a product is of pure grade the terms are interchangeable and the distinction is not really necessary but for products of lower grade the distinction helps to avoid confusion.

Table 30 Assessment factors for magnesium sources and products

Factor	Description
Solubility*	For an efficient and fast precipitation of struvite the magnesium added should be in solution (which means in ionic form) or it should to an acceptable degree dissolve in stored urine which is a very alkaline environment. If the chosen source does not have an acceptable solubility in urine pre-processing would be unavoidable.
Price*	The produced struvite is further used as a fertilizer which means the price of the end product has to be competitive with similar fertilizers on the market. Since magnesium is a major part of struvite it contributes to a considerable degree to the end price. As a measurement for the magnesium cost the price per mol of dissolved magnesium ions is taken.
Concentration^	The magnesium concentration (percentage of weight) of the used product should be as high as possible to avoid high and unnecessary transportation cost.
Side products*^	Unless pure magnesium metal is used the magnesium product will be a compound of magnesium and other substances. Since it is probably unfeasible to only add the magnesium ions to the urine the other compounds will be added to the urine as well. They are likely to stay in solution and might hinder the further use of the processing effluent. When assessing magnesium sources and products it is therefore important to consider the other compounds as well. Attention has especially to be paid to heavy metals. Although it has been shown that the percentage precipitating with struvite is very low (Ronteltap *et al.* 2007) the heavy metals will remain in the processing effluent and might render it unfit to be used for any further fertilizing purposes.
Sustainability^	The magnesium product should be easily available and should come from a sustainable source. Further it should not be of an environmentally polluting nature. If struvite wants to be promoted as an organic fertilizer its origin and background are also important. A factor which should also be taken into account is its source of production. A product that is locally available is generating income within the country whereas imported products lead to a drain of resources.

* applying to magnesium sources; ^ applying to magnesium products

Which different sources of magnesium are available? Three different classes of possible magnesium sources have been identified: *magnesium salts* (magnesium chloride $MgCl_2$, magnesium sulphate $MgSO_4$), *magnesium carbonates* (magnesite $MgCO_3$, dolomite $[Ca,Mg]CO_3$) and *magnesium oxides* (magnesium oxide MgO, magnesium hydroxide $Mg(OH)_2$). The magnesium salts are highly soluble and have shown good precipitation results but only have a low magnesium content. Magnesium carbonates (magnesite) on the other hand has a considerably high magnesium content but is likely to be usable only after pre-treatment with acid. Dolomite seems unusable. Magnesium oxides have a very high magnesium percentage but solubility and precipitation efficiency are uncertain.

4.2.1 Identified magnesium sources

In line with the above mentioned criteria three main classes of possible magnesium sources have been identified: magnesium salts, magnesium carbonates and magnesium oxides. Magnesium salts are produced abundant and are the sources for many other magnesium products. The two most important magnesium salts are magnesium chloride ($MgCl_2$) and magnesium sulphate ($MgSO_4$). They are mainly produced and traded on the market in the form of *magnesium chloride hexahydrate* ($MgCl_2 \cdot 6H_20$) and *magnesium sulphate heptahydrate* ($MgSO_4 \cdot 7H_2O$). Since these products are commonly of high grade and differ only by their hydrate form from the original salts the distinction between the magnesium source and the actual products is sometimes omitted.

Magnesium carbonate ($MgCO_3$) on the other hand is a naturally occurring compound which is present in sedimental deposits. It is closely related to calcium carbonate and can be found in vast parts of the world in its vicinity. In higher concentration the magnesium carbonate is present in the minerals *magnesite* ($MgCO_3$) and *dolomite* ($[Ca,Mg]CO_3$). Since both minerals naturally occur in pure form one can also speak of magnesite and dolomite stone. Magnesite is the mineral/stone name for magnesium carbonate and is therefore by definition almost completely made up of magnesium carbonate. Normally it only contains smaller amounts of side products; especially iron, manganese, calcium, cobalt and nickel (Mindat, access 22.02.2009). Dolomite on the other hand is a compound of magnesium carbonate and calcium carbonate. The ration of magnesium to calcium ions is normally around 1:1. Minor occurring impurities are Fe, Mn, Co, Pb and Zn (Mindat, access 22.02.2009).

Besides magnesium salts and magnesium carbonates the *magnesium oxides* can be regarded as a third group of magnesium sources. *Magnesium oxide* (MgO) and *magnesium hydroxide* ($Mg(OH)_2$) are the most common compounds of this group. Magnesium hydroxide is normally produced from watery solutions containing magnesium chloride (e.g. seawater) whereas magnesia oxide is produced by heating up magnesium hydroxide or magnesium carbonate (a process called calcination) (Webelements, access 22.02.2009). If magnesium carbonate is used as a source tree grades have to be distinguished depending on the temperature of burning: caustic, hard burned and dead burned magnesium oxide. Since hard and dead burned magnesium oxides show practically no reactivity anymore only caustic magnesium oxide is of interest as a magnesium source. As both substances are gained through processing the traded grade is normally high. Lower grade products mainly contain silicium dioxide, sulphate, calcium oxide and ferric oxides.

Table 31 gives an overview of the mentioned magnesium sources whereas *Table 32* lists the magnesium products identified for the production of struvite.

Table 31 Identified magnesium sources for struvite production

Magnesium compound	Chemical formula	Soluability in water [g·l^{-1}]
Magnesium chloride	$MgCl_2$	1670 [1)]
Magnesium sulfate	$MgSO_4$	710 [2)]
Magnesium carbonate	$MgCO_3$	0.106 [3)]
Calcium magnesium carbonate	$[Ca,Mg]CO_3$	*
Magnesium Oxide	MgO	0.086 [2)]
Magnesium Hydroxide	$Mg(OH)_2$	0.009 [3)] §

[1)] Science Stuff Inc. (access 22.02.2009); [2)] Thermo Fisher Scientific Inc. (access 22.02.2009); [3)] GESTIS Substance Database (access 22.02.2009); * not found but can be assumed to be similar to magnesium carbonate; § Magnesium hydroxide shows good solubility in ammonium salt solutions

Table 32 Identified magnesium products for struvite production

Product	Magnesium component	Weight [gmol-1]	Avg. grade of magnesium component [% of weight]	Mg content [% of weight]	Magnesium [mol/kg]	Amount needed for 1kg of struvite [1)] [kg]
Magnesium	Mg	24.3	100%	100.0%	41.15	0.10
Magnesium Chloride Hexahydrate	$MgCl_2 \cdot 6\ H_2O$	203.3	up to 99%	12.0%	4.92	0.83
Magnesium Sulfate Heptahydrate	$MgSO_4 \cdot 7\ H_2O$	246.5	up to 99%	9.9%	4.06	1.00
Magnesite	$MgCO_3$	84.3	95%	27.4%	11.27	0.36
Dolomite	$MgCO_3$	84.3	40%	11.5%	4.74	0.86
Magnesium Oxide	MgO	40	100%	60.8%	25.00	0.16
Magnesium Hydroxide	$Mg(OH)_2$	58.3	100%	41.7%	17.15	0.24

[1)] based on a molar ratio of Mg:P = 1:1

4.2.2 Pre-treatment and process evaluation

The various identified magnesium sources show very different chemical properties. Due to their strongly distinct solubility and the side products contained different behaviour in struvite precipitation is also likely. In the following section short considerations about eventually needed pre-treatments and the precipitation processes are given.

Magnesium chloride

Magnesium chloride has been used by different people for the production of struvite from source separated urine and showed good results. The handling of magnesium chloride is easy since its solubility is high. Due to the good availability of magnesium ions in the solution the precipitation process is fast and a high percentage of phosphorus can be fixed (Tilley *et al.* 2008b). Due to its high water content the magnesium content of magnesium chloride is only 12% by weight. As a result of this, a comparably large amount of magnesium chloride is needed for the production of struvite (approx. 0.83kg for 1kg of struvite on a stoichiometric basis). Since magnesium chloride itself is promoted as a magnesium fertilizer the contained chloride ions which stays in solution in the processing effluent can be regarded as unproblematic for any further usage of the effluent.

Magnesium sulphate

The chemical properties of magnesium sulphate and magnesium chloride are very similar. It can be estimated that magnesium sulphate will show comparable results for the production of struvite. Since the magnesium content of magnesium sulphate is even slightly lower than that of magnesium chloride approximately 1kg is needed for 1kg of struvite. Magnesium sulphate is like magnesium chloride marketed as a fertilizer and the sulphate ions which stay in solution are even of value to soils and plants under certain conditions.

Magnesium carbonate

As displayed in Table 31 magnesium carbonate can be considered as almost non-soluble in water. Since it is estimated that its solubility is even worse in the alkaline environment of stored urine it is unlikely be useable without any further treatment. As a mean of breaking up the carbonate molecules a pre-treatment with acidic solutions has been identified and is suggested. As suitable acids for this purpose the widely used acids hydrochloric acid (HCl), sulphuric acid (H_2SO_4) and phosphoric acid (H_3PO_4) could serve. Theoretical considerations suggest that through this pre-treatment the magnesium ions are split apart from the carbonate ion which in turn neutralises the acid and leaves the process as carbon dioxide. In a dry setting the magnesium ions conjoin with chloride to magnesium chloride if hydrochloric acid is used and to magnesium sulphate in case of sulphuric acid. Since the acids are normally shipped and handled in solutions of water the salts are not formed but they directly dissolved in ionic form in the solution (for a more detailed process assessment for hydrochloric and sulphuric acid see Annexes B.1 and B.2). As a result of this pre-treatment a solution containing magnesium ions can be expected as if magnesium chloride or magnesium sulphate had been dissolved in it. A study conducted by Gunay et al. (2008) on the feasibility of using magnesite (magnesium carbonate) tested hydrochloric and phosphoric acid for dissolution of magnesium carbonate. Whereas they found a dissolution of nearly 100% when using hydrochloric acid (Mg:Cl = 1:2) only a poor solubility of approx. 20-50% was achieved when using phosphoric acid ($Mg:PO_4$ = 1:1).

Theoretically the usage of phosphoric acid to break up magnesium carbonate is interesting because in this way it can be used for two purposes. On the one hand it can help to disassociate the magnesium ions from the carbonate as with hydrochloric or sulphuric acid. The phosphate ions staying in solution on the other hand increase, when added to the urine together with the magnesium, the phosphate content of the urine. Like this the amount of struvite that could be produced should theoretically increase by +200% of the amount producible normally (for 3 magnesium ions in solution 2 phosphate ions are added to the solution for which again 2 magnesium ions are needed). This does not only increase the amount of struvite that can be produced from one litre of urine threefold but also allows fixing more of the nitrogen that is contained in the urine. However, the study of Gunay et al. (2008) shows that phosphoric acid is not dissolving magnesium carbonate entirely and that the additional use of hydrochloric acid is needed. This renders its use less favourable. Additionally it has to be considered that ⅔ of the phosphate actually sold as "eco-struvite" would likely come from a not renewable source. This also means that a production based on such a process would only slightly profit from otherwise very welcome price increases for phosphorus (and analogically phosphoric acid). If the process seems feasible an economic analysis might still be worthwhile.

For all this considerations it has to be acknowledged that this pre-treatment with acids adds considerably more complexity to the otherwise rather simple process of struvite production. This is especially the case since the handling of the stated acids is of an imminent danger to the personnel and requires sophisticated protection measurements and appropriate instruction. Therefore it is at least questionable whether such an approach is feasible in a developing country context.

Calcium magnesium carbonate

Most of the considerations made for magnesium carbonate are also true for calcium magnesium carbonate. However, one big difference is the presence of the calcium which is normally in a ration of 1:1 to magnesium. When treated with the above mentioned acid this means that beside the magnesium chloride or magnesium sulphate produced (both in solution) also calcium chloride (in solution) or calcium sulphate (gypsum, solid) is present. Gypsum can be considered as unproblematic as it is a product used for fertilizing. However, the calcium ions in solution (when using hydrochloric acid) would to a certain degree precipitate with the phosphate present in the urine as hydroxylapatite ($Ca_5(PO_4)_3OH$) and therefore decrease the amount of struvite that could precipitate. This in turn decreases the amount of nitrogen that can be fixed in the process). Besides this the presence of calcium has yet more undesired effects: On the one hand it means that the concentration of magnesium in the product is only half and therefore double as much material has to be handled. On the other hand this also means that double as much acid is needed compared to pure magnesium carbonate to dissolve all the magnesium. Especially this fact renders dolomite very unfavourable since it increases the processing costs heavily.

Magnesium oxide and hydroxide

As magnesium oxide forms in the presence of water magnesium hydroxide both oxides are covered here in the same section by assuming that magnesium oxide is converted to magnesium hydroxide before further processing. According to *Table 31* magnesium hydroxide show a very low solubility in water. This puts it into the same category as the carbonates mentioned higher in the text and it can also be assumed that magnesium hydroxide could be treated with acids to disassociate. However, one property that fundamentally differs between the carbonates and magnesium hydroxide is the fact that magnesium hydroxide shows a good solubility in ammonium salt solutions as which the urine can be considered. The solubility is largely increased since the ammonium ions react with the hydroxide of the magnesium by forming ammonia. Ammonia is rather volatile though and it is likely that a large amount is lost by aeration. This is not desirable. Despite this, research done by Quintana et al. (2004) shows that magnesium oxide is still a viable magnesium source for struvite precipitation. With a Mg:P ratio of 2:1 similar precipitation performances could be obtained as with magnesium chloride with a Mg:P-ratio of 1:1. Since the magnesium concentration of MgO is approx. 60% this is despite the worse ratio compared to magnesium chloride a very interesting option.

What magnesium products are available in Nepal and for which costs? No demand for magnesium products could be found on the Nepalese market and thus availability is poor. Magnesium salts can be imported from India but the costs are relatively high (21-32 $NRp \cdot kg^{-1}$). Magnesite was quarried locally in Nepal but the mine is not operated at present. Not any magnesium oxides could be found. In general the found price level for magnesium as well as acids was very high due to a worldwide price hike in most commodities at the time of research. It can be estimated that prices will level down again.

4.2.3 Magnesium product availability and costs

Even though a large effort has been spent to assess the market availability of the identified magnesium products and to get tenders the actual success has been mediocre. Magnesium products seem not to be searched after heavily in the Nepalese market. Table 33 lists a compilation of prices that could be established for the time of the research (summer 2008).

Table 33 Listing of established magnesium product prices [1)]

Product	Additional specification	Price [2)] [$NRp \cdot kg^{-1}$]	Add. treatment costs [3)] [NRp/mol Mg]	Mg^{2+} price [$NRp \cdot mol^{-1}$]	Price for 1kg of struvite [$NRp \cdot kg^{-1}$]
Magnesium chloride	Shipped from a company in southern Nepal (Birgunj), product imported from India, transport costs to Kathmandu not included, effective product composition not obtained	32	-	6.51[5)]	26.5
Magnesium sulfate	Shipped from a company in southern Nepal (Birgunj), product imported from India, transport costs to Kathmandu not included, effective product composition not obtained	21	-	5.18[5)]	21.1

Magnesite	Supplied by Kathmandu company, product imported from India, deposits in the company's mine are approved but no magnesite shipped yet, effective product composition not obtained	8	3.08[4)]	3.79	15.4
Dolomite	Supplied by Kathmandu company from company owned quarry in Nepal (exact source not known till present), product composition not obtained up to present but promised	4	~6.20[4)]	~10.20	~41
Dolomite	Sourced from a proximate marble quarry at the south-eastern edge of Kathmandu Valley (Godawari) and directly supplied by the quarrying company, material for pilot phase would be provided free of charge, the laboratory analysis obtained shows a comparably low content of magnesium carbonate (32%), a high calcium carbonate value (60%) and also a high concentration of RO_3 (4.7% , FeO_3 and AlO_3).	3	~12[4)]	~15	~61
Magnesium oxide	No offers obtainable	-	-	-	-
Magnesium hydroxide	No offers obtainable	-	-	-	-
Bittern	Contact has been established with an Indian salt manufacturing company (Marine Chemicals, part of The Archean Group of Companies, Gujarat) which has shown interest.	-	-	-	-

[1)] for each identified magnesium source only the best offer is listed unless the cheapest products usability is questionable
[2)] approximate exchange rate at time of writing: 100 NRp ≈ 1 EUR / 1.50 CHF; all prices stated excl. VAT of 13%
[3)] given costs only include input cost for acids needed but no processing and labour cost
[4)] for price calculation see Annexes B.3 and B.4
[5)] stated prices calculated without knowing the actual grade of the product (assumption 99%).

The table shows that as by now the usage of magnesite in conjunction with hydrochloric acid suggest being the cheapest method to get magnesium ions in solution. For one mol of dissolved magnesium costs of 3.79 NRp are estimated. However, it has to be considered that these costs only include the input costs for the acids that are needed and do not include additional costs for processing (facilities, protection equipment, labour). Regarding this fact the costs of the second cheapest product magnesium sulphate, which are roughly 5.18 NRp per mol, are very competitive. The use of dolomite on the other hand is strongly discouraged by economic reasons because of the high pre-treatment costs.

One product that has not been mentioned so far but is also displayed in Table 33 is *bittern*. Bittern is a side product of sea salt production. It is a naturally occurring product rich in magnesium salts and mainly contains magnesium chloride and magnesium sulphate. The composition can vary but the magnesium concentration is approx. 32g per litre which is almost 30 times higher than in seawater (Lee *et al.* 2003). Research done by Lee et al. shows that bittern is actually as efficient for struvite precipitation as magnesium chloride. Only slightly smaller performances of ammonium are detected. Over a dozen sea salt manufacturing companies in India, Pakistan and China have been contacted for the availability of this product but the results have been disillusioning. Only one company has replied and shown small interest but without offering any specific product or price.

Which magnesium product is best suited for struvite production under local conditions? Magnesium salts are the only product class whose availability is reasonably assured. They allow a simple and efficient struvite precipitation they. Magnesium sulphate is slightly cheaper and the product of choice. Locally sourced magnesite might be an option for the future but its availability and the handling of acids puts question marks. Bittern, a by-product of sea salt production, might be an interesting option for the future.

4.2.4 Assessment of identified magnesium sources

Putting all the considerations and the present established knowledge together four conclusions can be made:

- Firstly, the efforts undertaken have shown that the demand for any of the studied magnesium products is extremely low if not to say nonexistent in the Nepalese market. Many of the contacted potential suppliers of these goods have not any stock available at all or at least established links to manufacturers abroad. Because of this, only a few were willing to submit an offer. A few interested businessmen could be found though and it can be assumed that it will be possible to have an adequate amount of magnesium available for a reasonable price for the pilot phase in autumn (delivery periods are 2-4 weeks). It is further likely that the motivation of the trading companies increases with a boost in demand and that the prices, especially for the magnesium salts, might come down locally to a certain degree. According to a non representative survey on the B2B platform alibaba.com world market prices are around 20 NRp/kg for magnesium chloride and 14 NRp/kg for magnesium sulphate at the time of research.

- Secondly, it can be concluded that the magnesium salts are the easiest to use and at the present moment probably as well the cheapest magnesium products (including all costs). They are readily available on the market and do not demand large additional resources for pre-treatment as the also considered carbonates. Magnesium sulphate is at the present market condition the considerable cheaper one of the two salts available and is therefore the first choice. This large price difference may be because a small demand for magnesium sulphate has been reported in Nepal whereas not any of the contacted domestic suppliers has any magnesium chloride in stock. Since fairly exacta 1 kg of magnesium sulphate is needed for 1 kg of struvite the total input cost for 1 kg of struvite produced at the present comes up to about 25 NRp including VAT. The disadvantage of magnesium sulphate is that it is a product which has so far not been produced in Nepal and is therefore imported from India or China.

