Master Thesis

MAP crystallization from urine–assessment of the international adaptability

Implemented within Project SANIRESCH in Eschborn

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- Implemented within Project SANIRESCH in Eschborn -

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Statement of Honour

I hereby declare that I personally have completed the present scientific work. The ideas obtained from other direct or indirect sources have been indicated clearly.

This work has neither been submitted to any other course or exam authority, nor has previously been published.

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Place, Date Signature

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Abstract

In GIZ German headquarters in Eschborn, a MAP reactor for struvite crystallization from urine was installed within the research project SANIRESCH. The MAP crystallization reactor is designed and manufactured by HUBER SE. Because urine has a high potential of nutrient recovery, especially phosphorus, phosphorus can be recycled as MAP fertilizer and applied in agriculture. Within this thesis, international feasibility of this technical approach was investigated.

Urine and MAP's characteristics were reviewed through a literature study. The technological performance of MAP crystallization reactor in project SANIRESCH was determined and evaluated. By using a utility analysis, based on the fundamentals of sustainable sanitation, the potential for international transferability was assessed.

In summary, MAP crystallization from urine provides a possibility to recover phosphors from urine in a decentralized sanitation system despite the optimization potential of its economic feasibility. Concerning worldwide transferability, forty-five countries were assessed in the study. Due to the environmental conditions including phosphorus import and consumption, eutrophication, high population density and high urbanization rate, and also the Mg reserves, urban areas in sub-Sarah and south-Asia and south-America were identified as hotspot of the implementation of MAP reactor.

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Abbreviations

AHP	Analytical hierarchy process
Avg.	Average
BMBF	Federal Ministry of Education
EU	European Union
l	Liter
MBR	Membrane bioreactor
MADM	Multi attributive decision method
MAP	Magnesium-Ammonium-Phosphate
MAUT	Multi attribute utility theory
MCDA	Multi criteria decision analysis
MODM	Multi objective decision method
Mg	Magnesium
N	Nitrogen
P	Phosphorus
PE	Polyethylene
SANIRESCH	Sustainable sanitary recycling Eschborn
USGS	United States Geological Survey

1 Introduction

Phosphorus is an essential nutrient for all living lives. However phosphate rock is a non-renewable resource which cannot be manufactured. About 90% of mined phosphate rock worldwide is used for agricultural and food production, predominately for fertilizers today (Prud Homme, 2010). One of an important reason for the increasing demand of phosphorus is changed feeding manner. The increasing popularity of meat- and dairy- based diet especially in growing economies regions such as China and India contributes to the increased consumption of phosphorus greatly (Cordell et al., 2009).

Nearly 100% of the phosphorus eaten in food can be excreted (Jönsson et al., 2004). Human urine contains amounts of nutrients, which provides a high potential of phosphorus recycling. Approximately 3 million tons of phosphorus globally can be found in human excreta every year which represent a huge amount of phosphorus source. However, only about 10% of urine can be recirculated back to agriculture because of end-of-pipe wastewater treatment system (Cordell et al., 2009). In order to protect the water body from Eutrophication, phosphorus is removed from waste water and transferred into the sludge, which is usually sent to landfills and cannot be used as fertilizer.

Nowadays more than 50% of people live in urban areas and it is estimated that there will be around 67% of urban population in the world in 2050 (UN, 2011). The increasing urbanization and also its huge demand of phosphorus present that cities have enormous opportunities for nutrient reuse from urine. This can be achieved both in low-tech approach, such as directly collecting and using urine as fertilizer to agriculture; or by using crystallization technology process to produce fertilizer product from urine. Struvite crystallization is a promising technique that can both remove phosphorus from wastewater and provide an alternative source of phosphate fertilizer (Jaffer et al., 2002).

Against this background, the German Federal Ministry of Education and

Research (BMBF) launched the research project “SANIRESCH -Sustainable sanitary recycling Eschborn” since 2009. Within the SANIRESCH project, a Magnesium-Ammonium-Phosphate (MAP) precipitation reactor (NuRec reactor), designed and produced by HUBER SE, is installed in the main building of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in Eschborn. The aim is to demonstrate the ecological sanitation (ecosan) concept with urine separate treatment, recovery phosphorus from urine and reuse MAP as fertilizer (Winker, 2011).

This thesis focuses on the MAP precipitation and reuse from urine in project SANIRESCH, mainly in the following two aspects:

1. Technical and economic assessment of MAP precipitation from urine based on existing data and experiments measurements

- Establish a mass-balance of phosphorus in collected urine sample and MAP and make a comparison to theoretically expected values

- Investigate how many percentages of solved P, N and K in urine can be recycled in Struvite (MAP).

- Characterize the Struvite (MAP) including its chemical composition and character.

- Calculate the cost of Struvite (MAP) product

- Summarize problem through operation

2. Appraise the international feasibility of MAP precipitation of urine

One of an important aspect within the research project is to investigate the global transferability of such a decentralized wastewater sub stream treatment approach. The key question in this context is whether MAP precipitation of urine is a feasible application in emerging and developing countries. To find out the ideal “hotspot” for the implementation worldwide, certain criteria for assessment should be defined. By using utility assessment, regions or countries can be appraised as feasible approach market.

Three hypotheses were assumed to the above mentioned questions:

Hypothesis 1: The MAP crystallization reactor, which is in used in Eschborn, is a pilot treatment model. Because of the pilot scale of the system, the optimization of the operation is relatively easy to be achieved. The technological performance of the reactor can be reliable and stable.

Hypothesis 2: New equipment and facilities need to be installed within the treatment plant. The investment cost and maintenance cost for MAP reactor and urine collecting system could be higher than the profit through using MAP as fertilizer.

Hypothesis 3: The MAP precipitation treatment reactor is very compacted and need sufficient supply of electricity; therefore it will be suitable to be applied in urban areas with high density (office building, school etc.) The hotspot regions of meaningful applications are areas with high demand of phosphate fertilizer.

2 Background

2.1 Nutrients in Urine

Urine has the largest proportion of nutrients found in waste water. However, urine makes only less than 1% of total domestic wastewater volume. As the most nutrient-abundant stream in wastewater- about 55% of phosphorus (P) and 80% of the nitrogen (N) and 60% of potassium (K) in wastewater originate from urine (Jönsson et al., 2000). Furthermore, only small amounts of heavy metal can be found in urine from 5% to 15% (Vinneras, 2001). This makes urine the target for phosphorus recovery from a very concentrated wastewater stream. Figure 1 and Table 1 shows the nutrient loads in urine and in German domestic wastewater.

Table 1 Nutrient loads in urine and wastewater in Germany (Source: ATV, 2000 and Meinzinger, 2009)

Nutrient Compound	Nutrient loads in urine (g/per. day) [1]	Nutrient loads in wastewater (g/per. day) [3]
N-total	10.2	11
P-total	1.0	1.8
K-total	2.7	5

1. Source: Meinzinger and Oldenburg, Characteristics of source-separated household wastewater flows: a statiscal assessment, 2009

2. Source: ATV-DVWK-A-131, 2000

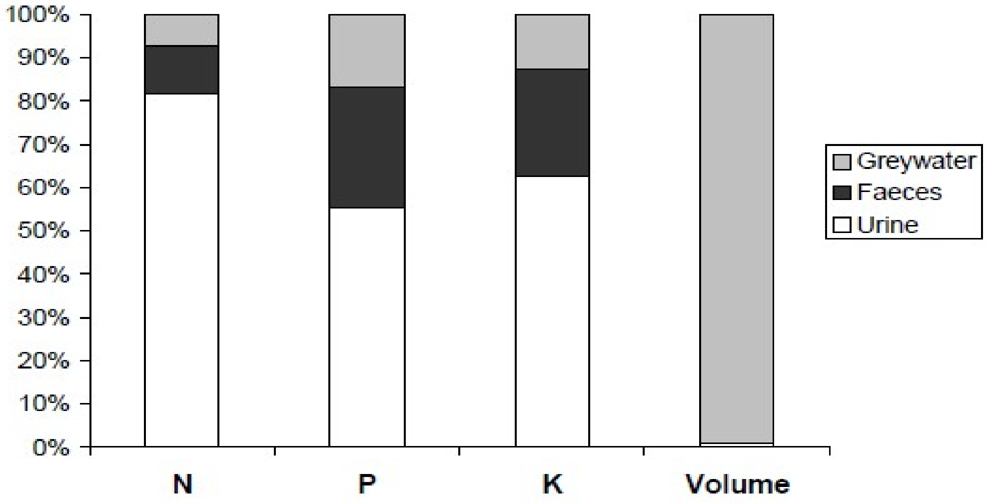


Figure 1 Content of Nutrients in domestic waster in Sweden (Source: WHO, 2001)

The major form of Nitrogen occurs in urine is urea (80%), while phosphorus is excreted as inorganic phosphate to buffer the pH of urine; potassium is mainly found in urine as ion (Vinneras, 2001). All of those nutrients are water-soluble, that makes it easily for microbiological digest or transfer to plant available compounds (Kirchmann, 1995).