- The third conclusion is that the usage of the locally available magnesium products magnesite and dolomite for the production of struvite would be possible. However, the added process complexity and the inherent danger of handling acids make them less appropriate. Their usage might still be justified though by an economic analysis of the process. Calculations show that with current acid prices on the market a kilogram of struvite can actually be estimated to roughly the same cost as with magnesium sulphate. Fact is however that at the time of research the acid prices in Nepal are experiencing a strong price hike and are 3-4 times higher than usual. Traders say that this is mainly caused through the detrimental effect of the Olympic Games on the market (forced production stops and export bans by China) and that they think that the prices are likely to level down again towards the end of 2008. Calculations with the acid prices from spring of 2008 suggest that by using magnesite with hydrochloric acid the input price of 1kg of struvite could be less than 10 NRp. This suggests that if the prices really level down again magnesite in combination with acids might still be a very attractive solution. Additionally a main advantage of this approach is that by using a local magnesium source and by producing a soluble form locally a considerably bigger part of the added value of the end product is produced in the country itself. Since Nepal is largely dependent on imports for most of its product and suffering under this fact this might be an important point to consider for the further promotion of struvite precipitation from urine. It is especially likely that, with this argument at hand, legislative hurdles for the introduction of struvite as a fertilizer would be leaped easier and that even policy changes supportive of struvite recovery would be possible.

- The fourth conclusion is that there might actually be a respectable potential in the so far not largely mentioned magnesium products magnesium (hydr)oxide and bittern. Unfortunately not a lot of market information could be established for both products. Magnesium (hydr)oxide has been produced in Nepal in earlier years but has not been supplied to the market for some time due to struggles during the Maoist conflict (USGS 2009). It is said however by different people that production should be started again. If this is the case then it might be that the price of locally available magnesium (hydr)oxide is competitive with the imported magnesium salts due to the local production even though it needs more processing. Bittern on the other hand seems to be a very ideal magnesium product for struvite production. As it is a waste product of sea salt manufacturing and mostly simply discharged back into the sea its price is likely to be low. Another big advantage of bittern is that it is a naturally occurring product, that it is sustainable and that it can even be regarded as organic. By using bittern the produced struvite could therefore justifiable be market as an organic fertilizer, something that would not be possible with any of the other used magnesium products.

5 Struvite Production Process Outputs

As already identified in Section 1.1 the main two process outputs of the production method under assessment are the *struvite* powder itself and the remaining partly nutrient-stripped urine or *processing effluent*. For struvite the main question of interest is whether the targeted use as a mineral fertilizer is feasible and beneficial under the local conditions. As it is made out of human urine an important point is whether struvite can be acceptance by the local farmers and communities. These points shall be assessed in the following subsection.

Besides struvite a larger amount of partly nutrient-stripped urine is generated as kind of a by-product. In order to assure a sustainable production cycle further treatment is of central importance. However, as this is a main task of STUN Phase II only some short considerations are given.

5.1 Struvite

In order to establish struvite production as an additional and beneficial usage option for source separated urine from EcoSan toilets the acceptance by the community is of central and decisive importance. Only if the local farmers perceive it as a viable, comfortable and profitable usage option they will incorporate it into their farming practices. Mainly four factors can be identified that have a vital influence on the acceptability of struvite:

- Socio-cultural acceptability
- Process performance
- Fertilizer performance
- Product costs

These four points will be of uttermost significance. The first three shall be looked at in the following subsections. Product costs are addressed later in Section 0.

Socio-cultural acceptability: Would struvite be accepted and used by local people? Use of human urine or faeces for fertilizing can pose a problem for certain Hindu cast. In the local Newar communities however a long tradition of human waste recycling exists and acceptance of struvite is high. Whereas a majority is disinclined to handle other person's urine no one has objections against struvite from mixed sources.

5.1.1 Socio-cultural acceptability

The handling of excreta in general and human excreta especially is something that is a touchy topic in most societies worldwide. Socio-cultural habits can largely affect the general attitude towards excreta and determine whether a society has rather faecophobic or faecophilic tendencies. The social and cultural sphere again is largely influenced by religious beliefs (Warner 2003). This statement also holds for Nepal which is mostly populated by deeply religious Hindu people. Therefore, when the socio-cultural acceptability is of concern the main issue can be identified as a religious one. However, as Warner (2003) writes, the disparities among the different casts can be stark and what is acceptable for one cast might be rejected by another.

The explanations in Section 2.3.1 already have shown that in most of the Newar communities in the peri-urban area of Kathmandu a long tradition of human waste recycling and nutrient recovery has been established. Both co-composting with faeces as well as urine has been in wide use and still is today. Therefore it already has been assumed in the project run-up that the use of a urine based fertilizer might be acceptable for these communities. When this topic was addressed in FGDs the people agreed. As they already use human waste in different forms and for different crops for fertilizing no one raised concerns about the usage of struvite. However, this acceptance largely stemmed from the fact that people are handling their own waste. It was told us already before that this is not the case for other people's waste. Because of this, for example, an earlier attempt to set up a collective central urine collection system / bank was turned down by the community. This was also confirmed by several of the people present at the FGDs. However, even though it was pointed out that struvite would also be made out of different people's urine no one raised any concerns. This is a remarkable difference to untreated urine.

As we have seen in Section 0 the aversion to use other people's urine has been a major reason for the low percentage of sharing among households. The conversion of urine into struvite could be a mean of bridging this socio-cultural barrier. Only a few people did not show any hesitation to use other people's (untreated) urine but everyone agreed that the usage of struvite should not pose any problems in the Newar communities. It can be concluded therefore that the socio-cultural acceptance of using urine in broad application could be substantially improved compared to presently available untreated urine.

During the FGD some people raised their concerns however that even though struvite might be easily accepted among Newar communities this might not be the case for Brahmin or Chetri people from the two higher casts. In fact these people mostly strictly reject the use of human waste for fertilizing purposes and only use other organic products for composting. Because of this the Newar people had doubt about the acceptability of struvite among these communities. Informal and not representative interviews with some members of the mentioned cast also showed that there really were larger objections against the use of either urine or struvite. However, as it was pointed out at one FGD, today it is even common for some of the Brahmin and Chetri communities to use excrements for fertilizing. Thus the opinion was that it might be a matter of time until their perception might change. Additionally it was added that through the distribution of produce through the market the individual product's origin is of less concern than before.

Process Performance: How is struvite production assessed compared to other usage options? In comparison to direct application of urine the performance of struvite production is seen differently by local farmers. Whereas some clearly see the advantage in user comfort struvite brings others point out the connected costs and the loss of nutrients.

5.1.2 Process Performance

Next to socio-cultural acceptability of struvite the perception of the whole process or production mode is of interest as well. How do the local people assess the value creation by the chosen production process? Or in other words, do they think it is worth to transform urine into a powder form mineral fertilizer? In the case of a commercial production the value added is more or less determined by the market economics, the prices of inputs and the final profit that is attainable with the outputs. However, since we are also looking at struvite production at a community level it is likely that not everything can be broken down to mere economics. The persuasion of the involved people is therefore of significance and will have a big influence on the motivation to participate in the undertaking.

Since the chosen production process is relatively simple it was perceived as possible to explain the main characteristics of the production process to the local people at a FGD and ask them about their opinion about the benefits and disadvantages of the chosen approach. For comparison reasons direct application was taken as alternative usage option since it promises the biggest benefit of the presently available usage options for source separated urine. At the first of two FGD meetings 12 out of 13 farmers or approx. 90% were in favour of struvite production despite the considerable loss of nutrients that is connected with it. The opinion of the majority was that the gained user comfort made up for the lost nutrient value. It was stated by the participants that in the form of a powdery fertilizer it would also be possible to use the urine nutrients on their crop fields, something that mostly was not done at present due to the problems in handling and transport. One farmer on the other hand did not see any reason in converting urine in a costly process since he could already take full benefit out of the untreated urine for free. However, it has to be added that this farmer has the advantage of having a major part of his crop fields directly attached to his house which means he is less confronted with transportation problems. At a second FGD meeting where the participants could be informed a little bit better than in the first, 2 out of 5 participants or 40% were in favour of struvite production over direct application. The other 60% followed the argument of the one farmer in the first FGD that they did not want to come up for the extra work and the nutrient loss connected with struvite precipitation.

How does struvite perform as a fertilizer? Struvite is a multi-compound fertilizer (NPK 6-29-0-Mg10) showing good crop yield performance. Due to its low solubility it is especially suitable for leaching conditions (heavy rainfall) and where long-time fertilizing effects are needed. However, N and K are not sufficiently present for single application and usage with other fertilizers is advised. It is believed that the introduction of struvite should have beneficial effects on long-term soil fertility (lower acidification and less heavy metals). Its local origin and guaranteed purity are likely advantageous, a pellet form would be preferred over powder however.

5.1.3 Fertilizer Performance

Most of the considerations done so far have been about different factors and properties of the local project environment in order to assess the feasibility of struvite production. Something that must not be forgotten however is that the ultimate usage of the produced struvite is for fertilizing purposes. This means that unless the state or other actors would willingly subsidize its production out of environmental or other considerations struvite has to be competitive on the hard-fought agro-input market. As on this market it is one product among dozens struggling for the favour of the farmer it is of importance not only to look at the different production approaches that might be feasible but also to assess whether the end product is actually desired on the market and competitive too. Besides product costs (which are covered in Section 0) the following four factors can be identified as being of major importance:

- crop performance
- long-term soil impact
- purity and reliability
- handling comfort

Crop performance

According to it's chemical composition struvite has an NPK-value of approx. 6 : 29 : 0 : (Mg) 10. Detailed numbers can be found in Table 34. This means that struvite can be considered as mainly a phosphate and magnesium fertilizer with a minor percentage of nitrogen. As it was neither in the scope of STUN Phase I nor possible within the available time, no field tests could be conducted with locally produced struvite and under local conditions. Thus only some general statements can be made based on literature data. A large collection of plant growth field tests with struvite can be found in Bridger et al. (1962) and Bridger (1968). According to these papers struvite showed the following fertilizer properties:

- Very slightly soluble in water and soil solutions: About 0.1-0.2g/l can be dissolved in water. This makes struvite nonburning to plants even in extremely high rates. Thus it can be applied to the soil in rates greatly exceeding those of conventional fertilizers and it is particularly suitable in areas where leaching is a problem (due to heavy rainfall) or where long lasting fertilizing effects are needed.
- Struvite is an effective source of nitrogen, phosphorous and magnesium: In many studies cited struvite fertilized crops performed as good are even better compared to conventional fertilizers. Nitrogen is mainly made available to plants through nitrification rather then solubility

However, since the author was holding a granted patent for struvite fertilizer application at the time of writing it is in question whether this account is entirely neutral (CEEP 2001). After having done a series of controlled pot trials with wheat Ganrot et al. (2007) also support the finding that struvite acts as a slow release fertilizer and a good source of phosphorous. All the same they notice that the plant available nitrogen was not enough for optimal growth and that higher struvite application significantly increased the soil pH level to a degree where it might have negatively affected nutrient availability and uptake. Johnston and Richards (2003) studied plant availability of P from struvite in pot trials with perennial ryegrass. They found that there was no significant difference between struvite and monocalcium phosphate, a source of water soluble P that is generally considered to be fully plant available. However, for optimal plant growth they added nitrogen, potassium and magnesium additionally to the pots.

Table 34 Struvite nutrient content as percentage of weight

Product	Nitrogen [N]	Phosphorus [P_2O_5]	Potassium [K_2O]	Magnesium [Mg]	Sulfur [S]	Calcium [Ca]
Struvite	5.7	28.9	0	9.9	0	0

The found literature suggests that struvite can be used as a beneficial nutrient source for crop cultivation. It shows some advantageous properties like a slow nutrient release and good P availability. However, for a general use fertilizer the magnesium content is very high and the ratio of the different nutrients skewed. In general the average amount of nutrients that should be applied to the soil follow the order N >= K > P > Mg. Thus it is not surprising that Ganrot et al. (2007) find a deficiency in nitrogen. It is suggested therefore that for an optimal use a combination of other fertilizers together with struvite should be used. Most suitably a ready-made mixture with an optimal nutrient ratio could be supplied. Since nitrogen is the nutrient that most of the farmers look for an increase of the nitrogen content would, for example, be advisable. Bridger et al. (1962) state that mixtures of struvite with other fertilizer products are possible as long as the other ingredients do not contain free acid. Ueno and Fujii (2001) on the other hand indicate that in Japan struvite recovered from sewage plants has been sold to a fertilizer manufacturing company which markets it mixed with other ingredients. The mentioned products contain between 20-30% struvite and are promoted as especially suitable for paddy rice cultivation.

Long-term soil impact

Agricultural mismanagement can have various detrimental effects on long-term soil fertility like erosion, compaction, salinization, acidification and pollution by heavy metals. Long-term intensive high yield crop farming based on inadequate application of mineral fertilizers additionally results in negative nutrient balances and thus to a significant depletion of soils (Gruhn *et al.* 2000). As main issues in connection with fertilizer application can be identified:

- Soil nutrient depletion
- Acidification

- Heavy metals

As the listed problems depend on a variety of parameters it is difficult to assess the effect of the introduction of struvite into the local agricultural practices on the above mentioned issues unless actual field studies were conducted. However, the following qualitative observations can be made:

Soil nutrient depletion: Long-term high yield crop farming in connection with an inadequate supply of mineral fertilizers irreversibly leads to the depletion of certain soil nutrient concentrations and eventually to decreasing crop yields. The findings in Section 3.3.3 and information received from local agronomists suggest that such an imbalance of nutrient application also applies to the local agricultural practices. Due to its low price and initially good response urea is used disproportionately high. Kumar and Yaday (2001) noted the same problem in Indian rice-wheat cultivation practices (largely similar to the ones found in Nepal) and studied the impact on soil fertility and production over a 20 years period. They found that unless a high and well dosed application of N,P and K (120-35-33 $kg \cdot ha^{-1} season^{-1}$) was implemented the yields decreased sharply. In this sense the application of struvite (6-29-0-Mg10) or at best a balanced mixture made of struvite enriched with N and K can be assumed to promote a more sustainable soil management and have a beneficial impact on the soil nutrient concentrations.

Acidification: Besides acidic rain the application of ammonium-based fertilizers is counted to the main causes of soil acidification (Moody 2006). Already acidic soil, as the majority of local soils is assumed to be, are especially at risk. Since struvite also has an ammonium component it might have a potential for acidifying effects. However, the individual impact of different ammonium-based fertilizers varies considerably and no literature data about acidification in connection with struvite application could be found. On the contrary, Ganrot et al. (2007) mention that pots with higher struvite application showed increased pH in their trials (see Crop Performance).

Heavy metals: Due to impurities in fertilizer products or other soil amendments minor fractions of contaminants can build up in the soil. The element considered as of most concern is Cadmium (Cd) due to its possible negative effect on human health. Other heavy metals of possible significance are arsenic (As), chromium (Cr), lead (Pb), mercury (Hg), nickel (Ni) and vanadium (V). Phosphate fertilizers are a main source of such contaminants since their major source phosphate rock often contains such impurities (Mortvedt 1995). However, for struvite is was shown that the maximum specific metal concentrations are several orders of magnitude lower than in commercial fertilizer products. Additionally no heavy metals could be detected in struvite precipitated from normal stored urine (Ronteltap *et al.* 2007).

Purity and Reliability

One of the big advantages of struvite that might be recognized by the local farmers is for sure its purity and product reliability. As described in Section *3.2.2* this is something that is not holding for most of the chemical fertilizers and complains have been uttered from farmers and specialists. Whereas the industrially supplied chemical fertilizers are likely to be polluted with unwanted side products and heavy metals, even when coming from official channels, for these fertilizers coming from informal sources (>60%) even the actual nutrient concentration itself is of big question. As locally produced fertilizer, struvite would surely get more credit from farmers because its source is known and a reliable availability can be expected. This might even be factors supporting a higher price compared to other fertilizers.

Handling Comfort

In the local project setting fertilizers are almost exclusively brought out on the fields by hand. Thus the comfort in handling and dosing are things that have to be kept in mind when assessing a fertilizer product. Some farmers mentioned at a FGD that some of the conventional mineral fertilizers are causing skin problem. Especially DAP was known for such problems. In this respect struvite is certainly superior since no such problems have been reported so far. However the powdery form of struvite has been marked negatively by the local farmers as they see problems in dosing it adequately. Further they saw a chance of nutrient loss due to wind and for caking because of high air humidity. All farmers agreed that a pellet form similar to the conventional fertilizers would be highly preferred.

What can be done with the processing effluent? Struvite precipitation can only fixate a minor part of the nutrients contained in urine (N 5%, P 95%, K 0%). A major part of the nutrients remain in the effluent. Approx. 1'700 litres of effluent would need further treatment in a full size community scale processing site per week. In order to achieve a sustainable process and likely also for economic feasibility it is inevitable to develop and research optimal subsequent processing options.

5.2 Processing Effluent

Besides struvite the so called processing effluent, which can in principle be regarded as phosphorous-stripped urine, is the second major process output. The further analysis and treatment of the process is an integral part of the second Phase of STUN. Hence only some preliminary considerations shall be part of this project phase.

Quality

According to the local precipitation test the effluent can by qualified as follows: N_{tot} 2200 $mg \cdot l^{-1}$, PO_4-P 15 $mg \cdot l^{-1}$ and K 750 $mg \cdot l^{-1}$ (see Table 17). In comparison to untreated stored urine this means that approx. 95% N, 5% P and 100% K are remaining in the effluent or 5% N, 95% P and 0% K are precipitated as struvite respectively (all figures as percentage of weight). Hence the major part of the plant macro-nutrients N, P and K contained in urine and all micro-nutrients can actually not be precipitated by struvite formation.

Figure 9: Nutrient fixation by struvite precipitation
The red squares indicate the amount of nutrients that can be fixed through struvite precipitation: nitrogen 5% and phosphorous 95% (by weight). The remaining nutrients stay in the effluent.

Quantity

With regard to the quantity of processing effluent that has to be expected, the amount is not differing observably from the all over quantity of urine which is processed. In accordance with the findings made in Section 4.1 this is estimated to be approx. 90'000 $l \cdot y^{-1}$ for the present conditions and if the excessive urine of all EcoSan toilets would be included. Broken down to possible collection and processing cycles an amount of approx. 250 $l \cdot d^{-1}$ or 1750 litres per week of processing effluent would need further treatment.

Implications

Based on these considerations the following conclusions can be drawn:

- A major part of the nutrients contained in the processed urine remains in the effluent. This has at least two consequences: Firstly, it means that the processing effluent cannot be disposed off somewhere without posing a major source of pollution to the environment. The struvite precipitation process cannot be perceived as a waste water treatment and purification process. At least a further treatment process would be needed to remove the remaining nutrients. Secondly, the remaining macro- and micro-nutrients are of considerable value. In order to achieve a sustainable nutrient recycling process and likely as well for economic feasibility a further processing and utilisation of the effluent seems indispensable.

- Regarding possible effluent usage options: giving the effluent back to the farmers is unlikely to be an option. On the one hand additional transportation costs may arise and on the other hand the average farmer has no storage option available. For sure the existent urine tanks of the toilets cannot be used. The usage of the effluent as liquid fertilizer through direct application seems uninteresting too. For logical reasons it makes not a lot of sense to extract a part of the nutrients from the urine only to apply both on the field again in a later stage, nota bene by spending additional money for processing and labour. However, one advantage of the processing effluent over untreated urine is notable: Since it can be expected that no more spontaneous precipitation should occur after struvite formation the effluent could be used as a clogging-free liquid fertilizer for micro-irrigation. This would safe a considerable effort necessary for the manually spreading of the liquid. Prospects and benefits of such an approach will be subjects to further studies in Phase II of the project.

6 Management and Economics

6.1 Urine Value

Whereas for many people in the developed world it might be a new concept that urine and especially human urine does possess a value this is nothing new for the Newar people living in the Kathmandu area of Nepal. Section 2.3.1 has shown that in the local context there is a long tradition to take advantage of the nutrients urine contains. These different traditional ways of urine usage as well as the newly promoted options in connection with the establishment of EcoSan toilets bestow a value on urine according to the benefit that is generated for the people. In the following subsection this value attribution to urine by the local people is investigated through qualitative interviews. Subsequently the urine value is additionally estimated based on a nutrient component value analysis and some further considerations about urine valuation are undertaken.

What value does urine have for the local people? The impression was that most of the people do not really have a clear concept for valuating urine and thus the results obtained are erratic. Figures range from 0-20 $NRp \cdot l^{-1}$ or up to 1 kg of urea per litre with an average of 8.5 $NRp \cdot l^{-1}$. These arbitrary results and the fact that one third does not really attribute a value to urine at all lets assume that proper awareness about the nutrients contained in urine and its benefit is lacking. However, there are examples where people realize full benefit of it and generate an impressive added value.

6.1.1 Value Attribution by Locals

In the context of this study the value attributed to urine is interesting in two ways. Firstly the value is important simply because it is central to know the costs that might arise for the sourcing of this primary process input in the case of a more commercially oriented production scheme. Obviously from this perspective a low attributed value would entail a better chance for profitability of the production process. However, a high value attributed to urine has also positive effects. On the one hand such a high value attribution largely increases the collection efficiency and on the other hand it would mean that secondary urine products like struvite might also profit from a higher valuation.

Methodology

In order to assess the value that the local people in the community attribute to collected source separated urine different informal talks with EcoSan toilet owners have been conducted in the field. Additionally a question block about urine value has been incorporated into the household questionnaire and the topic has also been discussed in a FGD.

Results

The assessment of the locally attributed value of urine collected with EcoSan toilets has shown to be nontrivial. The answers that were given in the informal talks with EcoSan toilet owners in the field were differing extremely and not any common perception could be detected. Whereas for some people urine did not have any value at all and it was stated that they just drained it somewhere, others had a distinctive knowledge about its benefits as a fertilizer and used it to produce high quality vegetables. For the first group of people with the 'no value' attribution a number of households have been found where urine is more or less just spoilt. As an extreme example of the 'high value' group especially one farmer met in Siddhipur shall be mentioned here. He is using all the organic manure from its farm including, of course, the human faeces and urine to grow organic vegetables which he is known for far beyond the realm of his community. When asked for the value he attributes to human urine he is not hesitant and reassures his willingness to pay up to 2'000 NRp or 30 CHF for 100 litres of urine even though the researchers hesitate to believe in his words. Not seldom people compared the 100 litres to an amount of urea and common amounts were somewhere in the area of 1-2 bags (à 50 kg). This would mean that 1 litre of urine would almost be equivalent to 1 kg of urea or have a value of up to 25 NRp, an amount hard to believe in especially when considering that some of these people also stated to sometimes drain some of their urine.

This division between 'no value' and 'high value' could also be detected in the household questionnaire data. 18 out of 27 or approx 65% of the people stated that the collected urine does have a value for them. One third on the other hand does not attribute a value to it. 11 out of the 18 people who said that urine has a value for them were also able to state a price. The values obtained vary extremely. The mean value attributed to 100 litres of urine was found to be approx. 850 NRp or a little bit over 12 CHF. The minimum value stated was 350 NRp and the maximum value 2000 NRp (CV 52%). However, during the data acquisition the impression was there that the figures stated were only given with hesitations and that the people could mostly not rely on a readily available conception from their experience.

Due to the erratic answers obtained during the informal talks and the household survey the question of urine valuation was also discussed in a FGD with five EcoSan toilet owners and the head of the EcoSan sub committee. As well 100 litres were taken as reference amount since this is the size of the majority of urine tanks installed at the toilets. Instead of asking for a monetary value however the equivalent in the most frequently used fertilizer (urea) was of interest. Again the discussion started with a rather high value of 25 kg which would mean that 1 litre of urine was equivalent to 250 g or urea. After some further considerations the group settled finally on 10 kg. This would mean that 100 litres of urine would have a value of approx. 200-250 NRp (3-4 CHF).

Discussion

Based on the received data to the following conclusions are possible:

- The strongly differing values attributed to urine suggest that there is not a clear conception of the value of urine established among the members of the community. A significant number of the interviewed persons did not give an answer at all and also many of the persons who did showed hesitations. Some answers also are doubtful since 25 $NRp \cdot l^{-1}$ is a remarkable amount in the local context and no one would just spoil something as valuable even if usage options were missing.
- The fact that one third of the EcoSan owners interviewed stated that they do not attribute a value to urine is remarkable. On the one hand this is a clear sign that feasible and beneficial usage options are lacking. On the other hand it also puts up the question whether an appropriate awareness building programme at the time of the EcoSan toilet introduction has been conducted.
- The examples of people like the farmer mentioned might be extreme cases but they show that if appropriate knowledge about urine application is present a big added value can be achieved with it. This not only might justify even such high expenses but clearly shows that urine has a value.

What value do the single plant nutrients have? Based on the prices of other fertilizer products the following prices are paid in the local community: nitrogen 58 $NRp \cdot kg^{-1}$, phosphorous 188 $NRp \cdot kg^{-1}$ and potassium 53 $NRp \cdot kg^{-1}$.

6.1.2 Nutrient Value Analysis

In contrast to the considerations done in the preceding section another more technical approach to assess the local value of urine is based on the value of its individual nutrient components. Since urine is mainly used as a fertilizer and a fertilizer is primarily assessed by and valued for its nutrient content the same can be done with urine. To achieve this, the value of the individual nutrient components has to be estimated.

Methodology

As a basis for assessing the individual nutrient's values the prices of other locally available fertilizers can serve. By correlating the fertilizer prices with their nutrient content the value of the single components can be estimated. In order to achieve this, a relatively simple linear regression model of the form (1) has been fitted to the established market prices. Finally, based on these nutrient values and the nutrient concentrations of the collected urine the fertilizer value of urine can be evaluated.

$$Price = \alpha_1 * [N] + \alpha_2 * [P_2O_5] + \alpha_3 * [K_2O] + \alpha_4 * [Mg] + \alpha_5 * [S] + \alpha_6 * [Ca] + \varepsilon \qquad (1)$$

Results

The results of this analysis, which can be found in Annex C.2, are displayed in Table 35. From the standard nutrient components N, P and K phosphate is with an estimated value of 82 $NRp \cdot kg^{-1}$ the most valuable one followed by nitrogen with 58 $NRp \cdot kg^{-1}$ and potassium oxide with 44 $NRp \cdot kg^{-1}$. The corresponding elemental values for nitrogen, phosphorous and potassium are 58, 188 and 53 $NRp \cdot kg^{-1}$.

Table 35 Predicted fertilizer nutrient values

Nutrient component	Predicted value [$NRp \cdot kg^{-1}$]
Nitrogen [N]	58
Phosphate [P_2O_5]	82
Potash [K_2O]	44
Magnesium [Mg]	167
Sulphur [S]	65
Calcium [Ca]	10

Discussion

Even though the model used for the analysis is very simple and does not take any further fertilizer properties or the advantage of combined nutrient products into consideration it is able to predict the prices of the different fertilizer products well (coefficient of determination $R^2 = 0.99$). It can be assumed therefore that the calculated values for the single nutrient contents are useable for further considerations. These values correspond well with the intuitive value attributed to the individual nutrients. The only price which seems to be out of order is the one of magnesium. It has to be considered however that this price is based on the prices that have been established for the magnesium sources and not on actual fertilizer prices since no magnesium products are locally available. It can be assumed that, if demand was there and magnesium fertilizers were locally available, the price would be considerably lower.

What value can be ascribed to the nutrients contained in urine? Based on current fertilizer prizes at the time of research and the qualitative analysis of urine samples it is estimated that urine collected with an EcoSan toilet has a nutrient value of approx. 250 NRp·m^{-3}.

6.1.3 Nutrient Component Value

The values obtained in the precedent section can be used to estimate the value of collected source separated urine from EcoSan toilets. The nutrient concentrations of urine found in Section 4.1.1 can serve as a basis.

The results of the calculations are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.** (for the calculations refer to Annex C.3).

Table 36 Estimated nutrient value of stored urine

Product	Value [NRp·m^{-3}]
Stored Urine (including precipitates)	314
Stored Urine (excluding precipitates)	246

This nutrient component analysis which is based on the nutrient value of other fertilizers suggests that 1000 litres of store urine have a value of roughly 300 NRp (including naturally occurring precipitates) and approx. 250 NRp not including precipitates. This is not an overwhelmingly big amount if compared to the price of clean but non-dinking freshwater on the market which is delivered to someone's home for about 100-120 NRp per 1000 litres. But it is still good value.

However, this comparison is not quite correct since the above made estimation only assesses the nutrient value of urine's major compounds N, P and K. For example, what is missing in the estimated value is actually and foremost the value of the water itself contained in urine. This and other factors having an influence on the actual value of urine are listed in Table 37

Table 37 Factors not incorporated into calculation of value

Factor	Description	Effect on Value
Water	The water urine mainly consists off can have both a negative as well as a positive effect on the value. Primarily it is assumed that it has a negative effect on the value of urine however. The nutrient component prices estimated are for dry and thus concentrated powder. This has manifold advantages in comfort (storage, transportation, application) compared to a liquid non-concentrated form. In cases of water shortage however it can also have a positive effect since it is additional source of water for plants. In the case of Nepal the winter month receive very low precipitation and this might be an important factor.	**- /(+)**
Other nutrients (micro-nutrients)	Besides the three macro-nutrients N, P and K it can be assumed that urine has a well balanced amount of other nutrients as well (as most organic waste based fertilizers have). At the moment application of micro-nutrients is not an issue in Nepal. However, for long-term soil fertility management it is a crucial factor.	**+**
Micropollutants	Depending on the nutrient and drug uptake it is possible that urine shows traces of micropollutants which are unwanted and might cause negative effects on crops and human health.	**-**

As the considerations listed in Table 37 show, it has to be considered when assessing the received values that these are theoretical estimations which do not take into account other properties of urine except its major compounds' value. The obtained figures can serve as a good indication but it is likely that the mentioned factors and eventually others can significantly alter its real value. Compared to the avg. value attribution by local people (approx. 8'500 NRp·m^{-3}) the estimated nutrient value is more than 30 times smaller.

What local value would struvite likely have? The local market value of struvite can be assumed to be somewhere around 30 NRp·kg^{-1} and a little bit more if local farmers are willing to pay for its magnesium content too. However, this value is a first approximation and struvite's real value can only be assessed through its application over time.

6.2 Estimated Struvite Value

Based on the nutrient content of struvite (see Table 34) it is possible to estimate the approximate market price of struvite by using the same technique as for the urine value. The calculations for struvite can be found in Annex C.2 and the results in Table 38.

Table 38 Estimated market price for struvite

Product	Unit	Value [NRp·kg^{-1}]	Value [CHF·kg^{-1}]
Struvite	[kg]	27 (1) 43 (2)	0.40 (1) 0.65 (2)

(1) if magnesium is not attributed any value
(2) if magnesium is attributed a value as well

The estimated market price of struvite is around 43 NRp·kg^{-1} if a value is also attributed to the magnesium it is containing. In the case only the value of N and P are considered a plausible market price of 27 NRp·kg^{-1} is likely. To compare the obtained results with other available fertilizer prices refer to Annex C.1. In their paper Ueno and Fujii (2001) write that in Japan struvite was sold at the wastewater treatment plant for a price of approx. 245 €·ton^{-1}. This would be about 25 NRp·kg^{-1}. However, it has to be assumed that the fertilizer prices in Japan and Nepal cannot really be compared.

The distinction in the price with magnesium and without magnesium seems justifiable because so far there has been no demand for any magnesium fertilizer in Nepal and it is therefore not likely that the farmers would be willing to pay for it. Further it is believed by some people that the high magnesium content might have no beneficial influence on the crop production but might be in some cases even detrimental. As it could not be resolved to which degree this is true and whether the magnesium would be favourable or neutral in the context of Nepal this distinction of prices is henceforth used. Supported by the opinion of an expert from the governmental Soil Management Division of MAOC it should be possible however to rule out that magnesium has a negative influence on soil or crops. In reality is has to be assumed that the real price or value of struvite might be somewhere between 27-43 NRp·kg^{-1}. The estimated amount of 43 NRp·kg^{-1} is likely too high since the real price of magnesium would most likely be lower as assumed as soon as there is a demand for such fertilizers in Nepal. On the other hand if this is the case then farmers would be willing to pay as well for the magnesium contained in struvite. Thus the price would be higher than 27 NRp·kg^{-1}.

Another important factor on the price of struvite should not be forgotten: as it is produced locally and because the nutrient content can be guaranteed through the chemical process it might have a noteworthy advantage over the imported fertilizers. It can be assumed that the farmers might be willing to pay a mark-up for its more reliable and trustworthy origin.

Urine and Struvite Economics

In the preceding chapters reference values have been established for different parameters. Based on these values it is possible to compile some urine and struvite economics. The established reference values are compiled in Table 39 in conjunction with economic estimations.

Table 39 Estimated urine economics

Product	Unit	quantity	Value incl. VAT[4] [NRp]	Value [CHF][5]
Collected urine (incl. precipitates)	[m^3]	1	314	4.71
Collected urine (excl. precipitates)	[m^3]	1	246	3.69
Struvite	[kg]	1	43 [1)] 27 [2)]	0.65 [1)] 0.41 [2)]
Struvite per m^3 urine	[$kg \cdot m^{-3}$]	1.9	81 [1)] 50 [2)]	1.21 [1)] 0.75 [2)]
Magnesium sulphate needed for struvite precipitation	[$kg \cdot m^{-3}$]	2.2 [3)]	52	0.78
Value of processing effluent	[m^3]	1	195	2.93

[1)] struvite value when the magnesium is attributed a value as well; [2)] struvite value when the magnesium is not attributed any value; [3)] calculated for a molar ration Mg:P = 1.1:1 and a process efficiency of 90%; [4)] VAT 13%; [5)] exchange rate applied 100 NRP = 1.50 CHF

The following conclusions can be made:

- The calculations done show that, as already described earlier in the text, urine has definitely a notable value. Considered that in the local context it is worth transporting water over larger distance, which is having less than half the value of urine, this shows that at this price level there is a market potential.
- Struvite precipitation alone only allows to fix 20% of the total value of urine when not attributing a value to magnesium or 33% respectively including magnesium value.
- At the present market conditions the input costs of the struvite production (magnesium) are exactly as high as the value of the produced struvite if the magnesium is of no value. This mainly says that unless magnesium is of value to the farmers and they are willing to pay a price for it, the production of struvite without any further use of the effluent is – assumed that the made assumptions are correct – economically far away from being profitable as no costs have been included yet for labour (urine transportation and processing) and reactor set-up costs.
- The value of the processing effluent is approx 80% of the initial value of the unprocessed urine. This suggests that under the present conditions and with the made assumptions the production of struvite alone without any further use of the effluent is not justifiable. It is imperative that the effluent is further treated and some or all of its value recovered.

How much struvite could be produced in Siddhipur? What value would it have? It is estimated that roughly 170 kg of struvite could be produced per year under the present conditions. This struvite would have an approx. value of 5’000-7’000 NRp or 75-100 CHF.

6.3 Community Scale Struvite Production in Siddhipur

Based on the established parameters and reference values a vague picture of a possible struvite production at community scale in Siddhipur can be drawn. In order to run a full size community scale struvite production approx. 90’000 litres of urine per year or 1’700 litres per week would be available. This would result in a total struvite output of approx. 170 kg per year. Roughly 200 kg of magnesium sulphate are needed as process input. Further a weekly amount of 1’700 litres of effluent would need additional treatment or disposal (see Table 40).

Table 40 Community Scale Struvite Production

Product	Quantity $[l \cdot y^{-1}]$ / $[kg \cdot y^{-1}]$	Quantity $[l \cdot week^{-1}]$ / $[kg \cdot week^{-1}]$
Urine collected with EcoSan toilets	150’000	2’900
Estimated urine available for struvite production	90’000	1’700
Magnesium sulphate requirements	198 [1)]	3.8 [1)]
Struvite	171	3.3
Processing effluent	90’000	1’700

[1)] calculated for a Mg:P ratio of 1.1:1 and a process efficiency of 90%

In financial terms the total value of all collected urine for Siddhipur is ca. 47’000 $NRp \cdot y^{-1}$. The total struvite value can be estimated to 5’000-7’000 $NRp \cdot y^{-1}$ (see Table 41)

Table 41 Estimated annual struvite economics for Siddhipur

Product	Unit	quantity	Value [NRp]	Value [CHF]
Urine collected in Siddhipur (incl. precipitates)	$[l \cdot y^{-1}]$	150’000	47’000	705
Urine collected in Siddhipur (excl. precipitates)	$[l \cdot y^{-1}]$	150’000	37’000	550
Share of urine available for struvite production	[%]	60%	-	-
Urine available for struvite production	$[l \cdot y^{-1}]$	90’000	22’200	330
Struvite recovered from available urine	$[kg \cdot y^{-1}]$	171	7’400 [1)] 4’600 [2)]	110 [1)] 70 [2)]
Processing effluent	$[l \cdot y^{-1}]$	90’000	17’600	260

[1)] struvite value when the magnesium is attributed a value as well; [2)] struvite value when the magnesium is not attributed any value

6.4 Management Approaches for Struvite Production

As we visit and discussion with Siddhipur people different management model can be implementing. Most feasible model should be community management model. In this model there is one central collection system people bring to collect at one point and for sustainability it needs to make user committee which is totally responsibility for struvite production project as well as operation and maintenance. Other option is economical model which is handling by single person or company. In this model someone collect urine from every household with giving some money or may be return some struvite after is production. Once they produce struvite they sell to the market or local farmers who are completely profit oriented and project work must be responsible himself.

As we already discussion with focus group meeting it can also possible to make same organization for struvite making committee this committee will help how to collect stored urine from EcoSan house hold and for producing struvite and after production of struvite and for operation and maintenance. At the moment Siddhipur water supply and sanitation user committee (WSSUC) which is the one of the major user committee in Siddhipur which controls, handling and responsibility of whole Siddhipur drinking water supply, environmental sanitation and solid waste management work. If you look different activity in Siddhipur it is clear, when we going to make large amount of struvite community management model is one of the appropriate model in Siddhipur. Once it is run very well after few years when people aware fully and to know the important of struvite and than commercial model can also possible.