2.5 Urine diversion

Ecological Sanitation (EcoSan) is an alternative sanitation approach based on ecosystem and the closure of material flow cycles. Urine diversion may be used in EcoSan system, but not a necessary (Von Münch and Winker, 2011). When urine is not mixed with faeces in the toilet, the urine can be used safely through simple storage (WHO, 2006). Urine is essentially sterile and contains more than 50% the phosphorus required to fertilize cereal crops (Cordell et al., 2009). Through a separation system, urine can be collected and stored in a tank before a further phosphorus reuse as fertilizer. The urine diversion is based on a toilet that can separate urine from faeces. There are different types of urine diversion toilets in the market. Urine diversion dehydration toilets (UDDTs) are dry toilets that separately collect urine and faeces with a special toilet seat or pan (Rieck and von Münch, 2011). There are also some UD toilets with flush water (UD flush toilets). Waterless Urinals – widely used by men at public toilets – can also work as urine diversion devices because pure urine is collected separately from faeces.(Winker and von Münch, 2011)

Research presented in this paper was conducted on pilot-scale systems using the urine diversion flush toilets NoMix™ (from company Roediger Vacuum) and waterless urinals (from company Keramag). (Figure 2)

Figure 2 NoMix UD toillets (right) and waterless urinals (Source: Hartmann, 2011)

The NoMix™UD flush toilets are made by Roediger with two separate bowls: a conventional bowl for brownwater and paper located at the back, and a front bowl for urine which is closed by a movable plug (Roediger, 2001). Each of the bowls is connected to two separated pipe connections (Werner, et al. 2009). Theoretically, the urine is collected undiluted without flush water by means of a valve located below the urinal bowl, which is opened when the user sits down (Roediger, 2001; Werner et al., 2009; Münch & Winker, 2009). (Figure 3)

By using the NoMix™UD flush toilets; urine can be collected nearly without flushing water, while faeces are flushed away with water. In addition, there are two different types of flushing buttons depending on the amount of water to flush. When pushing the small button, about 1-3L of water will be used to clean the urine bowl. The larger button uses 6L of water to flush away the faeces (Werner, et al. 2009).

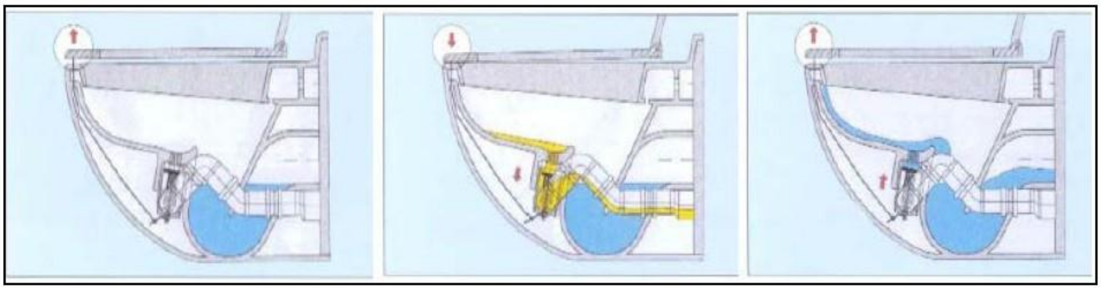


Figure 3 Functioning of the valve in the NoMix toilet (Source: Roediger, 2001)

The waterless urinals (model Centaurus), which are made of sanitary porcelain, are equipped with a sieve made of high-grade steel and a flat rubber tube as odour seal (Figure 2). The flat tube opens when urine flows through it. The sieve traps pubic hair which could otherwise stop the flat rubber tube from closing properly. (Winker, 2011)

2.3 MAP crystallization

Magnesium ammonium phosphate （MAP or struvite） precipitates in the presence of Mg^{+2} (M), NH_4^+ (N) and PO_4^{-3} (P) in water according to following reaction:

$$Mg^{+2} + NH_4^{+} + PO_4^{3-} + 6H_2O \rightarrow MgNH_4PO_4 \cdot 6H_2O \qquad \text{Equation 1}$$

MAP is a colorless crystal, with rhombohedra lattice type (Ganrot, 2005). (Figure 4) Dry MAP crystal contains 28% nutrient indigents Magnesium, Nitrogen and phosphor. The remaining 72% of MAP are 44% crystal water and other ammonium or phosphate compounds. The density of MAP crystal is $1.71 g/cm^3$ (Gmelin, 1953).

In wastewater treatment plants the precipitation of struvite occurs usually after anaerobic digestion of solids. The process release considerable ammonium and phosphate into the digester liquor (Barak and Stafford, 2006). Struvite can cause some problems by depositing in pipes. Therefore forced precipitation of struvite was originally investigated as a method to prevent problems in the operating system (Stratful et al., 1999).

However, struvite has a potential use as a slow release fertilizer because of its composition. When struvite is added to soil, phosphorus release appears to be largely the result of microbial nitrification of the ammonium constituent rather than simple dissolution (Bridger et al., 1962). In the recent decades, many researches focused on the recovery phosphate from wastewater or waste streams as MAP and reuse MAP as fertilizer.

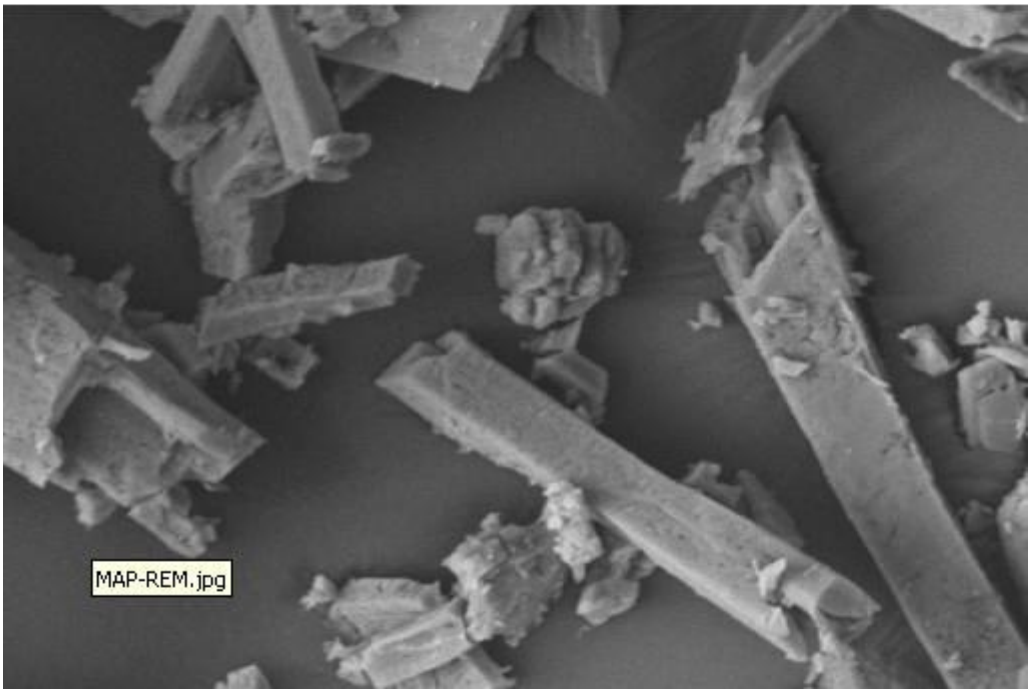


Figure 4 MAP crystall (Source: Hartmann, 2011)

There are several factors can affect the crystallization and growth of MAP.

- **pH**

pH is one of the major influencing parameters, as both NH_4^+ and PO_4^{3-} are strongly pH dependent: with increasing pH values the activity of PO_4^{3-} increases while NH_4 becomes less prevalent (Ronteltap, 2009).

Struvite has a low solubility in water (ca. 0.02 g/100ml water by 25°C), is highly soluble in dilute acidic solutions and highly insoluble in alkaline solutions (Weast et al., 1981). Crystallization of MAP is possible as pH is between 7.5 to 11 (Imtiaj et. al, 2004). The most favorable condition for struvite precipitation occurs at pH intervals around 9-10 (Mohajit et al., 1989)

- **Temperature**

Temperature is also an influence parameter to MAP crystallization. It has influence on both the solubility product of struvite and crystal growth. (Ronteltap, 2009) Struvite solubility was shown to increase with temperature from $0.3 \cdot 10^{-14}$ at 10 °C to an optimum of $3.73 \cdot 10^{-14}$ at 50°C (Aage *et al.*, 1997), so the precipitation of struvite is more difficult to obtain at high temperatures an additional factor is that the region of ammonia evaporation must be avoided. Struvite is thermally instable in temperatures over 50°C (Sarkar, 1991). Generally, temperature has only a subordinate influence on crystallizations grad of MAP.

- **Magnesium**

The molar ratio of MAP is Mg:N:P=1:1:1. But it was recommended in different literatures that Mg: P=1.3:0 is optimal for MAP precipitation (Montag, 2008). However Schulze-Retter et al. (2007) pointed the ratio more than up to Mg:P=1.5:1 cannot increase the phosphor recycling grad any more. Therefore in practical magnesium will be dosed from Mg:P=1.3:1 to 1.5:1.

To choose a suitable magnesium source as a MAP precipitant, several factors must be taken into consideration. The magnesium source has to be soluble in hydrolyzed urine, i.e. under alkaline conditions. In order to minimize transportation costs, the product should have reasonable magnesium content (Gantenbein and Khadka, 2008). One important aspect is also the price. Different form of magnesium has huge influence of MAP product. A brief comparison of magnesium precipitant by solubility and its price is shown on Table 2.

Table 2 Solubility and price of different magnesium precipitant (Source: Hartmann, 2011)

	MgO (technical)	MgO (analytical)	$MgCl_2 \cdot 6H_2O$	$MgSO_4 \cdot 7H_2O$
Solubility in water (20°C)	practically insoluble	practically insoluble	542 g/l	300g/l
Price	Ca. 20 €/kg 0.8 €/mol Mg	Ca. 500 €/kg 20 €/mol Mg	Ca. 20 €/kg 4 €/mol Mg	Ca. 50 €/kg 12 €/mol Mg

The most common precipitant for laboratory experiments is magnesium chloride and magnesium oxide (Etter, 2010). To find a cheap and efficient magnesium source is the very important. The profit of sale of struvite should cover the magnesium cost so that it would be financially feasible.

- **Stirring**

Turbulence can contribute to struvite formation, with as main reason the local rise in pH caused by CO_2 stripping (Stratful *et al.*, 2004). By accelerating the mixing in the process, the potential of struvite precipitation can be enlarged due to an enhancement of mass transport in the system (Kim et al., 2009).

However stirring may also have negative effects. Stirring had virtually less effect on the soluble P effluent concentration, yet higher mixing speeds led to a higher percentage of scaling on the reactor wall. Furthermore, high mixing speeds can limit crystal growth (Le Corre, 2006) and can break the final crystal, so that the crystal size may be reduced. (Ronteltap, 2009)

2.3 SANIRESCH Project

In order to demonstrate and research the implementation of an ecological sanitation (EcoSan) concept, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH started the SANIRESCH research project since 2009 with the approval of German Federal Ministry for Education and Research (BMBF). The project system was installed in main building “House 1” at GIZ’s headquarters in Eschborn (Figure 5), SANIRESCH stands for Sanitary Recycling Eschborn.