6.4.1 Supportive Institutions and Structures

When we visit in Siddhipur in different time and discussion with different people there have already built different institution for better management of water supply, solid waste management and sanitation work. Especially there have different institution working as like following way (*Figure 10*).

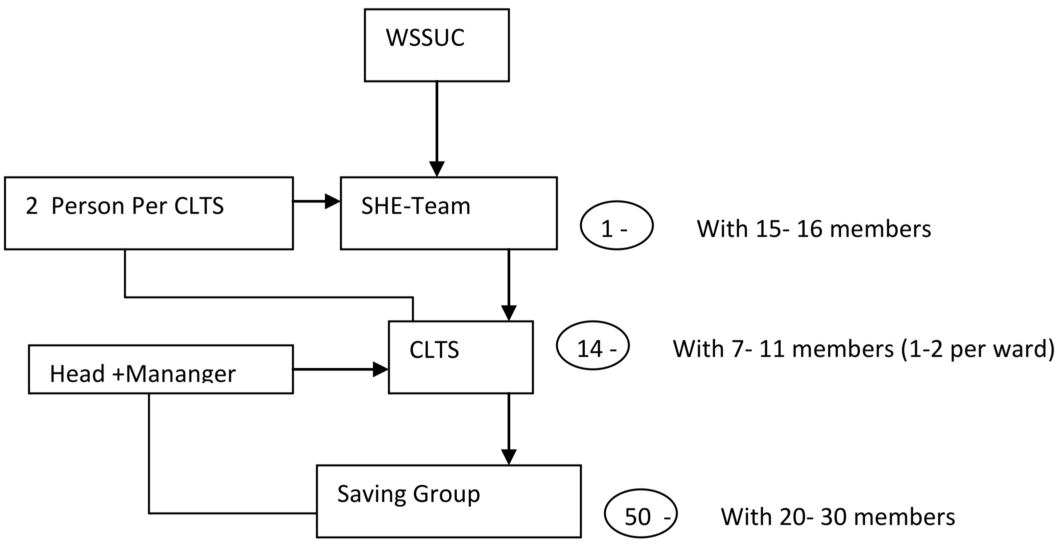


Figure 10: Institutional Arrangement of Siddhipur user Committee

When you discussion with focus group meeting it can also possible to make same organization for struvite making committee this committee will help how to collect stored urine from EcoSan house hold and for producing struvite and after production of struvite and for operation and maintenance. At the moment Siddhipur water supply and sanitation user committee (WSSUC) which is the one of the major user committee in Siddhipur which controls, handling and responsibility of whole Siddhipur drinking water supply, environmental sanitation and solid waste management work. Under this there has SHE Team in which including 15-16 active women group they are supporting different environment and sanitation work in Siddhipur and under SHE- Team CLTS in which including 7-11 member from each ward 1-2 member or every saving group one Head and one Manager should come to the CLTS (community lead total sanitation) .They are working about different sanitation improving programme and solid waste programme and also plastic collection programme with the taking help from women saving group. In Siddhipur they have all together 50 number of this type of saving group in which including 20- 30 women member they are mainly working for micro financing and also they support to the CLTS in different solid waste collection work and sanitation improvement in Siddhipur area.

According to discussion with user committee people for struvite project they will support like same above organization. But need to discussion about detail when we are going to start pilot struvite project. Any way they will be very positive to support struvite making project.

7 Conclusions

Siddhipur V.D.C was a good choice for the investigation of the given project targets. The community showed to be very supportive and enthusiastic about the project and interest in struvite production is high. Good links with a large number of stakeholders have been established and a big support from various sides could be felt. According to the figures received a considerable amount of urine is collected by the 100 EcoSan toilets in the community. In average it is estimated that 350 litres are collected with an EcoSan toilet per adult household member. However, it was found that the present usage options available to the people are suboptimal and a substantial amount of the collected urine is used in ways which do not allow the realization of its full benefit. It is hypothesized therefore that the introduction of additional usage options for source separated urine can provide more alternatives to the people and thus increase the benefit that can be realized from the EcoSan toilets and the urine that is collected by them.

The main research question of the project was to assess whether struvite production at a community scale is possible and socially and economically feasible in the context of a peri-urban settlement in Nepal. The research undertaken shows that the production of struvite within the given context is possible. Magnesium sources are scarce but feasible to obtain. Since there is no demand within the country for magnesium products the sourcing is difficult however and the input costs are comparably high. The analysis of urine collected by EcoSan toilets shows that the nutrient concentrations are low but within a reasonable range. Social acceptance of struvite was found to be good as there is a long tradition of human waste recycling within the local Newar communities. However, concerns have been raised that the application of struvite might be objectionable for other, higher casts like Brahmins and Chetris. The present availability of industrially produced mineral fertilizer is surprisingly high. By far the most popular product is urea, a straight nitrogen fertilizer. Compound fertilizers and especially diammonium phosphate (DAP) are used rarely because of their prohibitive price level. Organic fertilizers are scarce as only a few household within the community have cattle. Thus composting and EcoSan toilets, for those who have access to one, are the only sources. Due to the low application of organic fertilizers and the high popularity of urea an insufficient supply of phosphorous and potassium is assumed. Since struvite is a compound fertilizer having 6% nitrogen and 29% phosphate it might provide a welcome additional source of phosphorous for the local farmers.

The economic feasibility assessment of a community scale struvite production produced unequal results. Based on the present fertilizer prices the nutrient value of urine can be estimated to approx. 250 $NRp \cdot m^{-3}$. However, only 20% of this value can be retained by struvite precipitation whereas 80% remain in the processing effluent. As Siddhipur is a community of a very rural character and all of the households having an EcoSan toilet are still engaged in agriculture this raises concerns whether struvite precipitation is an appropriate approach for the processing of the collected urine. About half of the farmers interviewed stated to prefer direct urine application over struvite precipitation whereas the other half favoured struvite precipitation due to the gained comfort in storage, transportation and handling. Undebatable however is the fact that the processing effluent, which is in principle phosphorous-stripped urine, is of major concern. As the main share of the nutrients cannot be precipitated in the form of struvite the further usage / treatment of the processing effluent is of utmost importance. It is unlikely that struvite precipitation from source separated urine is becoming ecologically and economically desirable in a rural setting unless a beneficial usage can be found for the effluent. The application as a clogging-free liquid fertilizer for micro-irrigation, as it is studied in Part II of the STUN project, might be such an option. The present magnesium input costs for struvite are approx. 27 $NRp \cdot kg^{-1}$ of struvite. The market value of struvite on the other hand is estimated to ca 30-35 $NRp \cdot kg^{-1}$ depending on the valuation of magnesium by the local farmers. As the magnesium cost are almost of the same order as the market value of struvite and the labour and processing costs for the production (urine collection, reactor set-up, processing, eventual price of urine) are not yet included it has to be assumed that the production of struvite is unlikely to become economically feasible under the present market conditions and within the researched scale and scope. Besides the mere economics the scale of the production also poses questions. According to the most likely estimations a full scale community based struvite production within Siddhipur would presently generate approx. 170 kg of struvite per year. This is the fertilizer demand of 2 average households. Even if Siddhipur became an "EcoSan village" with UDDTs installed in 100% of all households (approx 1200) the fertilizer demand of only approx. 20-30 households could be covered.

However, the interest and enthusiasm of the people of Siddhipur should not be left unconsidered. The potential to locally produce one's own fertilizer of guaranteed quality and to be part of an innovative and future oriented nutrient recycling programme might outmatch possible economic imponderabilities. Further the possibility is given that with bittern or locally quarried magnesite cheaper magnesium sources can be tapped in the future. Indubitable is that the price for phosphorous will steadily climb as the cheap sources of this for modern agriculture indispensible resource are going to be depleted.

Acknowledgments

We would like thank our project initiators and supervisors Elizabeth Tilley and Kai Udert for giving us the possibility and the confidence to work on this research project. We could always count on their counseling and support.

A big thank you goes to our partner organization UN-HABITAT Nepal and all their staff for accommodating us in their office and supporting us whenever possible. Special thanks deserve Dr. Roshan Raj Shrestha, Anjali Sherpa Manandhar and Mingma Sherpa for sharing their valuable insight and advice with us. Rajana Maharjan was a big support in the field and helped us bridging the language gap to the local community.

We also thank all the local organizations, ENPHO, CIUD, D-NET, Lumanti, SMD, SSMP and their staff for openly sharing their knowledge with us and helped us in doing our research.

Last but not least we say dhanyabad to all the inhabitants of Siddhipur and especially Mr. Krishna Maharjan and Bal Ram Maharjan for accepting us in their community, answering hundreds of curious questions and rendering our research possible.

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Annex

A Qualitative and Quantitative Urine Analysis

A.1 Comparison of Urine Values

Type of Urine			Fresh urine		Stored urine					Collected with EcoSan (stored urine)		
Source			Udert et al. (2006)	Development Network (2003)	Udert et al. (2006)	Vinnerås et al. (2004)	Jönsson et al. (2005)	Jönsson and Vinnerås (2003)	Jönsson and Vinnerås (2003)	Ek et al. (2006)	Manandhar(2004)	Shrestha(2005)
Country, Place			N.N.	Nepal, Siddhipur	N.N.	Sweden	Sweden	India	China	N.N.	Nepal, Khokana	Nepal
Remarks			compilation of different sources	5 samples	simulated values, closed system	compilation of different sources	compilation of different sources	analytically calculated	analytically calculated		4 samples	2 samples
Dilution			no	no	no	(no)	(no)	(no)	(no)	yes	(yes)	(yes)
Nitrogen loss			no	no	no	yes	(yes)	(yes)	(yes)	yes	yes	yes
Urine		$[l \cdot pe^{-1} y^{-1}]$	455		455	550	550					
pH			6.2	6.0	9.1					9.1	8.9	9.05
Nitrogen	N_{total}	$[mg \cdot l^{-1}]$	9200	8740	9200	7000	7300	4600^	7000^	3600	9000	4800
Phosphorus	P	$[mg \cdot l^{-1}]$	740	300	540	640	600	600^	800^	310	200	150
Potassium	K	$[mg \cdot l^{-1}]$	2200	1150	2200	1750	1590	2200^	2600^	900	800	700
Magnesium	Mg	$[mg \cdot l^{-1}]$	100		0							
Sulfate	SO_4	$[mg \cdot l^{-1}]$	1500		1500		460			300		
Calcium	Ca	$[mg \cdot l^{-1}]$	190		0							
N:P:K ration	N		100	100	100	100	100	100	100	100	100	100
	P		8	3	6	9	8	13	11	9	2	3
	K		24	13	24	25	22	48	37	25	9	15
time at home		% of day				60%	63%					

all nutrient values rounded to 10mg; () assumptions; ^ calculated for an assumed annual excrition of 500l urine

Own Sampling Data

Type of Urine			Fresh undiluted Urine	Stored diluted Urine
Dilution			no	(yes)
Nitrogen loss			no	yes
Water content			0	?
pH			5.63	8.6
Nitrogen	N_{total}	$[mg \cdot l^{-1}]$	6030	2352
Phosphorus	PO_4- P	$[mg \cdot l^{-1}]$	388	252
Potassium	K	$[mg \cdot l^{-1}]$	1869	802
Magnesium	Mg	$[mg \cdot l^{-1}]$	45	
Sulfate	SO_4	$[mg \cdot l^{-1}]$	878	
Calcium	Ca	$[mg \cdot l^{-1}]$	89	
N:P:K ration	N		100	100
	P		6	11
	K		31	34

Established Reference Values

Type of Urine			Fresh undiluted Urine	Stored diluted Urine
Dilution			no	yes
Nitrogen loss			no	yes
Water content			0	15%
pH			5.6	8.6
Nitrogen	N_{total}	$[mg \cdot l^{-1}]$	6000	2400
Phosphorus	PO_4-P	$[mg \cdot l^{-1}]$	400	250
Potassium	K	$[mg \cdot l^{-1}]$	1900	800
Magnesium	Mg	$[mg \cdot l^{-1}]$	45	0
Sulfate	SO_4	$[mg \cdot l^{-1}]$	875	875
Calcium	Ca	$[mg \cdot l^{-1}]$	90	0
N:P:K ration	N		100	100
	P		7	10
	K		32	33

A.2 Urine Sampling Siddhipur (Stored Urine)

Samples taken in Siddhipur on 26.06.2008

Random sampling with coin flip in front of house

sample #	Household #	Sampling	Sample taken	Remarks
1	11-101			
2	21-21	Yes	Mix 1	Urine drain of right toilet congested
3	11-111			
4	6-97			
5	6-100			
6	6-111	Yes	Mix 2	
7	6-110			
8	6-121			
9	1-02	Yes	-	Urine tank empty
10	16-32	Yes	-	Urine tank empty
11	16-31	Yes	Individual 1	
12	16-30	Yes	-	Access to urine container not possible (paddy field)
13	16-25			
14	14-23	Yes	-	tap broken (urine tank empty)
15	16-06			
16	16-15			
17	16-13	Yes	Mix 3	
18	16-14	Yes	Mix 4	
19	16-115	Yes	Individual 2	
20	16-116			
21	16-117			
22	18-28	Yes	Mix 5	
23	18-22			
24	18-01	Yes	Mix 6	
25	17-26	Yes	Individual 3	D-Net toilet (different model)
26	19-07	Yes	Mix 7	
27	18-12	Yes		Urine tank empty, urine is flowing directly into compost
28	12-21			
29	11-129			
30	11-137			
31	11-20	Yes	Mix 8	
32	11-21			
33	2-19			
34	6-222	Yes	Individual 4	Family with 11 members, 100l container full every week
35	6-130			
36	7-19			
37	11-37	Yes	Mix 9	
38	11-38	Yes	-	tap broken (urine tank empty)
39	11-63	Yes	Mix 10	Urine drain of right toilet congested

Total number of heads when flipping coin:	20
Toilets encountered with no urine collection:	4

20 % of toilets examined were not fit to collect urine. However, most of them could likely be fixed again without much effort.

A.3 Laboratory Report Stored Urine Analysis

Govt. Reg. 108/047/048
SWC Reg. 283/047/048

ENPHO
ENVIRONMENT AND PUBLIC HEALTH ORGANIZATION

ENPHO Research Laboratory
P.O.Box: 4102, New Baneshwor, Kathmandu, Nepal
Tel: 977-1-4468641, 4493188, Fax: 977-1-4491376 E-mail: enpho@mail.com.np

Nepal Laboratory Accreditation Scheme
Accredited Laboratory
Accreditation No. Pra. 05/057-58

URINE ANALYSIS REPORT

Lab Reg. No. 2634 - 2639/(064-065) Code : US

Client : Eawag Aquatic Research
Address : Sidhipur, Lalitpur
Sampled By : Client

Source of Sample : Urine
Location/Area : Sidhipur, Lalitpur
Received on : 27th June 2008
Date of Analysis : 27 June - 5th July 2008

PHYSICO-CHEMICAL ANALYSIS

S. No.	Sample ID	Parameters			Test Method
		Total Nitrogen (mg/L)	Phosphorus (mg/L)	Potassium (K) (mg/L)	
1	LR - 2634: 1	-	374	-	**Total Nitrogen : Kjeldah dijestion & Titration**
2	LR - 2635: 2	-	264	-	
3	LR - 2636: 3	-	123	-	**Phosphorrus: Ammonium molybdate**
4	LR - 2637: 4	-	182	-	**(Spectrophotometric)**
5	LR - 2638: 5	2352	259	802	
6	LR - 2639: 6	2240	16.47	744	**Potassium:** Atomic Absorption Spectrometer (AAS)
					(Flame Emission)

ANALYSED BY

CHECKED BY

for AUTHORIZED SIGNATURE

Note: (1) The results refer only to the parameters tested of the samples provided/collected for analysis. Endorsement of products is neither inferred nor implied.
(2) Total liability of our organization is limited to the invoiced amount only.
(3) The reproduction of this report wholly or partly cannot be used as an evidence in the court of Law and should not be used in any advertising media without prior written permission from us.

A.4 Stored Urine Analysis

Random Sampling taken in Siddhipur on 26.06.2008, not filtered

Measurements taken at 26°C

	pH [-]	EC [mS/cm]	EC_{25} [mS/cm]	PO_4-P [mg/L]	N_{Total} [mg/L]	K [mg/L]
Individual Samples						
Sample 1	8.83	62.6	61.4	374	-	-
Sample 2	8.57	40.1	39.3	264	-	-
Sample 3	8.00	24.0	23.5	123	-	-
Sample 4	8.48	31.1	30.5	182	-	-
Average Ø	**8.47**	**39.5**	**38.7**	**236**	-	-
CV%	4%	43%	43%	46%	-	-
Median	8.53	35.6	34.9	223	-	-
Mixed Sample*						
Mix Untreatead Urine	**8.67**	**38.2**	37.5	**259**	**2352**	**802**
Mix Struvite Effluent	8.59	38.5	37.7	16.47	2240	744
Total average Ø (14 smpls)	**8.61**	**38.56**	**37.80**	**252**	-	-

* mixture of 10 samples taken from individual containers

NPK-ration of mixed sample: 2352 : 259 : 802 ↔ 100 : 11 : 34

Struvite production:

Assumed P concenration = 200 gP*m^{-3} Mg : P ration of 1.4 : 1.0

Actual P concentration = 259 P*m^{-3} Mg : P ratio 1.08 : 1.0

Stiring for 20min

		measured	theoretically
P difference urine effluent	[mg]	242.5	N.A.
Struvite	[gL^{-1}]	1.94*	1.922
N difference	[mg]	112.0	109.7

* urine was not filtered before addition of magnesium

Efficiency of Phosphorus fixation 93.6%

Loss of N in struvite production process 2.3 mg ≈ 2.1 %

A.5 Fresh Urine Analysis

Samples collected 21 November 2008, filtered 0.7mm and 0.45mm, analyzed on 24 November at Eawag laboratories, Switzerland

Lab number	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 [mg/l]	COD Dr. Lange [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. EC_{corr} Cond electr. [°C]	EC_{25} Cond electr. [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	8	30	1	30
Median	418	4422	5961	383	6406	822	8	6340	37	74	1939	3275	5.46	22.0	20.7	23.7

A.6 Theoretical Quantification of Storage Processes and Dilution

Theoretical Urine Transformation Process

		Fresh Urine (undiluted)		Assumed Precipitation Processes		Stored Urine[3] (undiluted)		Stored Urine (diluted)
				Struvite[1]	Hydroxyapatite[2]			
		[$mg \cdot l^{-1}$]	[$mmol \cdot l^{-1}$]	[$mmol \cdot l^{-1}$]	[$mmol \cdot l^{-1}$]	[$mmol \cdot l^{-1}$]	[$mg \cdot l^{-1}$]	[$mg \cdot l^{-1}$]
Nitrogen	N_{total}	6030	430.71	-1.85		428.86	6004	2352
Phosphorus	PO_4-P	388	12.56	-1.85	-1.33	9.37	290	252
Potassium	K	1869	47.80			47.80	1869	802
Magnesium	Mg	45	1.85	-1.85		0	0	-
Calcium	Ca	89	2.22		-2.22	0	0	-

1) $MgNH_4PO_4 \cdot 6\ H_2O$

2) $Ca_5(PO_4)_3(OH)$

3) theoretical calculation

Estimation of Storage Precipitation

	[$mmol \cdot l^{-1}$]	[$mg \cdot l^{-1}$]
Struvite	1.85	454
Hydroxyapatite	2.22	1115

Estimation of Dilution and Nitrogen Loss

Based on ratio of nutrient values for	Stored undi-luted urine	Stored diluted urine	Corresponding urine content	Corresponding estimated loss of N through evaporation		Corresponding difference / error to actual value	
						K	P
	[$mg \cdot l^{-1}$]	[$mg \cdot l^{-1}$]	[%]	[$mg \cdot l^{-1}$]	% of Total	[$mg \cdot l^{-1}$]	[$mg \cdot l^{-1}$]
Phosphorous (P)	290	252	87%	-2872.38	48%	+824	-
Potassium (K)	1869	802	43%	-224.39	4%	-	-128

A.7 Short Individual Questionnaire for FGDs Siddhipur

Name of person interviewed (): ....