Figure 5 he main building ("House 1") at the GIZ headquarters in Eschborn near Frankfurt, where this project is implemented (Source: GTZ, 2009).

In GIZ's headquarters there are four buildings. The SANIRESCH system was built in House 1 during a renovation from 2004 to 2006. Within the SANIRESCH system, there is a separated collection and treatment of different wastewater streams, including greywater, urine and brownwater (Figure 6). In the middle part of the GIZ main building (House 1), 38 urine-diversion flush toilets and 23 waterless urinals are installed in order to collect brownwater and urine separately (Figure7). Nevertheless, unlike conventional sanitation system, three piping – systems were built within the building, one for greywater, brownwater and urine each. There are also four urine storage PE tanks with 2500l volume each installed in the basement floor. The pipe network allows filling each tank separately (Werner, et al., 2009).

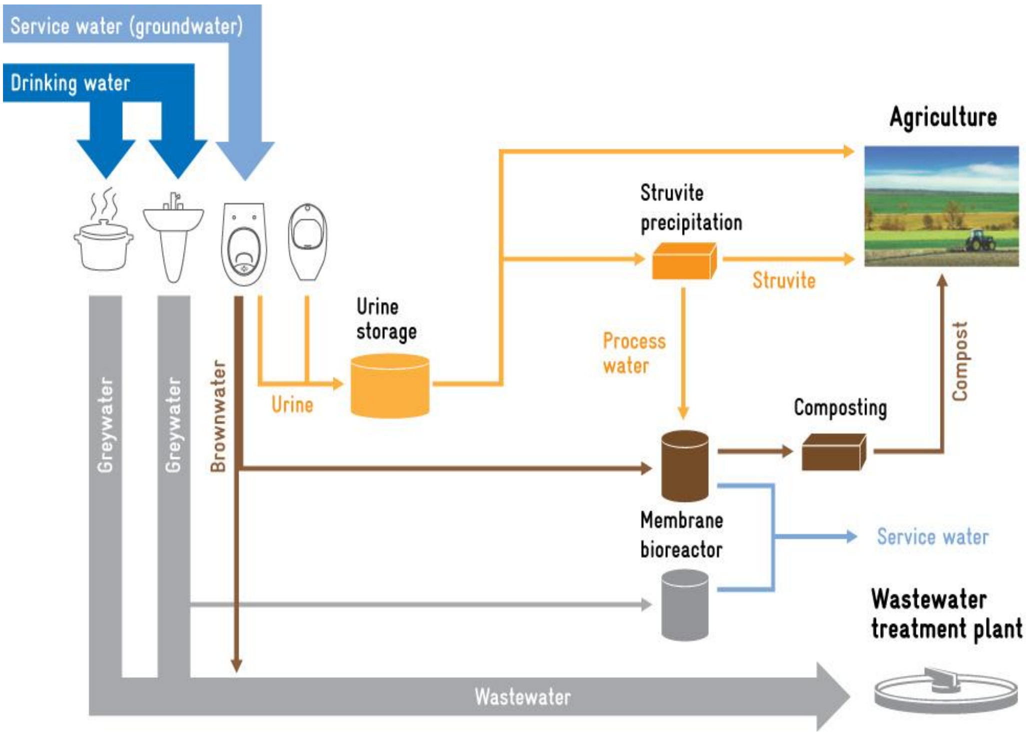


Figure 6 Sanitation system implemented within the SANIRESCH project (Source: GIZ, 2009)

The current employee working in the GIZ main building is about 650. There are approximately 190 employees connected to the separation toilets in the middle part of the building (Bischer, 2012). An exact number of users of the separation toilet are difficult to be estimated. Guests, visitors and external workers have to be considered, using especially the visitor toilets on the ground floor.

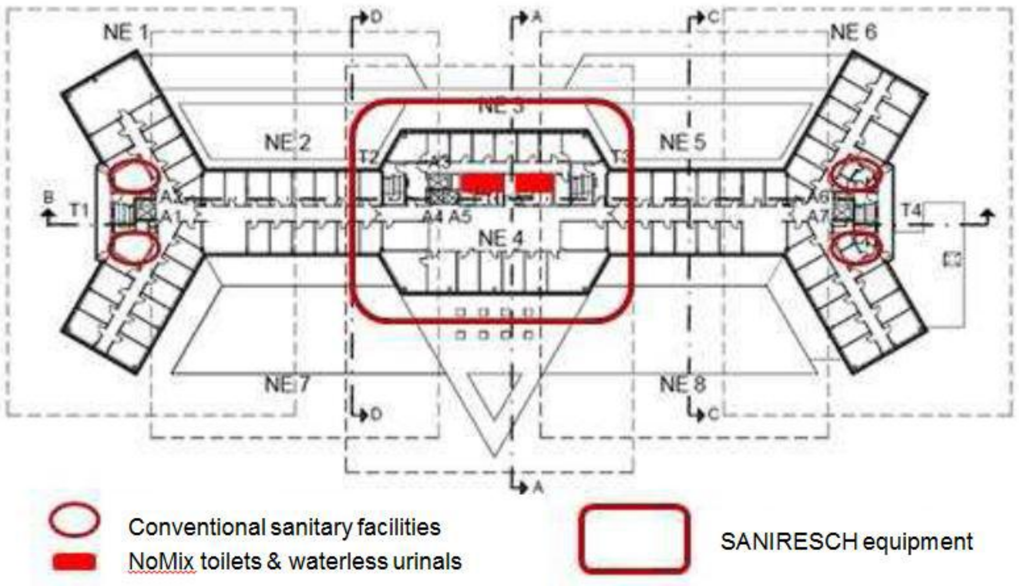


Figure 7 Ground plot of GIZ main building; (Winker et al., 2011)

Greywater is wastewater connected from kitchen sinks and dishwashers and hand wash basins will be transported to a MBR reactor. Brownwater will be led to another MBR reactor. Both of the two MBR reactors locate in the basement of GIZ main building. The detail description of MBR reactors will not be introduced here in this study. Flow charts of the two MBR reactors are shown in figure 8 and figure 9.

After the purifying of greywater and brownwater, the outflow of MBR reactors is so called service water, which can be reused as toilet flushing water. However, currently service water does not lead to actual reuse. This is because the GIZ had installed ground water pumps which supply the toilets with ground water as flushing water before the SANIRESCH project was started. Those ground water pumps have to be run to prevent that the ground water level rises too high which would cause problems in the two story underground car park underneath the GIZ office building. It will be led to conventional wastewater sewer system after MBR treatment. During the research, we assume that the ground water supply does not exist and service water gained through the MBR-purification process is reused in the building.

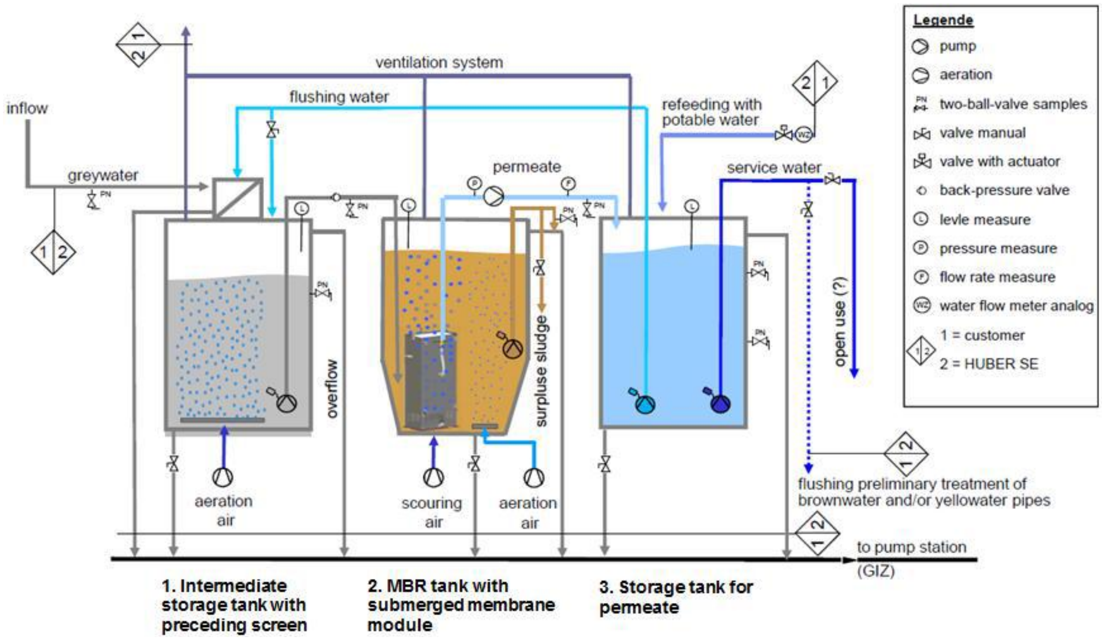


Figure 8 Flow chart of greywater treatment plant; (HUBER SE, 2011)