0.1 How many members does your household consist of? ....

0.2 Who is normally emptying the urine container when it is necessary?

- ❑ Interviewed Person (0)
- ❑ Other member of the household (1)
- ❑ Someone else (2)

0.3 How big is the urine storage container of your EcoSan toilet (liters)?

- 4 ❑ 100 liter plastic tank
- 3 ❑ 50 liter plastic tank
- 2 ❑ Built in brick container
- 1 ❑ Other, namely: ....

0.4 How often do you in average empty the urine container of your EcoSan toilet?

- ❑ Every ……………. Week(s) (0)
- ❑ Every ……………. Moth(s) (1)

0.5 To what level is the container normally filled, when you empty it?

- 4 ❑ Up to the top (1/1)
- 3 ❑ About 3/4
- 2 ❑ About 1/2
- 1 ❑ About 1/4

Remarks (usage of urine):

....
....
....
....
....
....
....
....

A.8 Data Analysis «Short Individual Questionnaire for FGDs Siddhipur»

Data from "Short Individual Questionnaire Survey" with Participants of Focus Group Discussions in Siddhipur 25./26.06.2008

Questionnaire Data								Urine collection	
Questionnaire Number	FGD	Name	# of people in household	Resp. for emptying urine container	Size of urine storage container (litres)	Average emptying every ... weeks	Average level of urine when emptying	Urine collected per year [l]	Urine collected per person and year [l]
1	1	Khadga Bahadur Maharjan	6	0	15	0.43	0.75	1360	227
2	1	Parbati Maharjan	11	0	100	1.00	0.75	3900	355
3	1	Chameli Maharjan	5	0	100	4.00	0.75	975	195
4	1	Jeetendra Maharjan	4	1	100	8.00	0.75	488	122
5	1	Balaram Maharjan	4	1	100	2.00	0.75	1950	488
6	1	Manju Maharjan	6	0	100	4.00			
7	1	Chameli Maharjan (2)	4	0	100	6.00			
8	1	Manmaya Maharjan	5	1	100				
9	1	Punmaya Maharjan	4	0	100	6.00	1	867	217
10	1	Buddhi Govind Maharjan	6	0	40	6.00	1	347	58
11	1	Samjhana Maharjan	5	1	100				
12	1	Maiya Maharjan	7	1	100	6.00	1	867	124
13	2	Ruku Maharjan	3	0	100	6.00			
14	2	Jeevan Maharjan	6	0	100	6.00	1	867	144
15	2	Sumitra Vaidya	4	0	100	10.00			
16	2	Laxmi Devi Maharjan	3	0	100	12.00	1	433	144
17	2	Raju Maharjan	5	1	100	12.00	0.75	325	65
18	2	Ram Maharjan	8	0	40	2.00	0.75	780	98
19	2	Krishna Kumaru Maharjan	2	0	100	52.00	0.25	25	13
20	2	Mahabir Maharjan	8	0	100	8.00	1	650	81
21	2	Radha Maharjan	4	0	100	8.00	0.75	488	122
22	2	Siddhi Kumari Maharjan	4	0	100	26.00	0.5	100	25
23	2	Ratna Devi Maharjan	6	0	100	4.00	0.75	975	163
24	2	Santa Maya Maharjan	4	0	100	6.00	0.75	650	163
25	2	Yachu Maya Maharjan	5	0	100	2.00	0.5	1300	260
26	2	Krishna Devi Maharjan	3	0	100	34.00	1	153	51
Average			**5.1**						**155.6**
CV%			38%						74%
Median			5.0						134.1
Min			2.0						12.5
Max			11.0						487.5

Responsible for emptying urine container: 0 = interviewed Person, 1 = other member of the household, 2 = someone else

Urine Availability Siddhipur

Number of EcoSan Toilets	Avg. members per household	Avg. Urine collected per Person [$l \cdot y^{-1}$]	Total collected Urine [$l \cdot y^{-1}$]
100	5.1	155.6	78'995

A.9 Data Analysis Urine Collection (Household Survey)

Data from Baseline Household Questionnaire Survey Siddhipur Aug./Sept. 2008

Questionnaire Data					Urine Collection	
Q -Nr.	**Household-Nr.**	# household members (incl. absence)	Size of urine collection tank [l]	Avg. time to fill urine tank [weeks]	Urine collected per year [l]	Urine collected per person and year [l]
1	06-101	7	100	14	371	53
2	11-111	5		8		
3	19-01	6	100	10	520	87
4	17-18	6	100	8	650	108
5	01-09	2	100	52	100	50
6	06-121	2	100			
7	11-123	4	100	8	650	163
8	11-20	5	100			
9	11-21	3	100			
10	16-83	12	100			
11	16-32	5	100	8	650	130
12	16-31	7	100	20	260	37
13	16-13	2	100	12	433	217
14	17-17	5	100	8	650	130
15	14-43	4	100	12	433	108
16	18-13	4	100	2	2600	650
17	12-21	3	100			
18	16-115	6	100	4	1300	217
19	17-25	6	40			
20	06-203	3	100	25	208	69
21	14-33	4	100	12	433	108
22	02-19	4	100	12	433	108
23	14-20	6	100	8	650	108
24	14-52	5	40			
25	16-04	3	100	8	650	217
26	16-14	4	100	8	650	163
27	18-42	6	100	12	433	72
Avg.		**4.78**				**147.1**
CV%		43%				91%
Min		2				37
Max		12				650

Urine Availability Siddhipur

Number of Ecosan Toilets	Avg. members per household	Avg. Urine collected per Person [$l \cdot y^{-1}$]	Total collected Urine [$l \cdot y^{-1}$]
100	4.8	147.1	70'286

A.10 Detailed Toilet Usage Statistics Siddhipur

During 5 days in August 2008 detailed statistics have been collected from 6 randomly selected households in Siddhipur.

Urine collected during survey period

Dataset Nr	House hold Nr.	Urine level before [cm]	Time[1)]	Urine level after[2)] [cm]	Time end	Emtying inbetween [cm]	Actual height difference [m]	Time difference [days]	Volume of urine[2)] [l]	Leakage[3)] [l]	Total urine collected [l]
1	01-09	60	27.08.2009 17:30	54	01.09.2009 15:00	0	0.06	4.9	10.50	0.00	10.50
2	06-121	57	27.08.2009 17:30	55.5	01.09.2009 15:30	0	0.015	4.9	2.62	0.40	3.02
3	11-20	22.5	27.08.2009 17:30	19	01.09.2009 16:00	0	0.035	4.9	6.12	0.00	6.12
4	17-18	28.5	27.08.2009 17:30	8	01.09.2009 13:30	0	0.205	4.8	35.86	0.00	35.86
5	18-28	18	27.08.2009 17:30	4	01.09.2009 14:45	9.5	0.235	4.9	41.11	0.00	41.11
6	19-01	39	27.08.2009 17:30	35	01.09.2009 13:00	0	0.04	4.8	7.00	0.00	7.00
							Avg.	4.9		**Total**	**103.62**

[1)] The actual time was not recorded, but all samples were taken between 16:30 - 18:30

[2)] Tank radius [m] 0.236

[3)] tab leaking

Average amount of urine excreted per urination

Dataset Nr.	House hold Nr.	Adults	Children	Urinations weekdays: Adults	Urinations weekdays: Children	Urinations weekend[1)]: Adults	Urinations weekend[1)]: Children	Urinations total: Adults	Urinations total: Children	Total urinations adults and children	Total urinations corrected[2)]	Urine per urination (adult person) [l]	Dulution[3)] [l]
1	01-09	2	0	17	0	27	0	44	0	44	44	0.24	0
2	06-121	2	0	18	0	3	0	21	0	21	21	0.14	0
3	11-20	4	1	11	1	14	2	25	3	28	26.5	0.23	0
4	17-18	4	2	36	15	69	19	105	34	139	122	0.29	0
5	18-28	4	0	47	0	74	0	121	0	121	121	0.34	0
6	19-01	3	2	18	6	16	12	34	18	52	43	0.16	0
Total		19	5							405	377.5		
Avg.		3.2	0.8									**0.274**	

Total Persons	24
% Children	21%
Total person days	117

[1)] Friday - Sunday

[2)] Urinations of children counted as 1/2

[3)] all households stated not to flush urine with water

Urinations per person and day (time correction of statistic for one full week)

Statistic Nr.	House-hold Nr.	Total urinations weekdays	Total urinations weekend	Time weekdays	Time weekend[1)]	Avg. urinations per Pe and day	Urinations time corrected per Pe and day
1	01-09	17	27	1.9	3	4.5	4.5
2	06-121	18	3	1.9	3	2.1	2.9
3	11-20	12	16	1.9	3	1.1	1.2
4	17-18	51	88	1.8	3	4.8	4.7
5	18-28	47	74	1.9	3	6.2	6.2
6	19-01	24	28	1.8	3	2.2	2.3
Average						3.5	**3.6**

[1)] Friday - Sunday

Data from Household Survey

Amount of water added to urine for cleaning pan with water [l/mth]	3.22
% of households cleaning toilet with water	96%
Avg. times of cleaning per month	4.85
Avg. nr of household members (absences accounted for)	4.8
Avg. amount of water added to urine tank for cleaning [$l \cdot y^{-1} pe^{-1}$]	7.7
Chance that a surveyd toilet was cleaned once during usage statistics measuring time	76%
Statistical correction of avg. amount of urine per adult person to include cleaning [$l \cdot d^{-1}$]	0.00514
Statistical correction of avg. amount of urine per adult person and day to exclude cleaning [$l \cdot d^{-1}$]	-0.016

Estimated urine collection

Adult person		undiluted	diluted by cleaning	Share of cleaning water
Day	[$l \cdot d^{-1}$]	0.982	1.003	2.1%
Year	[$l \cdot y^{-1}$]	358	366	2.1%

A.11 Estimation of Urine Quantity and Dilution Based on Toilet Usage Statistics

Data From Toilet Usage Statistics		
Amount of undiluted urine collected per urination (adult person)	[l]	0.274
Avg. urinations per day	[-]	3.6
Amount of undiluted urine collected per year(adult person)	[$l \cdot pe^{-1} \cdot y^{-1}$]	358

Data from household survey		
Water added by flushing per urination	[l]	0.14
Share of people flushing after urination	[%]	26%
Water added to urine for cleaning pan	[l/mth]	3.22
Share of households cleaning toilet with water	[%]	96%
Avg. times of cleaning per month	[-]	4.85
Nr. of household members (absences accounted for)	[-]	4.8
of which adults	[-]	3.0
of which children	[-]	1.8
Avg. amount of water added to urine tank by cleaning	[$l \cdot pe^{-1} \cdot y^{-1}$]	7.7

Estimation of Urine Quantity and Dilution

Parameter		Unit	Collected data	*Scenario A 75% flushing*	*Scenario B 50% flushing with 0.4l*
Nr. of urinations per day		[-]	3.6	*3.6*	*3.6*
Avg. urine collected per adult person and urination		[l]	0.274	*0.274*	*0.274*
Share of people flushing after urination		[%]	26%	*75%*	*50%*
Water added through flushing per urination		[l]	0.14	*0.14*	*0.4*
Water added by a flushing person per day		[$l \cdot pe^{-1} \cdot d^{-1}$]	0.50	*0.50*	*0.90*
Water added by a non-flushing person per day		[$l \cdot pe^{-1} \cdot d^{-1}$]	0	*0*	*0*
Avg. amount of water added by a person per day through flushing		[$l \cdot pe^{-1} \cdot d^{-1}$]	0.13	*0.38*	*0.68*
Avg. amount of water added by a person per year through flushing		[$l \cdot pe^{-1} \cdot y^{-1}$]	47.8	*138.0*	*246.4*
Avg. amount of water added to urine tank per person and year by cleaning		[$l \cdot pe^{-1} \cdot y^{-1}$]	7.7	*7.7*	*7.7*
Total avg. amount of water added to urine per person and year		[$l \cdot pe^{-1} \cdot y^{-1}$]	55.6	*145.7*	*254.1*
Avg. amount of undiluted urine collected per adult person and year		[$l \cdot pe^{-1} \cdot y^{-1}$]	358.0	*358.0*	*358.0*
Avg. amount of undiluted urine collected per child and year[1)]		[$l \cdot pe^{-1} \cdot y^{-1}$]	179.0	*179.0*	*179.0*
Adult:	**Total amount of diluted urine collected per year**	**[$l \cdot pe^{-1} \cdot y^{-1}$]**	**414**	*504*	*629*
	Water content	[%]	13%	*29%*	*43%*
Child:	**Total amount of diluted urine collected per year**	**[$l \cdot pe^{-1} \cdot y^{-1}$]**	**235**	*325*	*450*
	Water content	[%]	24%	*45%*	*60%*
Avg. household member	**Total amount of diluted urine collected per year**	**[$l \cdot pe^{-1} \cdot y^{-1}$]**	**346**	*683*	*808*
	Water content	[%]	17%	35%	49%

[1)] assumption: 50% urine excretion of an adult person

Urine Availability Siddhipur

Number of EcoSan Toilets	Household members	Urine collected per household member [$l \cdot y^{-1}$]	Total collected urine [$l \cdot y^{-1}$]
100	4.8	346	166'288

A.12 Time Spent at Home Calculation

Planting and Harvesting Season (5 month)																																
		Time																									Number of days	Hours at home	Hours out	% at home	Weighted % at home	Weighted whole year
		0	1	2	4	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23						
Man	Field work					1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1		6	10	10	50%	54%	60%
Man	Resting					1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1		1	16	4	80%		
Woman	Field work					1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1		4	13	7	65%	71%	77%
Woman	Household					1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	1	1		3	16	4	80%		
Child older	School					1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1		5	12	8	60%	62%	58%
Child older	Field work					1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1		1	10	10	50%		
Child older	Resting					1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1		1	17	3	85%		
Child younger	School					1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1		6	12	8	60%	64%	64%
Child younger	Resting					1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1		1	17	3	85%		
Woman old	Working					1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1			6	17	2	89%	88%	86%
Woman old	Resting					1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1			1	15	4	79%		
Man old	Resting					1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1			7	14	5	74%	74%	74%

Off Season (7 month)																																
		0	1	2	4	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23						
Man	Field work					1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1		3	10	10	50%	64%	
Man	Resting					1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1		2	17	3	85%		
Man	Market					1	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1		2	13	7	65%		
Woman	Household					1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1		6	17	3	85%	81%	
Woman	Relatives					1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	1		1	12	8	60%		
Child older	School					1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1		5	12	8	60%	55%	
Child older	Resting					1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1		1	17	3	85%		
Child younger	School					1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	1	1		6	12	8	60%	64%	
Child younger	Resting					1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1		1	17	3	85%		
Woman old	Working					1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1			6	16	3	84%	84%	
Woman old	Resting					1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1			1	16	3	84%		
Man old	Resting					1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1			7	14	5	74%	74%	

Average time spent at home	
Group	Percentage
Child	75%
Adult Person	69%
Elderly Person	80%

Legend

(green)	field	(dark grey)	at home
(orange)	school / out of house		
(light grey)	sleeping		

Remarks: The sleeping hours in the night are not calculated fully since during this time the toilet is normally not used. It is estimated that it takes about 2-3h to go to the toilet after drinking and so the fact that most people have to pee when they get up and befor the go to bed is reflected.

A.13 Analytical Estimation Urine Availability Siddhipur

Expreted Urine per Person

	Urine excretion per year (undiluted) [l·y^{-1}]	Estimated time spent at home [%]	Urine excretion at home [l·y^{-1}]	Urine excretion outside [l·y^{-1}]
Child	180	75%	134	46
Adult person	360	69%	247	113
Elderly person	360	80%	287	73

Excreted Urine for Standard Household

	Age distribution [%]	Members per household *	Urine excretion per house-hold [l·y^{-1}]	Urine excretion at home per household [l·y^{-1}]
Children	36%	1.7	311	232
Adults	59%	2.8	1020	700
Elderly	5%	0.2	86	69

* average household size: 4.8

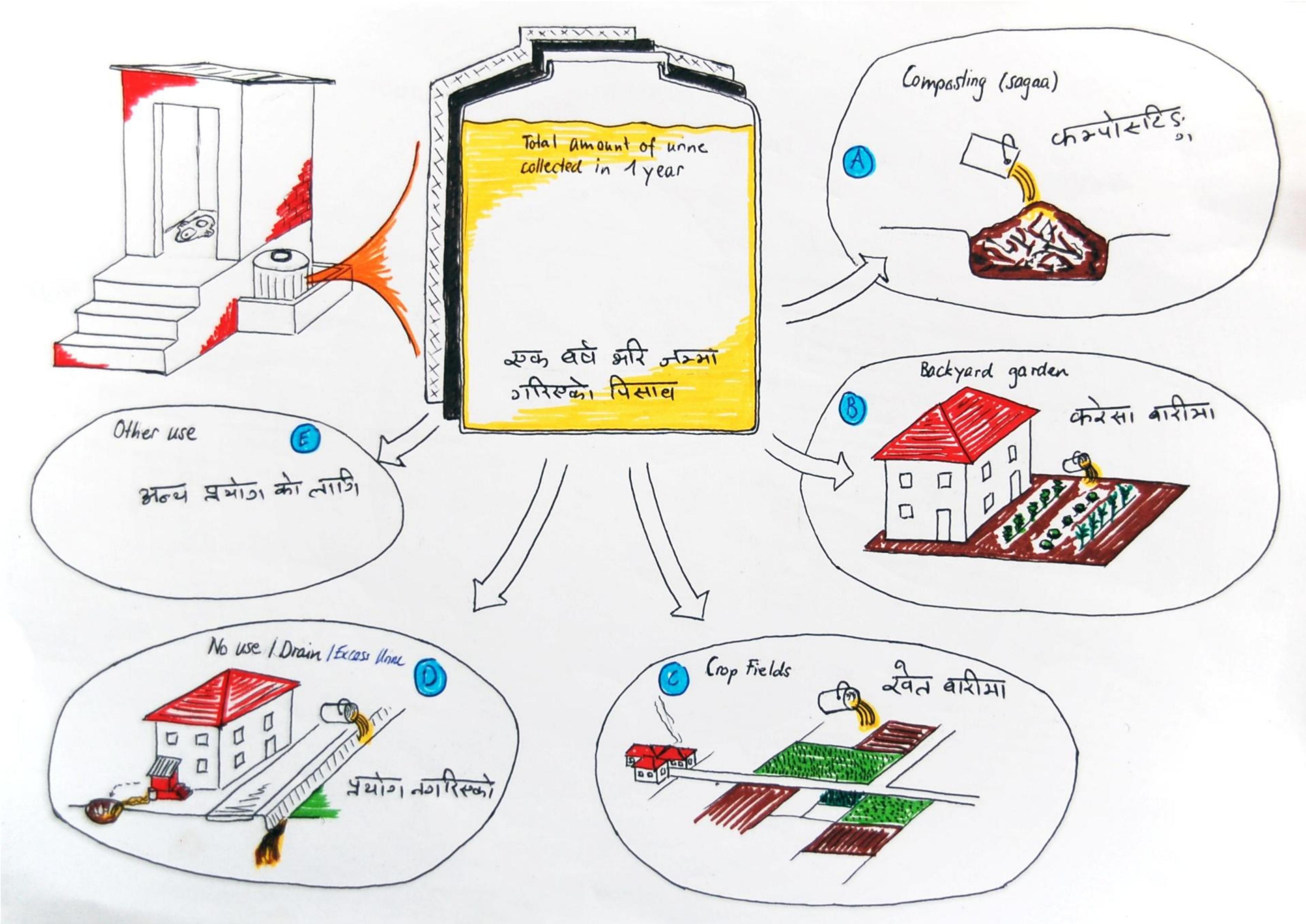
Total Urine Excretion

	Per household [l·y^{-1}]	[%]	Per Person [l·y^{-1}]
At home	1001	71%	209
Outside	415	29%	87
At home and outside	1417	100%	295