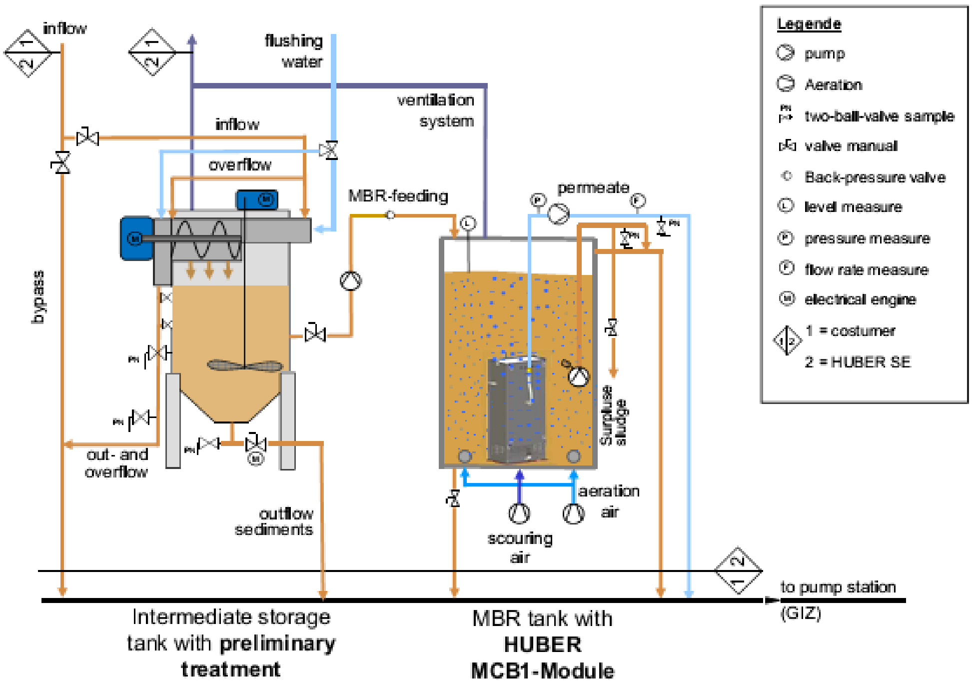


Figure 9 Flow chart of brownwater treatment plant; (HUBER SE, 2011)

Despite from water save and reuse, another component of the project is phosphor recovery from urine. A precipitation reactor for the extraction of magnesium ammonium phosphate (MAP or Struvite) from urine was installed. The urine after the precipitation process is led to the sewage system. Nitrogen recovery and further treatment of urine is not taking place in the project. MAP product gained from the treatment will be used as fertilizer. In the SANIRESCH project, MAP samples will be used as research purpose by project partner Uni Bonn. The exact mode of operation for the struvite reactor will be explained in the corresponding chapter 3.1.

3 Materials and Methods

3.1 Urine treatment

In May 2010, the MAP precipitation reactor, designed and constructed by HUBER SE (Figure 10) was installed in the 2nd basement of the main building of the GIZ. The treatment capacity of the reactor is 400l urine per day, up to 40 liter per cycle (Winker and Saadoun, 2012).

Figure 10 MAP reactor by HUBER SE (source: GIZ)

Approximately 400 people per working day produce 40m^3 per year urine are collected in four polyethylene tanks of 2.5m^3 each (Winker and Hartmann, 2010). Each tank captures approximately 2000 l of urine. Each batch of treated urine consists of 800 liters and contains 20 cycles. The temperature of the urine is not regulated. The pH of urine in the storage tank is between 8 and 9, whereby the precipitation of MAP is enabled (Hartmann, 2011). The urine tanks locate in the 1th basement in GIZ’s main building. The tanks are separately filled in with urine. (Figure 11)

Figure 11 Urine storage tanks

Since June 2010, the reactor is in operation. The reactor consists of a conical sedimentation tank with a stirrer, a conveying screw, through which the precipitant is added to a filtration step, five filter bags under as well as a vacuum pump, to discharge the treated urine into sewage. (Figure 12)

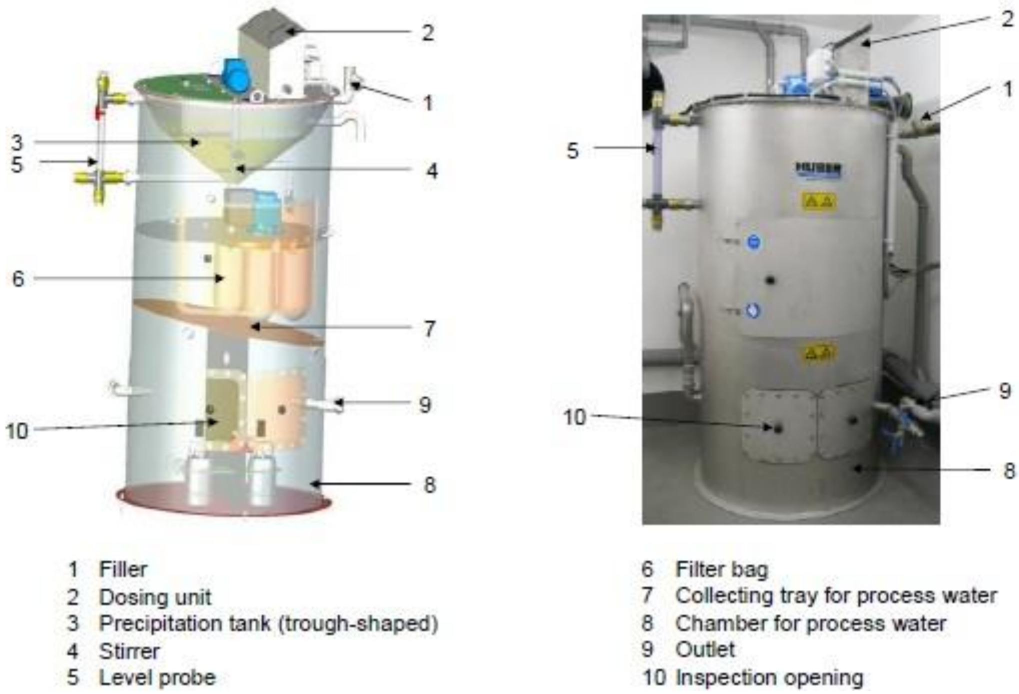


Figure 12 Individual parts of MAP reactor (Source: Huber SE)

In front of the reactor there is a basket strainer connecting urine inflow pipe and the reactor (Figure 13). Through the basket strainer some the solid impurities in the urine such as sediments can be removed, so that we can obtain MAP with better quality.

Figure 13 Basket strainer in front of MAP reactor

After the basket strainer there is a dirt trap directly installed before the inlet of the reactor. The wire mesh in dirt trap and hold fly larvas other organic deposits which occurs in urine pipe and urine tanks, to avoid those impurities get into the reactor.

Figure 14 Dirt trap of the MAP reactor (Source: GIZ, 2011)

A Conveying screw located on the top of the reactor, adding magnesium oxide

(MgO) bags into the urine for each batch automatically through a computer monitor. The MgO powder is weighted packed with water-dissolvable vinyl alcohol manually. The magnesium oxide used corresponds to the quality of technical MgO (pure, light) from the catalog of chemicals company Geyer GmbH & Co. KG (Hartmann, 2011). For 40l urine each batch, 14g MgO will be dosed into the precipitation process. There are totally 25 chambers in the conveying screw. This allows the reactor to operate with 25 cycles, before the precipitant are refilled.

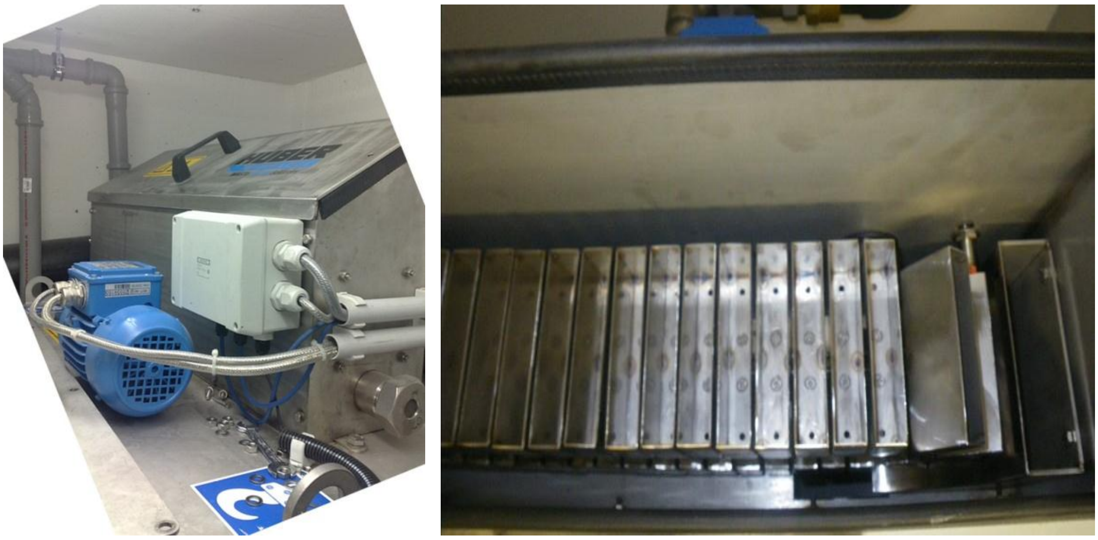


Figure 15 Conveying screw of MgO (Source: GIZ, 2010)

After the dosing of MgO there is a stirring in the reactor to mix the MgO with urine (Figure 16). During this chemical reaction between urine and MgO, forms Magnesium-Ammonium-Phosphate (MAP or so called Struvite).

Figure 16 agitator of the MAP reactor

The agitator of the reactor consists of three cross members, which are arranged offset from one another. In order to have an additional turbulence arise in the upper, crossbar plates are attached. Furthermore, the cross struts are slightly inclined. (Hartmann, 2011)

According to Winker, 95% of the precipitation process takes place within the first 30 to 90 min after the MgO has been added and the mixture has been stirred three times for 30 sec each with a 30 sec break after each stirring interval (Winker, 2012). Then sedimentation for 90 minutes takes place in the reactor to separate the urine and MAP crystal before filtration.

Filter bags with pore 10μm which made of polypropylene with a plastic ring are used for filtration (from company Schwegmann Filtrations-Technik GmbH). There are five filter bags anchored the in a rotatable device. After the processing of each cycle, the treated urine is filled in two filter bags. The sedimentation has two outlets. Through the first outlet, the majority of urine in upper part of the cone is released (25-35 l) after sedimentation in one of the five filter bags. On the second run, the last 5l of urine are released and (using a filter in a different position in the filtration revolver). After the urine has run through in one cycle (40l), the next two filter bags rotate to filter the urine of the upcoming cycle. Each filter bag filters the amount of four cycles in sum, so that five filter bags can be used in one batch (800l).