Total Urine Collection Siddhipur

Number of EcoSan toilets	[-]	100
Excreted urine at home per household (undiluted)	[l·y^{-1}]	1001
Total urine excreted in EcoSan toilets	[l·y^{-1}]	100'100
Water content of collected urine	[%]	15%
Total urine collected in EcoSan toilets (diluted)	[l·y^{-1}]	115'115
Total urine collected in EcoSan toilets per person (diluted)	[l·pe^{-1}·y^{-1}]	240

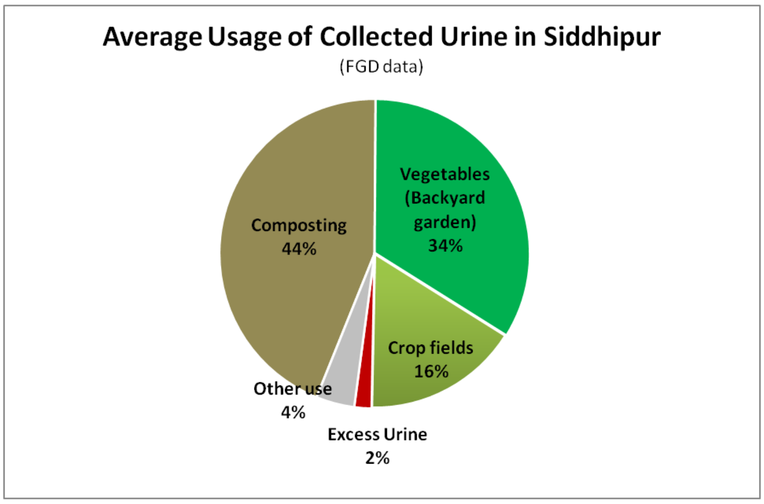
A.14 Urine Usage Distribution Play



A.15 Analysis Urine Usage Distribution Play (FGD data)

Data Analysis of Urine Usage Distribution Play with Participants of Focus Group Discussions in Siddhipur 25./26.6.2008

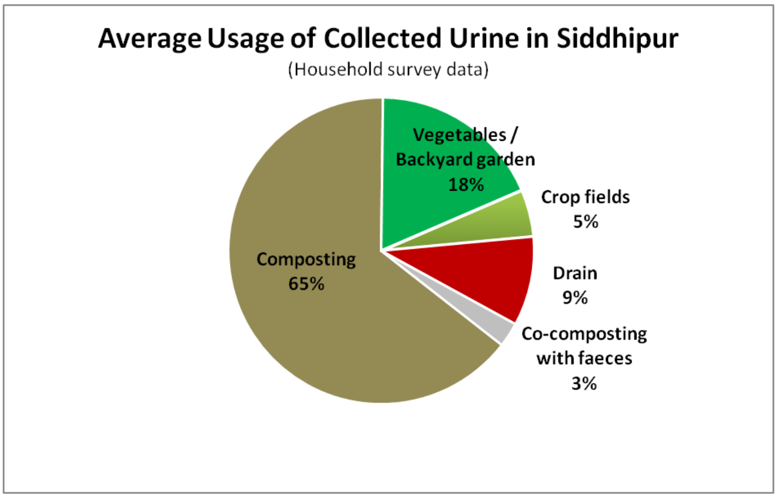
# of Person	Composting	Vegetables (Backyard garden)	Crop fields	Excess Urine	Other use	namely:
1	0.25	0.30	0.30	0.00	0.15	lost through leakages / transport
2	0.25	0.25	0.25	0.00	0.25	lost through leakages / transport
3	0.45	0.20	0.20	0.00	0.15	lost through leakages / transport
4	0.60	0.40	0.00	0.00	0.00	
5	0.60	0.30	0.10	0.00	0.00	
6	0.45	0.45	0.10	0.00	0.00	
7	0.40	0.30	0.10	0.05	0.15	gives urine to other people
8	0.70	0.25	0.00	0.05	0.00	
9	0.70	0.25	0.00	0.05	0.00	
10	0.45	0.25	0.20	0.10	0.00	
11	0.60	0.30	0.00	0.10	0.00	
12	0.45	0.30	0.25	0.00	0.00	
13	0.55	0.15	0.15	0.00	0.15	gives urine to other people
14	0.60	0.20	0.20	0.00	0.00	
15	0.50	0.50	0.00	0.00	0.00	
16	0.50	0.50	0.00	0.00	0.00	
17	0.30	0.25	0.45	0.00	0.00	
18	0.25	0.30	0.45	0.00	0.00	
19	0.35	0.30	0.35	0.00	0.00	
20	0.30	0.30	0.25	0.00	0.15	gives urine to other people
21	0.70	0.20	0.00	0.10	0.00	
22	0.20	0.60	0.20	0.00	0.00	
23	0.20	0.80	0.00	0.00	0.00	
24	0.25	0.20	0.55	0.00	0.00	
25	0.40	0.60	0.00	0.00	0.00	
Average	**44%**	**34%**	**16%**	**2%**	**4%**	



A.16 Analysis Urine Usage Distribution Play (household survey data)

Data Analiysis of Urine Usage Distribution Play assessed as part of the baseline household survey in Aug. / Sept. 2008.

Questionnaire Nr.	Household Nr.	Composting	Vegetables / Backyard garden	Crop fields	Drain	Co-composting with faeces
1	06-101	100%	0%	0%	0%	0%
2	11-111	30%	20%	40%	10%	0%
3	19-01	50%	20%	0%	30%	0%
4	17-18	75%	25%	0%	0%	0%
5	01-09	0%	0%	0%	100%	0%
6	06-121	100%	0%	0%	0%	0%
7	11-123	100%	0%	0%	0%	0%
8	11-20	40%	25%	35%	0%	0%
9	11-21	0%	100%	0%	0%	0%
10	16-83	100%	0%	0%	0%	0%
11	16-32	0%	30%	0%	0%	70%
12	16-31	40%	20%	0%	40%	0%
13	16-13	50%	0%	0%	50%	0%
14	17-17	100%	0%	0%	0%	0%
15	14-43	50%	25%	0%	25%	0%
16	18-13	100%	0%	0%	0%	0%
17	12-21	40%	60%	0%	0%	0%
18	16-115	50%	50%	0%	0%	0%
19	17-25	60%	40%	0%	0%	0%
20	06-203	100%	0%	0%	0%	0%
21	14-33	20%	20%	60%	0%	0%
22	02-19	90%	10%	0%	0%	0%
23	14-20	100%	0%	0%	0%	0%
24	14-52	100%	0%	0%	0%	0%
25	16-04	100%	0%	0%	0%	0%
26	16-14	50%	50%	0%	0%	0%
27	18-42	100%	0%	0%	0%	0%
Average		**65%**	**18%**	**5%**	**9%**	**3%**
CV%		55%	134%	297%	240%	520%
Median		60%	10%	0%	0%	0%
Min		0%	0%	0%	0%	0%
Max		100%	100%	60%	100%	70%



A.17 Organic Waste Generation in Siddhipur and Urine Application for Composting

Period	Population	Households	Fraction of year	Waste generation: Total[1)]	Waste generation: Per person	Waste generation: Per household	Waste Composition: Kitchen waste	Waste Composition: Straw waste[2)]	Waste Composition: Total organic
			[d]	[kg·d^{-1}]	[kg·d^{-1}]	[kg·d^{-1}]	[%]	[%]	[%]
Rainy Season	6046	1308	122	1366	0.226	1.044	34.2	46.4	80.6
Dry Season	6046	1308	243	705	0.117	0.539	64	0	64

[1)] according to ENPHO (2003); [2)] sukul production

Period	Organic waste generation: per household and day	Organic waste generation: per household and year	Optimal urine application for co-composting: optimal dosage	Optimal urine application for co-composting: per household and day	Optimal urine application for co-composting: per household and year
	[kg·d^{-1}]	[kg·y^{-1}]	[%]	[l·d^{-1}]	[l·y^{-1}]
Rainy Season	0.842	307	15% [1)]	0.13	46
Dry Season	0.345	126	15% [1)]	0.05	19
Total	-	433	-	-	65

[1)] according to Pinsem und Vinnerås (2003)

Application type	Present usage of urine: Percentage	Present usage of urine: per household and year	Advocated usage	Available for struvite production	New percentage of total
	[%]	[l·y^{-1}]	[l·y^{-1}]	[l·y^{-1}]	[%]
Compost	60%	1010	130§	880	8%
Direct application (backyard)	20%	340	-	-	-
Direct application (crop fields)	5%	80	-	-	-
Draining	10%	170	0	170	0%
Giving neighbours	5%	80	-	-	-
Total	100%	1680		1050	63%

§ to account for the popularity of composting with urine the estimated optimal amount of 65 litres has been doubled

B Magnesium Sources

B.1 Conversion of Magnesium Carbonate to Magnesium Chloride

Magnesium carbonate reacts with hydrochloric acid to form magnesium chloride, carbon dioxide and water:

$$\mathrm{MgCO_3 + 2\,HCl \rightarrow MgCl_2 + CO_2 + H_2O}$$

Actual chemical reaction

Magnesium carbonate is quarried as magnesite ($\mathrm{MgCO_3}$) or dolomite ($\mathrm{[Mg, Ca]CO_3}$) and traded as a white powder with a magnesium carbonate content of about 95% or 40% respectively. Hydrochloric acid is normally available on the industrial market in concentrations of 30-34%. Magnesium chloride on the other hand is strongly hygroscopic and will react with water to its hydrate form magnesium chloride hexahydrate.

Process inputs

Magnesium carbonate:	$\mathrm{MgCO_3}$	$(84.3\mathrm{gmol^{-1}})$
Hydrochloric acid:	HCl	(concentrations from 0-38%)

Process output

Magnesium chloride hexahydrate:	$\mathrm{MgCl_2 \cdot 6\,H_2O}$	$(203.3\mathrm{gmol^{-1}})$

Chemical process

$$\mathrm{MgCO_3 + 2\,HCl + 5\,H_2O \rightarrow MgCl_2 \cdot 6\,H_2O + CO_2}$$

Stochiometric Analysis

For the production of 1kg of magnesium chloride hexahydrate the following quantities are needed:

Magnesite° / Dolomite *	
$\mathrm{MgCO_3}$ content	kg
95% °	0.436
90% °	0.461
80% °	0.518
45% *	0.921
40% *	1.037

Hydrochloric acid		
Conc.	kg	Liter
10%	3.587	3.424
30%	1.196	1.040
32%	1.121	0.967
34%	1.055	0.902
38%	0.944	0.794

Results

The above made calculations suggest that for the production of 1kg magnesium chloride hexahydrate or 4.92 mol $\mathrm{Mg^{2+}}$ ions dissolved in water approximately 435g of magnesite or 920g of dolomite and 0.97l of hydrochloric acid with a concentration of 32% are needed.

B.2 Conversion of Magnesium Carbonate to Magnesium Sulfate

Magnesium carbonate reacts with sulfuric acid to form magnesium sulfate, carbon dioxide and water:

$$MgCO_3 + H_2SO_4 \rightarrow MgSO_4 + CO_2 + H_2O$$

Acutal chemical reaction

Magnesium carbonate is quarried as magnesite ($MgCO_3$) or dolomite ($[Mg, Ca]CO_3$) and traded as a white powder with a magnesium carbonate content of about 95% or 40% respectively. Sulfuric acid is normally available on the industrial market in concentrations of 10-98.3%. Magnesium sulfate on the other hand is strongly hygroscopic and will react with water to its hydrate form magnesium sulfate heptahydrate.

Process inputs

Magnesium carbonate:	$MgCO_3$	$(84.3 gmol^{-1})$
Sulfuric acid:	H_2SO_4	(concentrations from 10-98.3%)

Process output

Magnesium sulfate heptahydrate:	$MgSO_4 \cdot 7\,H_2O$	$(246.5 gmol^{-1})$

Chemical process

$$MgCO_3 + H_2SO_4 + 6\,H_2O \rightarrow MgSO_4 \cdot 7\,H_2O + CO_2$$

Stochiometric Analysis

For the production of 1kg of magnesium sulfate heptahydrate the following quantities are needed:

Magnesite° / Dolomite*	
$MgCO_3$ content	kg
95% °	0.436
90% °	0.461
80% °	0.518
45% *	0.921
40% *	1.037

Sulfuric acid		
Conc.	kg	Liter
10%	3.979	3.732
34%	1.170	0.935
62%	0.642	0.422
78%	0.510	0.299
98%	0.406	0.221

Results

The above made calculations suggest that for the production of 1kg magnesium sulfate heptahydrate or 4.06 mol Mg^{2+} ions dissolved in water approximately 435g of magnesite or 920g of dolomite and 0.22l of sulfuric acid with a concentration of 98% are needed.

B.3 Cost Calculations for the Conversion of $MgCO_3$ to $MgCl_2$

Formula of Reaction

$$MgCO_3 + 2\,HCl \rightarrow MgCl_2 + CO_2 + H_2O$$

Amount of Magnesium Carbonate needed for 1 mol of MgCl2 [mol]	1
Amount of HCl needed for 1 mol of MgCl2 [mol]	2

Constants

	g/mol
Magnesium Carbonate	84.3
Magnesium Chloride Heptahydrate	203.3

Hydrochloric Acid

Concentration [%]	Specific Gravity [kg/l]	Molarity [mol/l]	Price [Rp/kg]
10	1.05	2.87	
20	1.10	6.02	
30	1.15	9.46	
32	1.16	10.18	13.5
34	1.17	10.90	
38	1.19	12.39	45

Magnesite / Dolomite

$MgCO_3$ content [%]	g/mol $MgCO_3$	Price [Rp/kg]
95	88.7	8
90	93.7	
80	105.4	
45	187.3	
40	210.8	
32	263.4	3

	kg	mol
Targeted Amount of Magnesium Chloride	1	4.92

Needed Quantities

	content [%]	mol	kg	liter	costs [Rp]	costs/mol Mg [Rp]
Magnesium carbonate	95	4.92	0.436		3.49	0.71
	90	4.92	0.461		0.00	0.00
	80	4.92	0.518		0.00	0.00
	45	4.92	0.921		0.00	0.00
	40	4.92	1.037		0.00	0.00
	32	4.92	1.296		3.89	0.79
Hydrochloric acid	10	9.84	3.587	3.424	0.00	0.00
	20	9.84	1.793	1.633	0.00	0.00
	30	9.84	1.196	1.040	0.00	0.00
	32	9.84	1.121	0.967	15.13	3.08
	34	9.84	1.055	0.902	0.00	0.00
	38	9.84	0.944	0.794	42.48	8.64

Minimum Production Cost [Rp]

1 kg of MgCl2	1 mol Mg
18.62	3.79

B.4 Cost Calculations for the Conversion of $MgCO_3$ to $MgSO_4$

Formula of Reaction

$$MgCO_3 + H_2SO_4 \rightarrow MgSO_4 + CO_2 + H_2O$$

Amount of Magnesium Carbonate needed for 1 mol of MgCl2 [mol]	1
Amount of Sulfuric Acid needed for 1 mol of MgCl2 [mol]	1

Constants

	g/mol
Magnesium Carbonate	84.3
Magnesium Sulfate Heptahydrate	246.5

Sulfuric Acid

Concentration [%]	Specific Gravity [kg/l]	Molarity [mol/l]	Price [Rp/kg]
10	1.07	1.09	
34	1.25	4.34	
62	1.52	9.61	
78	1.70	13.55	
90	1.81	16.65	40
98	1.84	18.35	45

Magnesite / Dolomite

$MgCO_3$ content [%]	g/mol $MgCO_3$	Price [Rp/kg]
95	88.7	8
90	93.7	
80	105.4	
45	187.3	
40	210.8	
32	263.4	3

	kg	mol
Targeted Amount of Magnesium Sulfate	1	4.06

Needed Quantities

	content [%]	mol	kg	liter	costs [Rp]	cost/mol Mg [Rp]
Magnesium carbonate	95	4.06	0.360		2.88	0.71
	90	4.06	0.380		0.00	0.00
	80	4.06	0.427		0.00	0.00
	45	4.06	0.760		0.00	0.00
	40	4.06	0.855		0.00	0.00
	32	4.06	1.069		3.21	0.79
Sulfuric acid	10	4.06	3.979	3.732	0.00	0.00
	34	4.06	1.170	0.935	0.00	0.00
	62	4.06	0.642	0.422	0.00	0.00
	78	4.06	0.510	0.299	0.00	0.00
	90	4.06	0.441	0.244	17.64	4.35
	98	4.06	0.406	0.221	18.27	4.50

Minimum Production Cost [Rp]