Figure 17 Filter bags used in one cycle

Urine will be discharged directly into the sewer system after filtration. MAP remains in the filter bags. After the processing of one batch, the filter bags are taken out of the reactor and put into a drying box. Filled filter bags are hung into the box to let the urine liquid drop off and so that the filter bags start drying at an ambient temperature. (Figure 18) There is an outlet for dripping liquid at the bottom of the box.

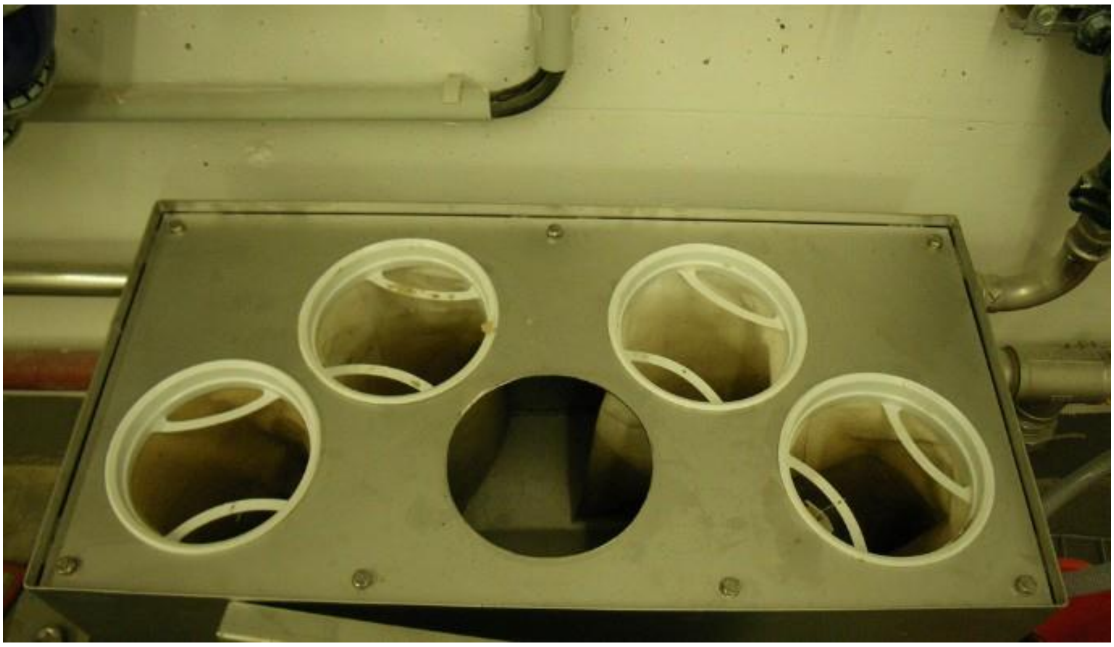


Figure 18 Drying box (Source: GIZ, 2010)

After 3 to 7 days the bags are put in a drying oven for up to 5 days in the summertime and up to 10 days in the wintertime until it is dried sufficiently for storage (Bischer, 2012). The temperature of the drying oven is about 39 ℃. The heating temperature of drying oven should be as low as 50 °C; otherwise it can cause irreversible transformations of MAP. The ammonium will begin to loss as a gas form.

The dried MAP is hanging on the inside of the filter bag after drying process. MAP powder should be removed from the filter bag manually by beating and scratching the bag. This can cause a loss of MAP, because it is not possible to gain 100% MAP from the filter bag. An average loss of 24.5% of the precipitated struvite has been assumed (Bischer, 2012). MAP is collected in clean glass bottles. (Figure 19) MAP is free of pharmaceutical residues that contained in urine (Winker and Tettenborn, 2011).

Figure 19 MAP gain from urine (Werner et al., 2009)

3.2 Laboratory experiments

The aims of experiments are to determine the concentration of phosphors, nitrogen, and ammonium in urine before and after the treatment and also in MAP gained from the urine; to establish a mass balance of phosphate in urine treatment. The phosphorus balance bases on the following equation:

$P_{inflow}=P_{outflow}+P_{struvite}+P_{loss}$ (Equation 2)

P_{inflow} – phosphate mass in urine inflow

$P_{outflow}$ – phosphate mass in urine outflow

$P_{struvite}$ – phosphate mass in MAP

P_{loss} – phosphate mass in urine inflow

In order to establish a phosphorus-mass-balance, the phosphorus mass in urine both in inflow and outflow and also in MAP should be determined. The aim is get a minimized difference between removed phosphorus in urine and recovered phosphorus in MAP.

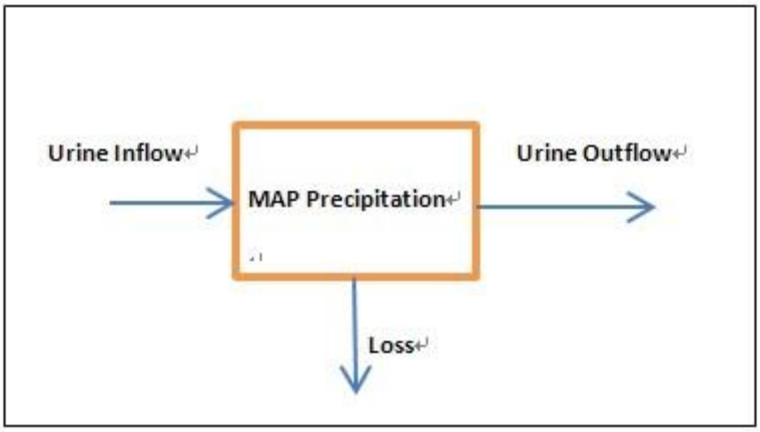


Figure20 Mass-balance in treatment

The recovery rate of phosphate can be calculated as following equation:

$$R_p = \frac{\text{Pstruvite}}{\text{Pinflow}} * 100\% \qquad \text{(Equation 3)}$$

The samples are taken under the following operation parameter:

Table 3 Operation parameter of sampling

Parameter	Time
Duration wait after dosing	420 seconds
Duration stirring	3 min
Duration sedimentation	90min

3.2.1 Sampling

Urine samples were taken from three days, in each measurement day the reactor ran three cycles. For each cycle, 25L urine was treated. The urine samples were taken in three parts of the reactor. The influent samples were taken directly from the semimetal tank before adding the MgO packet. The effluent samples are taken from two parts of the outlet of the reactor. As it was mentioned in section 3.1, the outlet of treated urine is divided to two parts, so for each cycle we need to get two samples for effluent. In the first run, 20l of urine came out from upper part of semimetal tank. In the second run, the last 5l urine mixture came out from another pipe. We got 3 urine samples in each cycle, which were preserved in 250ml plastic bottles. The reactor used urine was from tank number 1. (Figure 21)

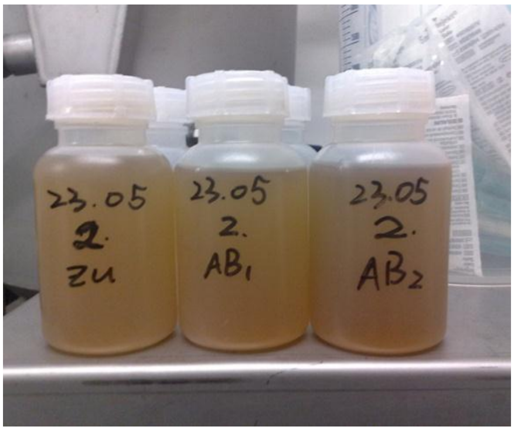


Figure 21 Sample bottles for urine

As the over dosage of MgO can cause a further reaction in the effluent of treated urine, MAP can still develop and deposit in the sample bottles. MAP built in the sample bottles however cannot represent the efficiency of the reactor. To obtain urine samples that not interfered by MAP reaction in the bottle after sampling, urine samples were filtered with membrane filter (pore size: 0.45μm) and preserved with 1% HNO_3 (9ml 1%HNO_3+1ml Sample). So that the pH in the tube above 7 and prevent the growth of MAP. (Figure) Urine samples were stored in refrigerator in laboratory of Institute IWAR, TU Darmstadt.

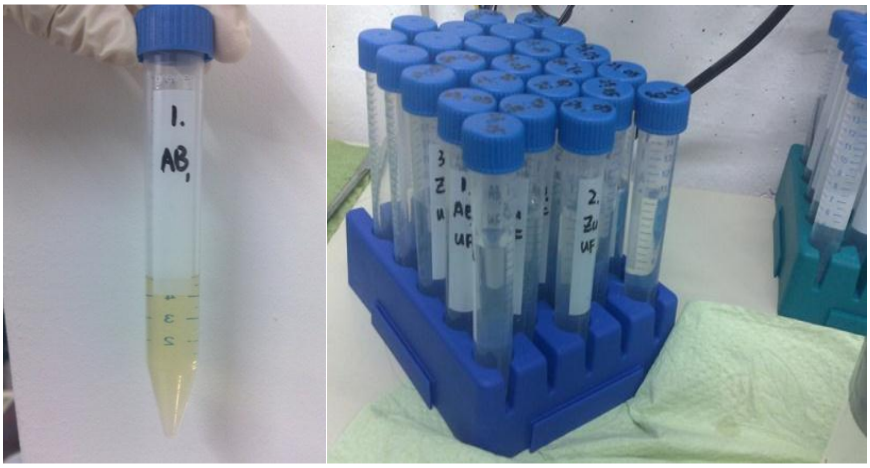


Figure 22 Filtered urine sample and tubes filled with HNO_3

After each batch (3 cycle), there are two filter bags filled with dry struvite collected from the reactor. The MAP solid samples was scratched by hand from the inside wall of the filter bags. MAP samples were preserved in glass bottles and putted into in a desiccator.

3.2.2 Analysis methods

Cuvette-Test (LCK 350) from Hach Lange was used to determine the orthophosphate, total phosphorus in urine samples. The determination method was carried out strictly according to the manufacturer's instruction, which is accompanied in the package of the cuvette-test. To ensure that the samples are in the range of cuvette-Test, the urine samples were diluted with distilled water. While the samples of the filtered precipitate from the reactor partially could be analyzed without dilution, the untreated urine had to be diluted 1:20 h the dilution of the filtered precipitate in the first 20L was 1:10.

The determination of the ammonia concentration was also performed with a cuvette-test (LCK 303) of Hach Lange. Each sample had a dilution of 1:100 with distilled water. The total Nitrogen was determined by cuvette-test (LCK338) with unfiltered original sample by dilution 1:50.

The MAP samples were washed with a saturated solution and then dried MAP for seven days at 30 ° C. Each of the samples of the P, N, Mg and Ca content in mg/kg was determined. The analysis of phosphorus, magnesium and calcium in accordance with DIN EN ISO 11885 using the ICP-OES (inductively coupled plasma optical emission spectrometry) in laboratory on the behalf of Institute IWAR TU Darmstadt. As parallel experiment, urine samples were also determined using ICP-OES for phosphor, calcium, potassium and magnesium.

3.3 Decision making tool

One of the main tasks of this master’s thesis is to find an international valid instrument for decision-making. Thus, an assessment system is meant to establish the preferential technical application and transfer in the case of MAP precipitation from urine. It shall identify whether it makes sense to implement an MAP precipitation system from urine at a particular place or in a particular application, or not.

The multi-criteria decision making (MCDM or MCDA) problem deals with the evaluation of a set of alternatives in terms of a set of decision criteria (Triantaphyllou et al., 1998). MCDM is divided into Multi-Objective Decision

Making (MODM) and Multi-Attribute Decision Making (MADM). (Figure 23) Based on the number of alternatives under evaluation, MADM methods aim to select discrete alternatives, while MODM are more adequate when dealing with multi-objective planning problems with a theoretically infinite number of continuous alternatives (Mendoza & Martins, 2006).

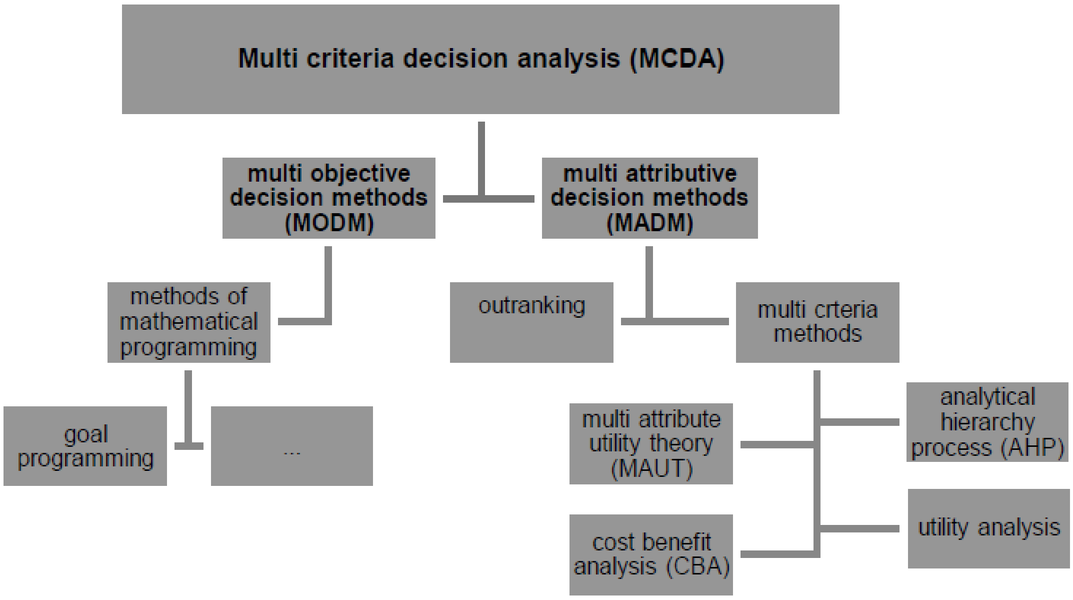


Figure 23 MCDM methods (source: Löw, 2011)

To identify the international transferability of MAP precipitation from urine, the multi attributive decision making (MADM) is an appropriate method. As MADM focus on the same object but there are several of alternative conditions in different part of the world. A suitable model within the group of multi criteria methods is the multi attribute utility theory (MAUT), it is based on strict adherence to use theoretical rationality axioms. In contrast, the utility analysis is a more heuristic method (Löw, 2011).

The utility analysis requires rating on regulation of priority; equal scoring results without preference are possible. In classical decision theory there are always two alternatives comparable. The decision maker can always make a statement and a clear preference, which of the two alternatives is strictly preferred (strict preference), or if both are equivalent (indifference). Outranking procedures aim to give a decision aid in situations of uncertainty and vagueness (Schuh, 2001).

The decision was taken to use the utility analysis in the thesis. The main reason for this decision has been the moderate demand of the tool for preference articulation. In regard of the international transferability of MAP crystallization technology, there are no first choice decisions available. Worldwide, many hotspots can be identified for meaningful implementation of phosphorus recovery from urine by MAP precipitation. Due to a wide range of influencing factors within the decision-making process, utility analysis is the most appropriate method, as it considers many aspects, not only economic ones such as cost-benefit analysis. Another advantage is the easy and heuristic application of the approach. An overview of advantages of utility analysis is shown in Table 4.

Table 4 Appraisal of utility analysis (Source: Schuh, 2001)

Attribute of utility analysis	**Performance**
Completeness	Yes
Transparency, traceability, objectivity	Transparency and accountability is obtained through the explicit disclosure of respective preferences in the form of criteria weights and aggregation procedures. This prevents that subconsciously factors are incorporated in the criteria rating. Objectivity will not be ensured by the procedure but at least traceability.
Accuracy and validity	Yes
Reliability	Yes
Influence of new alternatives	No influence of new alternatives on existing assessments
Structural openness of method	Yes, new criterion requires merely new weighting of all issues
Convenience and efficiency	Yes

Clearness	Yes
Required data input	According to the analysis method, quasi-cardinal data are necessary, but ordinal data are often regarded as sufficient if a fundamental transformability in benefit points is possible.

The utility analysis process is as follows:

- -Find out object problem
- -Definition the criteria and sub-criteria
- -Weight the criteria according to importance
- -Give each criterion a rating for object
- -Calculate the result

First, find out the applicable criteria for the decision making. Second, the criteria were weighted according to their importance for the objective of the decision making process. Rating and percentage are given according to the importance. Summary of all criteria is 100%. The rating and the criteria were listed and assessed in a matrix. The calculating method is shown in figure 24.

To perform the evaluation of a project, each sub point has been assessed regarding accuracy with the statement. In every assessment the sub criteria were multiplied by the weighting factors and summarized as a total value (Löw, 2011).

The result of the matrix is a percentage value that can be compared with each other. If the result is close to the total weight (100%), than it is more suitable to choose the object, which match the criteria.

Predictors = $[p_1, p_2, \ldots, p_n)$

Predictor Weights **a** = $[w_{p1}, w_{p2}, \ldots, w_{pn}]$ To be maximized

Criteria = $[c_1, c_2, \ldots, c_m]$

Criteria Weights **b** = $[w_{c1}, w_{c2}, \ldots, w_{cm}]$ Predetermined by Organization

$$\begin{array}{cc|c:c|}
 & & \textbf{Predictors} & \textbf{Criteria} \\
 & & 1\ 2\ \ldots\ n & 1\ 2\ \ldots\ m \\
\hline
\textbf{Predictors} & \begin{matrix}1\\2\\n\end{matrix} & \Sigma_{1\,1} & \Sigma_{2\,1} \\
\hdashline
\textbf{Criteria} & \begin{matrix}1\\2\\m\end{matrix} & \Sigma_{1\,2} & \Sigma_{2\,2} \\
\hline
\end{array}$$

$$r_{xy} = \frac{a'\,\Sigma_{1\,2}\;b}{\sqrt{a'\,\Sigma_{1\,1}\;a}\;\sqrt{b'\,\Sigma_{22}\;b}}$$

$$a = \frac{\Sigma_{1\,1}^{-1}\;\Sigma_{1\,2}\;b}{\sqrt{b'\,\Sigma_{22}\;b}}$$

Figure 24 Matrix calculation

To illustrate the utility analysis, a simple example is given:

Table 5 An example of utility analysis matrix

Criteria	Weight (total 100%)	**Object 1**		**Object 2**	
		Rating	**Result**	Rating	**Result**
Criteria 1	10	1	10	5	5
Criteria 2	20	5	10	10	20
Criteria 3	30	1	30	1	3
Criteria 4	10	10	10	1	1
Criteria n	20	10	20	1	2
Result (%)			**80**		**31**
Compare the results, for 80>31, Object 1 is suitable as Object 2 for the assessment					

Usually there must be a description of rating to each criteria attached to the matrix. As for each different evaluation, the ratings are given in different ways. This is determined by the aim of the assessment.

4 Results and Discussion

4.1 Performance of MAP crystallization reactor

- **MAP recovery from urine**

The average gain of MAP from 75L urine is 108.4g, which is equivalent to 1.45g dry MAP per liter urine. Total phosphorus in MAP is 0.10g P_{total}/g MAP. According to the total phosphorus in MAP and total phosphorus in urine influent, the phosphorus recovery rate was achieved by 72.50%.