1 kg of MgSO4	1 mol Mg
20.52	5.06

C Fertilizers

C.1 Available Fertilizer Products Siddhipur

Product Name	Importer / Manufacturer	Country of Origin	Ingredients	Percentage of weight						Price [NRp]		Discount	Remarks
				N [%]	P_2O_5 [%]	K_2O [%]	Mg [%]	S [%]	Ca [%]	kg	50kg (bag)	[$Rp\cdot kg^{-1}$]	
Milan Suppliers (fertilizer shop at main street with branch close to hospital)													
Urea	Krishak Bharati Cooperative Limited (KRIBHCO)	India	Urea $(NH_2)_2CO$	46	0	0	0	0	0	24	1000	4	small pellets, sample 3
Urea	MAOC / Shandong Hualu Hengsheng Chemical Co Ltd.	China	Urea $(NH_2)_2CO$	46	0	0	0	0	0	32	1450	3	big pellets, donated by Japan, sampel 2
Sona Sarvottam Mal NPK 20:20:0	Bagmati Fertilizers Ltd.	India		20	20	0	0	0	0	32	1450	3	sample 4
Sona Sarvottam Supermix NPK 20:20:10	Bagmati Fertilizers Ltd.	India		20	20	10	0	0	0	36	1600	4	sample 5
Sardar DAP	Gujarat State Fertilizers & Chemicals Ltd. (GSFC)	India	Diammonium Phosphate $(NH_4)_2HPO_4$	18	46	0	0	0	0	42	1900	4	subsidized
DAP	Monesh International / Philippine Phosphate Fertilizer Corporation	Philippines	Diammonium Phosphate $(NH_4)_2HPO_4$	18	46	0	0	0	0	48	2200	4	formerly 46/kg, sample 6
Sardar AS	Gujarat State Fertilizers & Chemicals Ltd. (GSFC)	India	Ammonium Sulfate $(NH_4)_2SO_4$	20.6	0	0	0	23	0	28	1200	4	formerly 26/kg, sample 7
MOP	Indian Potash Ltd.	India	Myriate of Potash / Potassium Chloride (KCl)	0	0	60	0	0	0	26	1100	4	sample 8
Agricultural lime	Godwari Marble	Nepal	$CaCO_3$	0	0	0	0	0	40				
Fertilizer shop close to southern bus stop													
Urea	Nagarjuna Fertilizers & Chemicals Ltd.	India	Urea $(NH_2)_2CO$	46	0	0	0	0	0	22	1000	2	small pellets
Urea	Pathibhara Agro Fertilizer Pvt. Ltd.	Nepal	Urea $(NH_2)_2CO$	46	0	0	0	0	0	30	1500	0	big pellets
Hira Mal NPK 20:20:0	Pathibhara Agro Fertilizer Pvt. Ltd.	Nepal		20	20	0	0	0	0	30	1350	3	subsidized, sample 1
Sardar AS	Manoj International Traders / Gujarat State Fertilizers & Chemicals Ltd. (GSFC)	India	Ammonium Sulfate $(NH_4)_2SO_4$	20.6	0	0	0	23	0	26	1250	1	
20:20:0	Purbanchal Fertilizers Pvt. Ltd.	Nepal		20	20	0	0	0	0	32	1500	2	
Potassium Fertilizer		India								25	1200	1	
DAP	Philippine Phosphate Fertilizer Corp.	Philippines	Diammonium Phosphate $(NH_4)_2HPO_4$	18	46	0	0	0	0				
Fertilizer shop close to southern bus stop at main street													
Urea	Indian Farmers Fertilizer Cooperative Ltd.	India	Urea $(NH_2)_2CO$	46	0	0	0	0	0	22	1000	2	
Urea	Bhudeo Trading / Saudi Basic Industries Corporation (SABIC)	Saudi Arabia	Urea $(NH_2)_2CO$	46	0	0	0	0	0			0	
Hira Mal NPK 20:20:0	Pathibhara Agro Fertilizer Pvt. Ltd.	Nepal		20	20	0	0	0	0	30	1500	0	

C.2 Regressional Analysis of Fertilizer Component Prices

Product	Origin	Chemical component	Nitrogen [N]	Phosphate [P_2O_5]	Potash [K_2O]	Magnesium [Mg]	Sulfur [S]	Calcium [Ca]	Price [NRp/kg]	Predicted price [NRp/kg]	Price difference [NRp/kg]
Urea	India	Urea $(NH_2)_2CO$	46	0	0	0	0	0	24	26.8	2.8
Urea	China	Urea $(NH_2)_2CO$	46	0	0	0	0	0	32	26.8	-5.2
Sona Sarvottam Mal NPK 20:20:0	India		20	20	0	0	0	0	32	28.1	-3.9
Sona Sarvottam Supermix NPK 20:20:10	India		20	20	10	0	0	0	36	32.5	-3.5
Sardar DAP	India	Diammonium Phosphate $(NH_4)_2HPO_4$	18	46	0	0	0	0	42	48.3	6.3
DAP	Philippines	Diammonium Phosphate $(NH_4)_2HPO_4$	18	46	0	0	0	0	48	48.3	0.3
Sardar AS	India	Ammonium Sulfate $(NH_4)_2SO_4$	20.6	0	0	0	23	0	28	27.0	-1.0
MOP	India	Myriate of Potash (KCl)	0	0	60	0	0	0	26	26.6	0.6
Urea	India	Urea $(NH_2)_2CO$	46	0	0	0	0	0	22	26.8	4.8
Urea	Nepal	Urea $(NH_2)_2CO$	46	0	0	0	0	0	30	26.8	-3.2
Hira Mal NPK 20:20:0	Nepal		20	20	0	0	0	0	30	28.1	-1.9
Sardar AS	India	Ammonium Sulfate $(NH_4)_2SO_4$	20.6	0	0	0	23	0	26	27.0	1.0
20:20:0	Nepal		20	20	0	0	0	0	32	28.1	-3.9
Urea	India	Urea $(NH_2)_2CO$	46	0	0	0	0	0	22	26.8	4.8
Hira Mal NPK 20:20:0	Nepal		20	20	0	0	0	0	30	28.1	-1.9
Magnesium Sulfate	India	$MgSO_4$	0	0	0	9.9	13	0	25	25.0	0.0
Agricultural Lime	Nepal	$CaCO_3$	0	0	0	0	0	40	4	4.0	0.0

Linear Regression Model for Value of Nutrients per % (10g)

price = a_1 * [N] + a_2 * [P_2O_5] + a_3 * [K_2O] + a_4 * [Mg] + a_5 * [S] + a_6 * [Ca]

	a_6	a_5	a_4	a_3	a_2	a_1
Coefficients a_x	0.10	0.65	1.67	0.44	0.82	0.58
Standard errors of coefficients	0.10	0.13	0.45	0.07	0.06	0.04
r^2, Standard error of price	0.99	4.08				
F, df	152.83	11.00				
SS_{reg}, SS_{resid}	15273.78	183.22				

Predicted Value of Nutrients

[NRp per 0.01kg or % of weight based od kg]

Nitrogen [N]	0.58
Phosphorus [P_2O_5]	0.82
Potassium [K_2O]	0.44
Magnesium [Mg]	1.67
Sulfur [S]	0.65
Calcium [Ca]	0.10

Estimated Value of Stuvite

Nitrogen [N]	Phosphorus [P_2O_5]	Potassium [K_2O]	Magnesium [Mg]	Sulfur [S]	Calcium [Ca]	Price not including Magnesium [NRp/kg]	Price including Magnesium [NRp/kg]
5.7	28.9	0	9.8	0	0	27.07	43.43

C.3 Calculation of Urine and Effluent Values

Nutrient Contents Table

		Fresh undi-luted urine Siddhipur	Fresh diluted Urine Sid-dhipur [2]	Stored di-luted urine Siddhipur	Magnesium added for precipitation (8.9 mol)[1]	Struvite precipi-tation (7.52mol)	Effluent after struvite produc-tion (Siddhipur urine)	Difference (loss?)
Nitrogen	[kgN·m^{-3}]	6.000	5.100	2.400	0.000	0.105	2.240	0.055
Phosphorous	[kgP·m^{-3}]	0.400	0.340	0.250	0.000	0.232	0.017	0.001
Potassium	[kgK·m^{-3}]	1.900	1.615	0.800	0.000	0.000	0.744	0.056
Magnesium	[kgMg·m^{-3}]	0.045	0.038	0.000	0.216	0.183	0.034§	-
Sulphate	[kgSO$_4$·m^{-3}]	0.875	0.744	0.744	0.000	0.000	0.744§	-
Calcium	[kgCa·m^{-3}]	0.090	0.077	0.000	0.000	0.000	0.000§	-

1) Mg:P = 1.1:1.0; 2) calculated values for an estimated dilution of the urine of 85% urine, 15% water; § estimated values

Nutrient Contents Table 2

		Fresh undi-luted urine Siddhipur	Fresh diluted Urine Sid-dhipur 2)	Stored di-luted urine Siddhipur	Magnesium added for precipitation (8.9 mol)1)	Struvite precipi-tation (7.52mol)	Effluent after struvite pro-duction (Siddhipur urine)
Nitrogen	[kgN·m^{-3}]	6.000	5.100	2.400	0.000	0.105	2.240
Phosphate	[kgP$_2$O$_5$·m^{-3}]	0.918	0.780	0.574	0.000	0.533	0.038
Potash	[kgK$_2$O·m^{-3}]	2.290	1.946	0.964	0.000	0.000	0.897
Magnesium	[kgMg·m^{-3}]	0.045	0.038	0.000	0.216	0.183	0.034§
Sulphur	[kgS·m^{-3}]	0.292	0.248	0.248	0.000	0.000	0.248§
Calcium	[kgCa·m^{-3}]	0.090	0.077	0.000	0.000	0.000	0.000§

Calculated value of stored Urine (Siddhipur) including precipitates	[NRp·m^{-3}]	313.5
Calculated value of stored Urine (Siddhipur) without precipitates	[NRp·m^{-3}]	245.9
Calculated value of effluent	[NRp·m^{-3}]	195.1
Calculated value of struvite produced from urine (~1.85kg à 43.4)	[NRp·m^{-3}]	80.4
Calculated value of struvite produced from urine not including Mg (1.85kg à 27.07)	[NRp·m^{-3}]	49.9
Value of magnesium added to urine (216g)	[NRp·m^{-3}]	36.1

D Questionnaires

D.1 Basic Household Information

STUN Project Phase 1

Q0 – BASIC INFORMATION

Questionnaire Number [ ]

Households (their **assigned household number**) that did **not** want to be interviewed before finding this household who takes part in the interview:

....

....

INTRODUCTION

Thank you very much for wanting to take part in this interview! We are not interested in any particular answers, just in the answers that really represent your opinion. We do not want you to engage in any behavior in particular, we would like to know why people are doing what they are doing so that we can assess the present situation and find the best solutions depending on this information.

So it helps us most if you answer as honest and properly as possible. Please help us in finding out how things really are.

We would like to get as much information as possible and therefore some questions of the same topics will be similar - we are sorry if they seem to be repetitive.

All the information collected with this questionnaire will be processed anonymously and no personalized data will be handed over to local authorities. We guarantee for your data privacy protection.

QUESTIONS ABOUT THE INTERVIEWD HOUSEHOLD

Assigned household number: ....

Date of the interview:...

Full name of the household head: ....

Full names of persons interviewed[1]: ....

Questionnaire was conducted with 27 randomly selected EcoSan households in Siddhipur during 29.08.08 and 08.09.08.

[1] At least two adult persons from the household (>18), preferably one female and one male

STUN Project Phase 1

DEMOGRAFIC INFORMATION

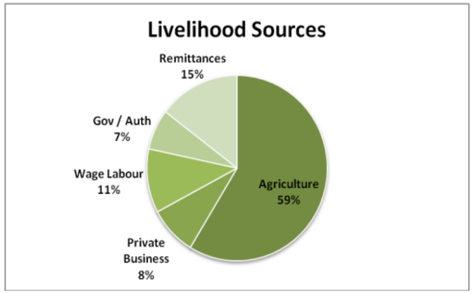
Household members									Sex		Age	Regularly absent from home (days/week)
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others	M	F		
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				
Father	Mother	Grandfather	Grand mother	Son (in Law)	Daughter (in Law)	Brother	Sister	others				

Average number of household members:	**5.19**
Males	**2.52 (49%)**
Females	**2.67 (51%)**
Children	**1.74 (34%)**
Adults	**3.22 (62%)**
Elderly	**0.22 (4%)**
Average number of household members incl. absences	**4.78**
Children incl. absences	**1.74 (36%)**
Adults incl. absences	**2.81 (59%)**
Elderly incl. absences	**0.22 (5%)**

0.1 What are your family's means with which you earn your livelihood? (several answers possible)

Percentage %

1 ❑ Agricultural production on private basis ....
2 ❑ Private Business (shop, trade, ...) ....
3 ❑ Wage labour ....
4 ❑ Employment with the Government / local Authorities ....
5 ❑ Remittances ....
6 ❑ Other, namely: ....
7 ❑ ....



0.1.1 *If 0.1 "Agricultural production on private basis"*: How much land does your family own where on which you conduct agriculture?

1 ❑ Bigha (~6800m2, 13.3 ropani) ....
2 ❑ Ropani (~500m^2, 16 aana) ....
3 ❑ Aana (~30m^2) ....

Average 2.7 Ropani (0.14ha)

0.1.2 *If 0.1 "Agricultural production on private basis"*: How much chemical fertilizer does your family use in average per year (2 seasons)?

Kg: Type

86.9 kg urea / y **13.7 kg DAP / y**

SANITARY SITUATION FAMILY

0.2 Are you satisfied with the present sanitary situation of your family?

❑ Yes (3) **23** ❑ More or less (2) **4** ❑ No (1) **0** ❑ Don't know (0)

0.2.1 What could be improved?

Drainage, management of sukhul waste (straw mats), house infrastructure

0.3 What type of toilets is your family using for daily sanitary needs most of the time when ***at home***? (primary toilet)

1 ❑ EcoSan toilet **27**
2 ❑ Pit / Latrine: ....
3 ❑ Open air
4 ❑ Public toilet facility
5 ❑ Other, namely: ....

STUN Project Phase 1

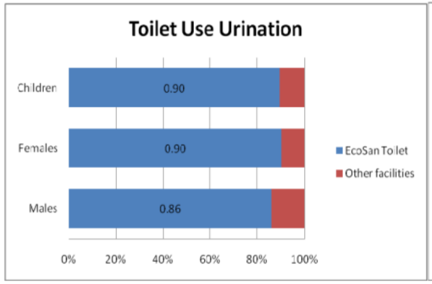
0.3.1 Are there any other toilets your family is using for daily sanitary needs when ***at home***? (several answers possible)

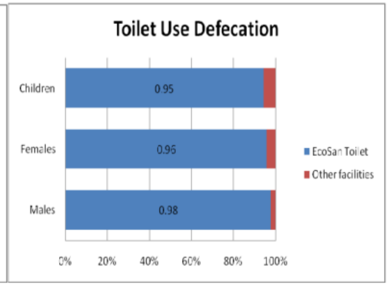
1 ❑ EcoSan toilet
2 ❑ Pit / Latrine: **4%** ....
3 ❑ Open air **15%**
4 ❑ Public toilet facility **4%**
5 ❑ Naugha
6 ❑ Kopra: Where is urine put? **7% (chamber pot)** ....
7 ❑ Other, namely: ....
8 ❑ No

If the family uses more than one toilet an EcoSan toilet is stated as either primary or secondary option complete:

Toilet usage

	Usage of [%]		
	.... Primary Sanitary Technology	.... Secondary Sanitary Technology	Other Facilities
Males	U:	U:	U:
	F:	F:	F:
Females	U:	U:	U:
	F:	F:	F:
Children	U:	U:	U:
	F:	F:	F:





If any irregularities in the usage of EcoSan toilet: What are the reasons?

In the night time the children use Kopra.

Because of the high age it is difficult to use the EcoSan toilet.

Distance from House to EcoSan toilet is to big

The EcoSan toilet is difficult to use.

If the EcoSan toilet is not the primary facility of the family for the daily sanitary needs answer questions 0.4. Otherwise go to 0.5:

0.4 What are the reasons that your family is using other facilities more than the EcoSan toilet?

1 ❑ The other options are more convenient to use. **4**
2 ❑ The EcoSan toilet does not belong to us.
3 ❑ The EcoSan toilet does not work properly.
4 ❑ Others, namely: ....

0.4.1 *If 0.4 "more convenient"*: What are the reasons that make the other facilities more convenient? (Several answers possible)

1 ❑ Other facilities are closer. **4**
2 ❑ The EcoSan toilet smells bad.
3 ❑ The EcoSan toilet is not hygienic.
4 ❑ The other facilities do not require as much maintenance effort as the EcoSan toilet does.
5 ❑ Others, namely: ....

0.4.2 *If 0.4 'EcoSan toilet does not work properly'*: What is the problem?

roof leakes water, tab is leaking

SANITARY SITUATION IN COMMUNITY

0.5 How do you assess the general sanitary situation of your neighborhood / community?

❑ Good (3) **17** ❑ Improvable, but ok (2) **6** ❑ Bad (1) **3** ❑ Don't know (0)

0.5.1 *If 0.5 "Improvable, but ok" or "Bad"*: What is the problem?

waste lying around, open drainage; no drainage; dirty alleys during rainy season (2 times); open drain, no outlet; sukhul waste; saghas, open drains; solid waste (2 times); drainage (dirty, blocked)

0.6 Do you have concerns that the quality of your primary *water source*, the *health situation* or the *environment* is affected negatively because of unsatisfactory sanitation technologies in the community?

❑ Strong concerns (3) **1** ❑ Minor concerns (2) **22** ❑ No concerns (1) ❑ Don't know (0)

0.6.1 *If 0.6 "Strong" or "minor"*: What is the cause of your concerns?

Dirty water causes diseases; neighbours septic tank, leaking drain outlet; Dirty water causes diseases, especially dirty during rainy season; septic tanks affect ground water; well water (2 times); well water polluted by septic tanks (2 times); diseases (3 times); well water quality; water dirty (2 times); water quality (2 times); well water polluted

STUN Project Phase 1

0.7 When you are in Siddhipur or on nearby fields but not at home, what do you mostly do if you need to defecate?

1 ❑ defecate somewhere in the open **17**
2 ❑ Use public toilet facility
3 ❑ Use friends toilet
4 ❑ Go home **10**
5 ❑ Other, namely: ....

0.7.1 How convenient is this option for you?

❑ Very convenient (2) **3** ❑ okay (1) **5** ❑ Not convenient (0) **15**

0.7.2 *If 0.7.1 "Not convenient"*: What is inconvenient? What could be improved?

hesitations, would like public toilets; public toilet (7 times); designate a place

0.8 When you are in Siddhipur or on nearby fields but not at home, what do you mostly do if you need to urinate?

1 ❑ Urinate somewhere in the open **23**
2 ❑ Use public toilet facility
3 ❑ Use friends toilet
4 ❑ Go home **4**
5 ❑ Other, namely: ....

0.8.1 How convenient is this option for you?

❑ Very convenient (2) **2** ❑ okay (1) **6** ❑ Not convenient (0) **15**

0.8.2 *If 0.8.1 "Not convenient"*: What is inconvenient? What could be improved?

hesitations, would like public toilets; public toilet (3 times); hesitations

0.9 Do you think there is a need for public toilets in Siddhipur?

❑ Yes (2) **23** ❑ No (1) ❑ I don't know (0)

0.9.1 *If 0.9 "Yes"*: How much would you be willing to pay for urinating? **1.17 NRp**..

0.9.2 *If 0.9 "Yes"*: How much would you be willing to pay for defecating? **2.14 NRp**..

0.9.3 Would it make a big difference for you if the public facilities were EcoSan toilets instead of conventional toilets? ***If EcoSan toilets not known, explain!***

1 ❑ Yes, prefer conventional toilets. **19**
2 ❑ No difference.
4 ❑ Yes, prefer EcoSan toilets. **4**
5 ❑ I don't know.

0.9.4 *If 0.9.3 "Yes, prefer conventional toilets":* Suppose there are a conventional public toilet as well as an EcoSan toilet. If the usage fee for the public EcoSan toilet is cheaper or even free, which one would you prefer to use?

1 ❑ Still prefer conventional toilets. **17**
2 ❑ No difference.
4 ❑ Prefer EcoSan toilets. **2**
5 ❑ I don't know.

0.9.5 If you could chose, where would be a good place for a public toilet in Siddhipur?
village corners; out of village (3 times); inside village (2 times); at the places of the old public toilets (3 times); Santipur, Devanani; inside village, village centre (4 times); out of Ram Dhoka at previous public toilet place at Ram Dhoka

0.10 For our project we need to collect urine. For this reason we are thinking of placing a few public mobile urinals at some places in Siddhipur. The urinals could be used free of charge. What do you think of this? ***(show photo!)***

❑ Good idea (2) **23** ❑ I don't mind (1) **3** ❑ Bad idea (0) **1**

0.10.1 *If 0.10 "Bad idea":* Why would you not like public urinals to be set up?
possibility to misuse

If the family has access to an EcoSan toilet complete *Questionnaire Q1 EcoSan Toilet!*
If the primary or secondary sanitary technology is not an EcoSan toilet complete *Questionnaire Q2 No EcoSan Toilet*!