Table 6 P-recovery in MAP

Nr.		**MAP (g)**	**Total P in MAP (g)**	**Total P in influent (g)**	**P-recovery rate**
1		108.15	11.56	15.60	74.10%
2		115.84	11.22	16.20	69.26%
3		101.34	11.10	14.97	74.15%
	Avg	**108.44**	**11.29**	**15.59**	**72.50%**
	MAP (g/l urine)	**1.45**			
	Total P (g/g MAP)	**0.10**			

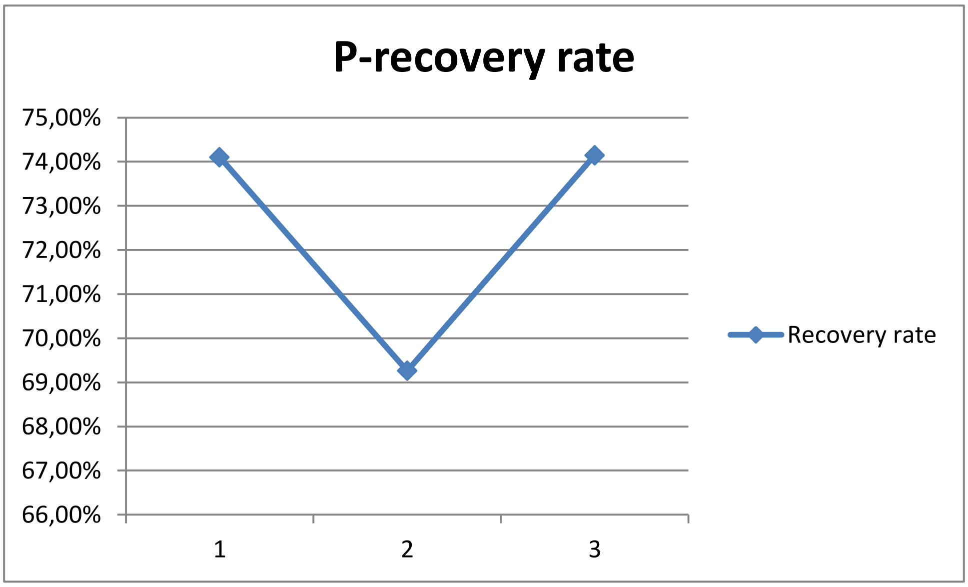


Figure 25 P-recovery rate determined by MAP

The calculated theoretical phosphorus in MAP is P_{total}=0.14g P/g MAP. The result shows P-recovery in MAP is achieved by a quite satisfied level.

There is still optimized space, as MAP can be practical recovered by 90%.

- **Phosphor (P) balance in MAP precipitation**

In urine, the major part of phosphorus is in form of orthophosphate. The result of the experiment showed that the difference between orthophosphate and total phosphorus concentration in urine influent is very little. (Figure 26) The average orthophosphate concentration in urine influent is 200.7mg/l while the total phosphorus in urine is 211.1mg/l.

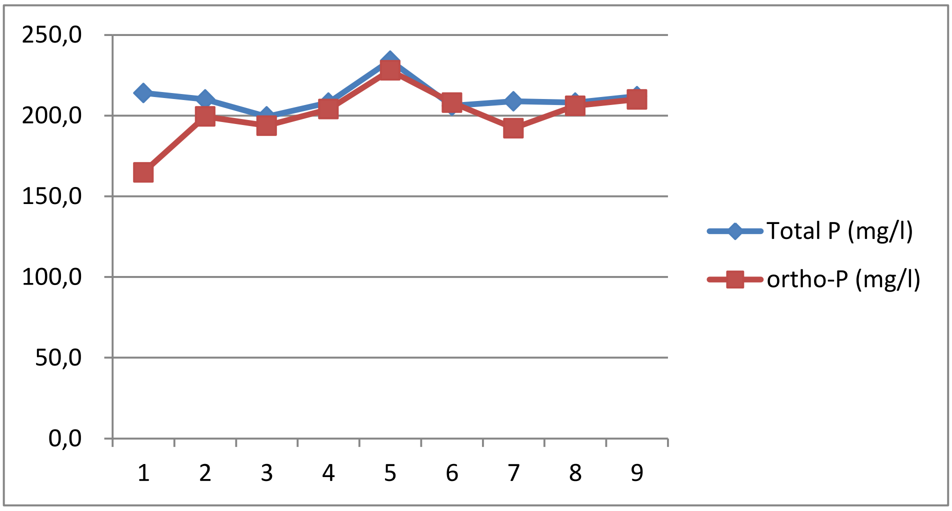


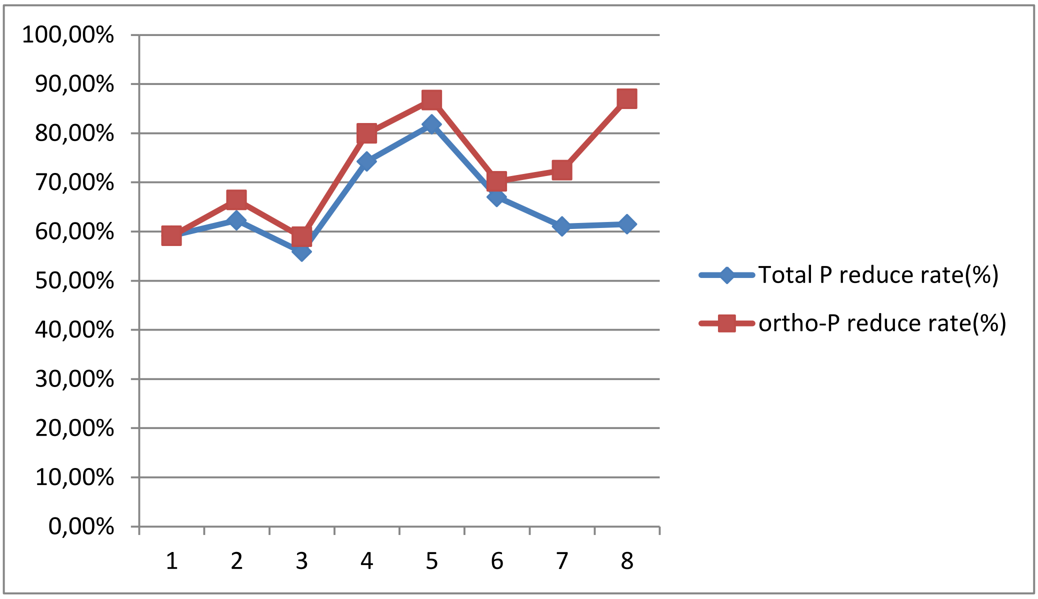
Figure 26 orthophosphate and total phosphorus in urine influent

In the view of total phosphorus, the difference between influent and effluent is smaller than orthophosphate. About 59-81% of total phosphorus or 59-86% of ortho-P can be removed from urine. (Figure 27)

process. Although a fluctuation of the performance can be observed from the recovery rate. The MAP precipitations can remove and recover about 65% of the total phosphor and 70% of ortho-phosphate from urine. Ortho-phosphate removal rate is higher than the value of total phosphor; this may be caused by the MAP built in the bottle. Ortho-phosphate in the sample bottle may had a reaction with over dosed MgO and further reduced after sampling.

The reduce rate of phosphor in urine matches well with the P-recovery rate in MAP, which is 65-70% to 72% on average.

Figure 27 Percentage of Ptotal an orhto-P removed from urine



Based on the experiment, the phosphorus mass balance was established. (Figure 28) Eliminated phosphors were determined as 11.45g in 75l urine which match the phosphors recovered in MAP quite well (11.22g in 75l urine).

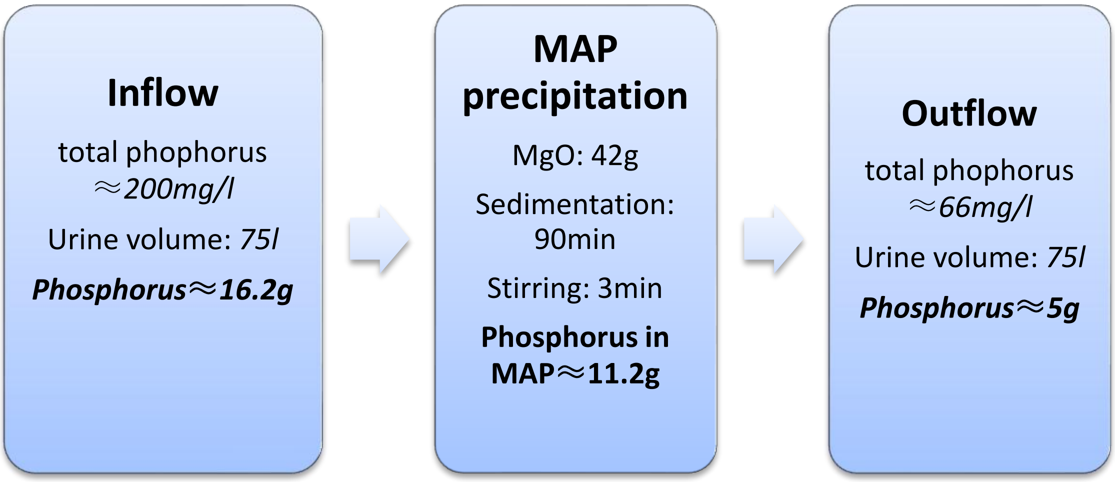


Figure 28 phosphorus mass balance for MAP reactor

- **Nitrogen (N) removal in MAP precipitation**

The influent NH_4 concentration in urine is 2933mg/l. But after the process, only 4.21% of the NH_4 was reduced on average. The NH4 concentration in treated urine is 2786mg/l. The NH_4 reduce rate is from 2% to 8% (Figure 29)

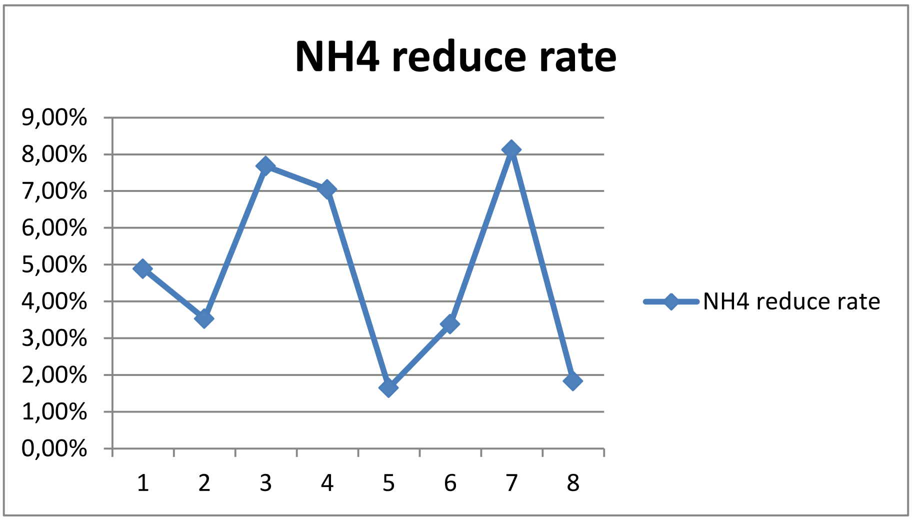


Figure 29 NH4-reduce rate

The total Nitrogen in urine influent was about 2974mg/l only 3.36% was removed after treatment, which means the total Nitrogen in urine effluent is 2869mg/l on average. The range of N_{total} reduce rate is from 2% to 5.5%.