END

Remarks:
....
....
....
....
....
....

D.2 EcoSan Toilet

Q1 – ECOSAN TOILET

Main questionnaire number: ....

Date of the interview: ....

TOILET CONDITION ASSESSMENT

1.1 Size of the urine collection tank (litres): ....

100 litres: 24; 40 litres : 2

1.2 Is the toilet working properly or are there any problems?

5 times: tab broken; 2 times: leakages; 2 times: bad smell

1.2.1 Is the family collecting urine with the EcoSan toilet?

❑ Yes (1) **23** ❑ Directly to compost (0) **2** ❑ No **1**

1.2.2 *If 1.2.1 "No"*: What is the reason? ....

....

....

1.3 Approximate Size of the flushing pot (millilitres): ....

GENERAL

1.4 For how long do your family members have access to an EcoSan toilet already? ....

Average 2.9 years (min 1, max 5)

1.5 Does this EcoSan toilet belong to your family?

❑ Yes (1) ❑ No (0)

1.5.1 *If 'No'*: Who is the owner of this EcoSan toilet?

1 ❑ a neighbor
2 ❑ a friend
3 ❑ employer
4 ❑ other, namely: ....

If the EcoSan toilet is not owned by the family interviewed, only complete section *Usage* and *General Assessment*!

CONSTRUCTION

1.6 Has the NGO offered you different types of toilets when you built your EcoSan toilet?

❑ Yes (1) **1** ❑ No (0) **26**

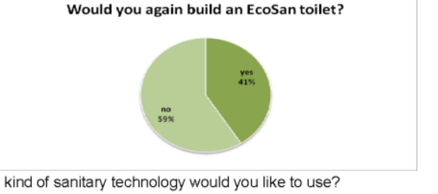
1.6.1 *If 1.6 'Yes'*: Have the different offered toilet types had been offered at comparable rates of subsidies?

❑ Yes (1) **1** ❑ No (0)

1.6.2 *If 1.6 'Yes'*: What are the reasons why you decided to build an EcoSan toilet instead of the other conventionally used sanitary technologies? **fertilizer**

1.7 If you could choose, would you again build an EcoSan toilet for your house or would you prefer a different technology now?

❑ Yes, would build again (1) ❑ No, would prefer other (0) ❑ Don't know.



1.7.1 *If 1.7 'No'*: What kind of sanitary technology would you like to use?

flushing toilet; pour flush toilet (10 times)

1.7.2 *If 1.7 'No*: What are the reasons that you would like to change to this other technology?

Difficult to use for guests (3 times); Not enough ash available, difficult to get (5 times); Difficult to use for children (3 times); Bad smell (2 times)

USAGE

1.8 What do you think do your neighbours and friends think regarding that you are using an EcoSan toilet?

2 ❑ They think it is good that we use an EcoSan toilet. **20**
1 ❑ They do not think in any special manner about us using an EcoSan toilet. **1**
0 ❑ They think it is bad that we use an EcoSan toilet. **6**
❑ I don't know.

Dilution

1.9 When you and the other members of the household use the EcoSan toilet for urinating, do you normally flush water after the urine?

❑ Yes (1) **26%** ❑ No (0) **74%**

1.9.1 *If 'Yes'*: How much water do you normally use for flushing?

1 ❑ 100 ml
2 ❑ 250 ml
3 ❑ 500 ml
4 ❑ 1000 ml
5 ❑ Other, namely: ....
6 ❑ ¼ water pot
7 ❑ ½ water pot
8 ❑ ¾ water pot
9 ❑ $^1/_1$ water pot

Average 140ml

1.10 When you clean the EcoSan toilet, do you normally use water for cleaning?

❑ Yes (1) **96%** ❑ No (0) **4%**

1.10.1 *If 1.10 'Yes'*: How much water do you think will go down the urine drain when cleaning?

1 ❑ 0.5 liter
2 ❑ 1 liter
3 ❑ 2.5 liter
4 ❑ 5 liter
5 ❑ Other, namely: ....

Average 770ml

1.10.2 *If 'Yes'*: How many times do you normally clean your toilet per month? ....

Average 4.85 times / month

Urinal

1.12 From your experience, how convenient is it for men to urinate in the EcoSan toilet compared to other conventional toilets?

❑ More convenient (2) **2** ❑ No difference (1) **11** ❑ Less convenient (0) **10** ❑ Don't know

1.13 What do you think of if your EcoSan toilet was added an external / internal urinal? ***(show picture!)***

❑ Good idea (2) **17** ❑ Not good, not bad (1) **1** ❑ Bad idea (0) **0** ❑ Don't know

1.13.1 *If person supportive*: If you can chose, would you prefer an internal or an external urinal?

❑ Internal (1) **14** ❑ External (2) **3** ❑ Doesn't matter (3)

1.13.2 Would you / the male members of your family use the EcoSan toilet more frequently for urinating if it had such a urinal?

❑ Yes (2) **16** ❑ May be (1) **1** ❑ No (0) ❑ Don't know

TOILET MAINTENANCE

1.14 Are there any costs to use the EcoSan toilet and keep it functioning (ash, saw dust, regular maintenance)? ....

Ash (1 bag for 10Rp with 1-2 bags per month) (8 times); New tab (2 times)

Faeces Handling / Usage (ask person who is actually doing it)

1.15 How often do you in average empty the faeces containers of your EcoSan toilet?.................................

Average 6.1 month

1.16 How many 50kg bags can you fill when you empty the vault? ....

Average 3 50kg bags

1.17 What do you normally do with the dehydrated faeces?

1 ❑ We put it on the compost (co-composting). **1**
2 ❑ We use it directly on our fields for fertilizing.
3 ❑ We store it on our farm for later use as fertilizer. **26**
4 ❑ We dump it somewhere because we have no use for it.
5 ❑ Other, namely: ....
....

1.18 Does the dehydrated faeces of your EcoSan toilet have a value to you or would you give it away for free?

❑ Yes, has value (1) **27** ❑ No, no value (0)

1.18.1 *If "Yes"*: How much (NRp)? *(only if the person has an opinion!)* ....

Average 1000NRp for 50kg bag

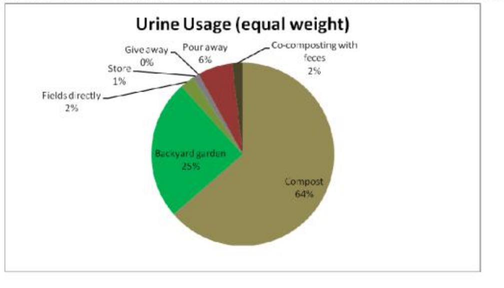
Urine Handling / Usage (ask person who is actually doing it)

1.19 How long does it normally take to fill the urine collection tank?

❑ ……. Weeks **Average 12.5 weeks**
❑ ……. months

1.20 What do you normally do with the collected urine when you empty the container? ***(open question, give no options! Several answers possible)***

1 ❑ We put it on the compost.
2 ❑ We use it directly for our backyard garden for fertilizing.
3 ❑ We use it directly on our fields for fertilizing.
4 ❑ We store it on our farm for later use as fertilizer.
5 ❑ We give it to someone else.
6 ❑ We pour it down the drains or somewhere else because we have no use for it.
7 ❑ Other, namely: ....
....

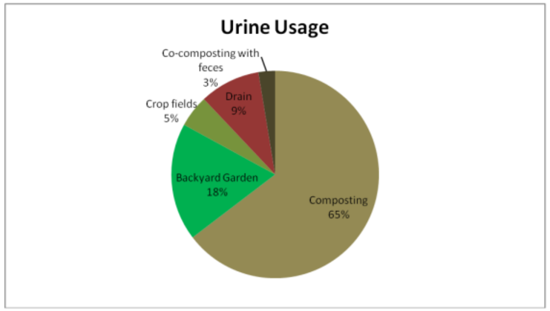


1.21 ***Play the Urine usage distribution play with the household members!***

Usage	A Composting	B Backyard Garden	C Crop Fields	D Drain	E other
Beans					
%					

State other usages: ....

....



1.21.1 *If some of the urine is poured down the drain:* At what times do you normally have to pour some of the urine away because you have no use for it? ***(only if the person knows!)***

J	F	M	A	M	J	J	A	S	O	N	D	
	M	F	C	B	J	A	S	B	A	K	M	P

Nominations: April 2 May 2 June 4 July 4 Aug 2 Sept 2 Oct 1

1.21.2 *If some of the urine is poured away:* Where exactly do you put the urine, if you do not have any use for it?

1.23 Do you have an idea, how much chemical fertilizer you can safe in average per year since you have an EcoSan toilet? Kg: **17.9 kg**

Urine Value

1.24 Does the *excess* urine you collect have a value to you or would you give it away for free?

❑ Yes, has value (1) **18** ❑ No, no value (0) **9**

1.24.1 *If 'Yes, has value':* If a neighbour of yours which you do not know very well is interested in your urine, how much money would he have to pay you for 100l of your urine (NRp)?

Average: 868 NRp for 100l

Composting

1.25 Do you use your urine for composting only when you have no other use or do you prefer composting over other usages?

❑ last resort instead of dumping (2) **15** ❑ preferred over other usages (1) **6** ❑ Don't know

1.25.1 *If "preferred over other usages":* Why?

easier to use; good all over effect; no other option (10 times); need much compost; good for compost

1.26 How do you apply your collected urine to the compost? (Amount, frequency, …)

with new waste (7 times); when tank full; daily (2 times); when tank full with a pipe; with new waste, 10l per time; direct connection to compost with pipe (2 times); 12l once a month every 2-3 month; directly to compost

1.27 Do you take any precautions to minimize nutrient loss from your compost?

❑ Yes (1) **6** ❑ No (0) **11**

1.27.1 *If "Yes":* What precautions?

plastic cover (4 times); cover with cement bag

ASSESSMENT OF MAINTENANCE / MANAGEMENT OPTIONS

1.29 Is the stated option *(see question 1.17)* to handle the dehydrated faeces convenient for you?

❑ Yes (2) **16** ❑ More or less (1) **8** ❑ No (0) **3**

1.29.1 *If 1.29 'More or less' or 'No':* What are the reason that the stated option to handle the dehydrated faeces is not very convenient to you?

bad smell, too wet, not completely decomposed; bad smell (3 times); lack of shovel / difficult to take inside (house?); lack of shovel; opening to small (2 times); low height of opening / vault (3 times)

1.29.2 *If 'More or less' or 'No':* What would you rather do with the dehydrated faeces if you could?

see that faeces is drier; no better options -> uses toilet only seldom!; smell reduction needed construct toilet with bigger vault opening (2 times)

1.30 Are you satisfied with the options you have to use the collected urine and are they convenient for you?

❑ Yes (2) **18** ❑ More or less (1) **4** ❑ No (0) **3**

1.30.1 *If 1.30 'More or less' or 'No':* What are the reason that the stated options to handle the urine are not very convenient to you?

bad smell (5 times); no space for composting and no time -> all drained

Public collection point

1.31 Do you sometimes have to get rid of your collected urine or faeces?

a) Urine: ❑ Yes (1) **30%** ❑ No (0)

b) Faeces: ❑ Yes (1) **11%** ❑ No (0)

If two times "No" go to public collection service!

1.31.1 *If 1.31 "Yes"*: Would it be a convenient option for you if there was somewhere a designated public place where you could dispose your urine or faeces for free?

a) Urine: ❑ Yes (1) **45%** ❑ No (0)
b) Faeces: ❑ Yes (1) **0%** ❑ No (0)

1.31.1.1 *If 1.31.1 "No"*: Why not?

❑ It is more convenient for us to dump the urine / faeces on our farm or somewhere nearby. **5**
❑ Others, namely: ....
....
bad smell of urine -> does not like to transport it

1.31.1.2 *If 1.31.1 'Yes'*: If you could chose, where should the collection point be located?
close to the house (3 times)

Public collection service

1.32 If someone regularly collected urine and faeces, would you give some urine / faeces away...

Urine:

... for free? ❑ Yes (1) **19%** ❑ No (0) ❑ Don't know
only ask if not for free:
... for money? ❑ Yes (1) **52%** ❑ No (0) ❑ Don't know

Faeces:

... for free? ❑ Yes (1) **0%** ❑ No (0) ❑ Don't know
only ask if not for free:
... for money? ❑ Yes (1) **22%** ❑ No (0) ❑ Don't know

1.32.1 *If 1.32 'No'*: What are the reasons why you would not give away some...

... urine:

1 ❑ We have use for all urine and do not want to give it away. **10**
2 ❑ We do not want anyone else to handle our faecal waste.
3 ❑ Others, namely: ....
....

... faeces:

1 ❑ We have use for all our faeces and do not want to give it away. **13**
2 ❑ We do not want anyone else to handle our faecal waste.
3 ❑ Others, namely: ....
....

1.32.2 *If for money only*: How much would the person have to pay you for ...

a) ... 100 litres of urine: **922 NRp**
b) ... a 50 kg bag of faeces: **1022 NRp**

1.32.3 *If 1.32 any 'Yes'*: The collection service might not be able to come to every household directly, how far are you willing to transport the urine / faeces to the collection service (in meter)? **Average 35m**

1.32.4 *If 1.32 any 'Yes'*: How many times should the collection service come by? Weeks: **4.4**

GENERAL ASSESSMENT

1.33 Over all, how does your family assess your EcoSan toilet compared to other sanitary solutions in regards of...

1.33.1 User Comfort

❑ much better (4) **1** ❑ better (3) **10** ❑ same (2) **4** ❑ worse (1) **12** ❑ much worse (0)

1.33.2 Hygiene

❑ much better (4) **1** ❑ better (3) **4** ❑ same (2) **10** ❑ worse (1) **11** ❑ much worse (0)

1.33.3 Maintenance costs and effort against benefit

❑ much better (4) **5** ❑ better (3) **21** ❑ same (2) **1** ❑ worse (1) **0** ❑ much worse (0)

END

Remarks:
....
....
....
....
....
....
....
....
....

D.3 Farming Questionnaire

FARMING QUESTIONNAIRE

Assigned household number: ....

Date of the interview: ....

Full name of the household head: ....

Full names of persons interviewed: ....

Questionnaire was conducted during 12. – 16.09.08 with 11 EcoSan households (ES) and 14 Non-EcoSan households (NES, neighbors of EcoSan households)

BASIC FARM CHARACTERISTICS

1 What is the size of your land on which you cultivate crops?

1 ❑ Ropani (~500m², 16 aana) ....
2 ❑ Aana (~30m²) ....

ES: 1.62 Ropani (0.082 ha)
NES: 1.69 Ropani (0.086 ha)
Total: 1.66 Ropani (0.084 ha or 842m²)

2 What is in average the distance from your house to the fields that you cultivate (meters or walking time in minutes)? ....

2.1 What is the minimum distance (meters or walking time in minutes)? ....
ES: 8 min (625m)
NES: 20 min (1470m)
Total: 15 min (1100m)

2.2 What is the maximum distance (meters or walking time in minutes)? ....
ES: 33 min (2510m)
NES: 36 min (2730m)
Total: 35 min (2630m)

CROP PATTERNS

3 What are the main crops and vegetables that you plant on your fields?

	Rainy Season %	Winter %	Other %
1 ❑ Rice / Paddy	**100%**.......	....	....
2 ❑ Wheat	....	**75%**..........	....
3 ❑ Maize	....	....	....
4 ❑ Millet	....	....	....
5 ❑ Potato	....	**3%**..........	....
6 ❑ Beans	....	**5%**..........	....
7 ❑ Mustard	....	**3%**..........	....
8 ❑ Chilly	....	....	....
9 ❑ Others, namely:	....	....	....
vegetables	....	**12%**..........	....
brick quarry	....	**2%**..........	....
....	....	....	....
....	....	....	....

FERTILIZERS

4 Do you have options to produce fertilizer locally on your farm?

1 ❑ Composting **ES: 100%, NES 100%**
2 ❑ Cattle **ES: 0%, NES 0%** ....
3 ❑ Other, namely: ....

4.1 *If 'have cattle'*: Are you using cattle urine for fertilizing crops or vegetables?

❑ Yes (1) ❑ No (0)

5 What kinds of fertilizers do you use on your farm? How much?

1 ❑ chemical fertilizers, brands: ....

ES:	**NES:**	**Total**
Urea 53 kg	**Urea 58 kg**	**Urea 55 kg**
DAP 3 kg	**DAP 15 kg**	**DAP 10 kg**

❑ organic fertilizers: ....

6 Do you prefer chemical fertilizer or organic fertilizer?

	❑ chemical fertilizer (1)	❑ organic fertilizer (2)	❑ Doesn't matter (3)
ES	**9%**	**64%**	**27%**
NES	**21%**	**50%**	**29%**
Total	**16%**	**56%**	**28%**

6.1 *If 'Yes'*: What are the reasons that you prefer this kind of fertilizer? ....

chemical:

insufficient organic fertilizer, organic fertilizer is difficult to transport; high yield (2 times); high impact / yield

organic:

plants grow well; cheaper than chemical fertilizer; good taste of crops (2 times); good for soil, high yield; good for soil (3 times); natural, high yield; chemical fertilizer destroys soil; nice plants with high crop yield; contains all nutrients needed (2 times)

URINE USAGE

7 Human urine is a good fertilizer and a number of people are using it for fertilizing crops and vegetables. Would you eat vegetables / crops fertilized with human urine?

	❑ Yes (1)	❑ No (2)	❑ Don't know (3)
NES:	**69%**	**8%**	**23%**

8 Did you know that human urine can be used for fertilizing vegetables and crops?

	❑ Yes (1)	❑ No (0)
NES:	**69%**	**21%**

If 8 "No":

9 Can you imagine using urine as fertilizer or would you have hesitations to use urine (cultural, religious, handling…)?

❑ Yes, would use (1) ❑ No use (2) ❑ Don't know (3)

If 8 "Yes, knows urine as fertilizer":

8 What do you think about human urine as fertilizer? ....

good fertilizer (6 times); good for composting (2 times); low yield, plants have diseases; good fertilizer with nice crop yield; very good fertilizer; good fertilizer, high crop yield, especially good for vegetables

If 8 "Yes, knows urine as fertilizer" or if Household with EcoSan toilet:

9 We are planning to set up a urine bank in Siddhipur.
Urine is an organic fertilizer.
It has a high nutrient value and a very good ratio of nutrients for the plants.

If you could buy urine fertilizer for a reasonable price and cheaper than chemical fertilizer (compared to the same nutrient amount), would you be interested to use urine?

	❑ for sure (5)	❑ probably (4)	❑ may be (3)	❑ rather not (2)	❑ for sure not (1)
ES:	**0%**	**0%**	**20%**	**0%**	**80%**
NES:	**18%**	**27%**	**18%**	**0%**	**36%**
Total:	**10%**	**14%**	**19%**	**0%**	**57%**

10 ***People with no EcoSan toilet:*** Would you be interested to have an EcoSan toilet?
Yes: 64% No: 36%

10.1 Why yes/no?
No: no space (2 times), bad smell (3 times)
Yes: to get fertilizer (7 times)

END

Remarks:
....
....
....
....
....