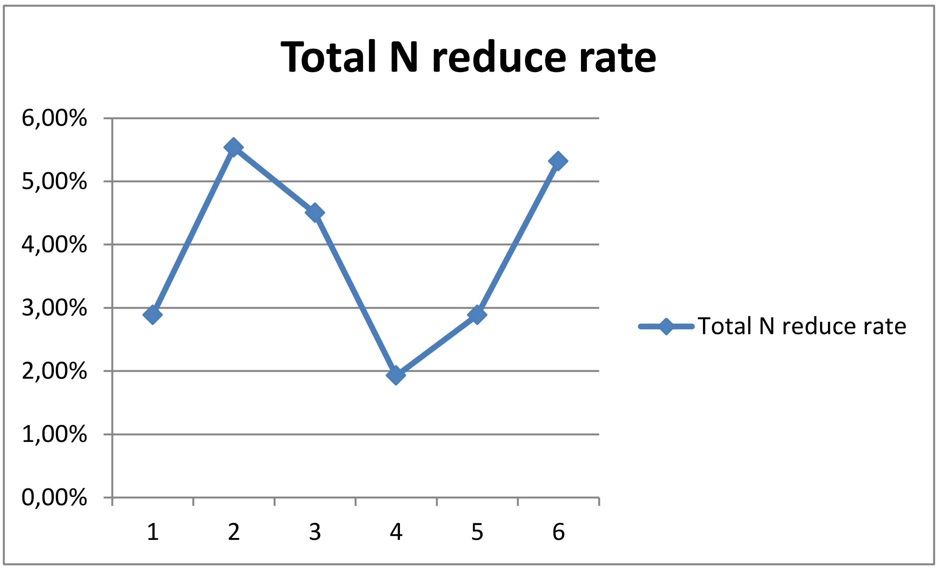


Figure 30 Total N reduce rate

A further treatment of nitrogen or ammonium is necessary, as the MAP precipitation alone cannot remove nitrogen effectively. The effluent concentration of NH_4 is still very high. The removal efficiency of NH_4-N of the MAP reactor is not enough to deal with the high ammonium concentrated waste water.

- **Potassium (K)**

In influent urine, the K concentration is on average 1464mg/l, while 1460mg/l in effluent. Only tiny amount of K will be removed from urine. The K concentration in MAP is from 5000-9000mg/kg MAP, which means the about 0.66% of the K from urine can be found in MAP.

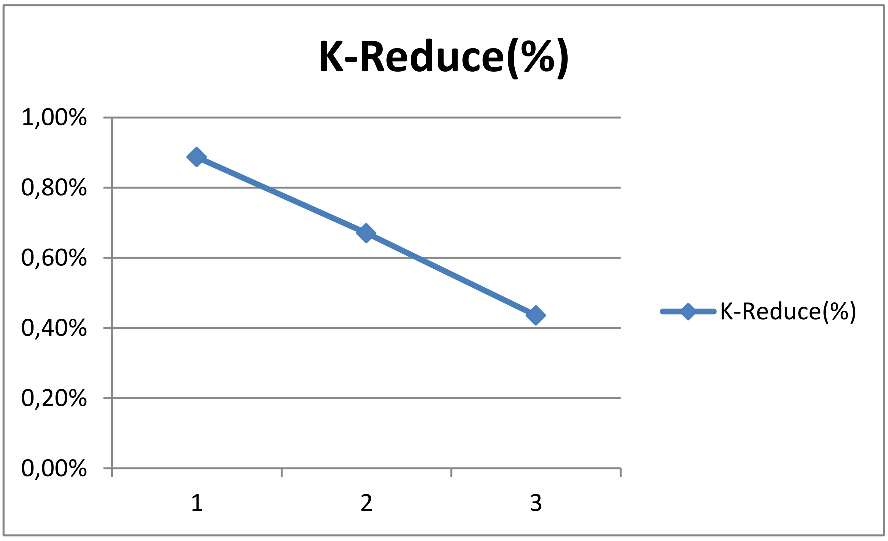


Figure 31 K-reduce rate in urine

- **Magnesium(Mg)**

First of all the composition of MgO was determined by ICP-test. In each 14g MgO packet, contains 59.4 mg Ca and 8080 mg Mg. Mg concentration in untreated urine is about 2.5mg/l. 3410mg of the 8080mg magnesium from urine and MgO will be found in MAP after the reaction. 42% percent of Mg will be changed into MAP.

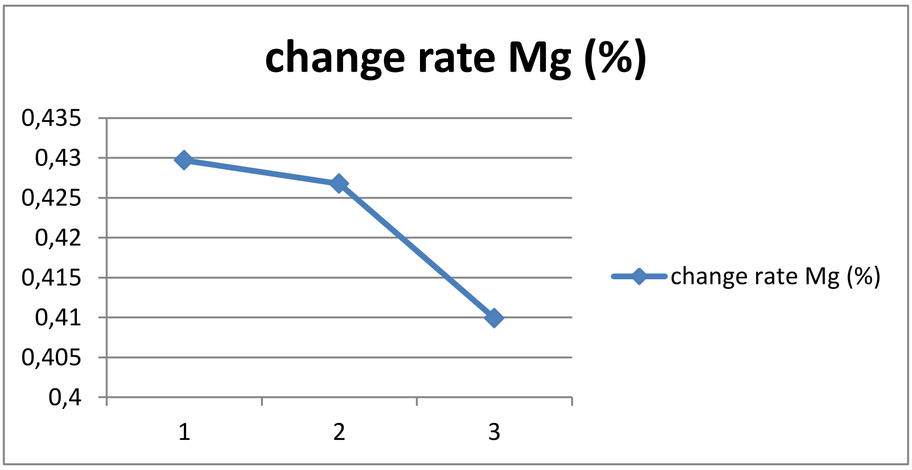


Figure 32 Change rate Mg in MAP

4.2 Operation problems

The P-removal performance in the second run of outlet of sedimentation tank is obviously better than the first run. As the total phosphors concentration in the first 20l is from 30 to 300mg/l while in the last 5l is only 1 to 6mg/l. This can be caused by an incomplete mixing of MgO and urine. And the MgO deposits quickly on the bottom of the tank, so that the reaction here is better than it is in the upper part of the tank. This should be optimized through further research by changing precipitant or stirring parameters.

The struvite-reactor can automatically operate stable and reliable. There are some still certain limitations in the interference-free operation of the urine separating toilets. The main problem turned out to be a constantly occurring blockage of the valves, which enable the urine separation process. (Bischer, 2012) The valves need to be replaced rather frequently. This blockage is caused by urine scale deposit. Even a cleaning with citric acid was performed once a month; this problem could not have been avoided. As a consequence, a high maintenance cost for replacing the valve and demand for cleaning procedure is needed. (Bischer, 2012)

To avoid the odor emission from the urinals, it is also necessary to replace the odor-stop rubber ring, which is installed in the urinals, once a year. This cost cannot be avoided, though the odor emission may not affect the performance of the reactor.

One further problem which ought to be mentioned is the high amount of manual labor needed for operation. First of all is clean procedure. For example, the MAP reactor needs to be cleaned once a week with citric acid. Both sentimental tank and the under part of the reactor have problem of scaling. MAP deposits on the inside wall of the sentimental tank and may and may block up main valve to emptying the tank. The main valve should be cleaned by a round brush manually as required. In the under part of the reactor there is storage chamber where treated urine is stored before it is pumped to sewer system. Because of a further reaction by over dosage of MgO after sentimental, struvite can build up in the storage chamber. It should also be cleaned regularly. Another blockage problem occurs in basket strainer and wire trap before the inlet of the reactor. It was observed that fly larvas and the other organic deposits from the urine tank and pipes could be hold back by the strainer and wire mesh in the dirt trap. After several running cycles of the reactor, they should be cleaned so that they can hold back the impurities and not blocked up by them.

The high demand of labor is cause by the fact that the MAP reactor in the SANIRESCH project is a pilot plant and therefore does not have a high scale of automation implemented. To obtain the MAP product, labors are needed to work with the further handling of the filter bags such as drying and scratch the MAP from filter bags.

4.3 Price of MAP production

The MAP precipitated from urine is about 56kg/a, whose value is equal to annually approximate 28€, which is extremely low comparing to the investing and running cost for the struvite system calculated. (See Appendix)

Table 7 MAP-Production cost

MAP-Production	
P - recovery [%]	55-75
precipitated MAP(dry)/urine [g/l]	1.45
MAP(dry) per day by 150 l [g/d]	217.5
MAP(dry) pro year by 353 l/d [kg/a]	56.55
World price MAP [€/kg]	0.48
Annually produced MAP by 353day l/d [€/a]	27.14

For MAP precipitation, investment cost including double-piping system, urine-diversion toilettes and MAP reactor, urine Tank etc.

In international application, different electricity cost and labor cost can result in different running cost. So for each project, the economic calculation should be according to the local condition.

In project SANIRESCH, The investment cost for MAP reactor is 28,000€, Cost for electricity 8,467.25 €/a, and labor cost is 8,064.29 €/a.

In summary, the total running cost for MAP reactor is 17,746.39 €/a. On the contrary to low value of benefit from MAP fertilizer, the running costs cannot be covered. Thus economically speaking, it is not a feasible application yet.

According to Baum, 2011, theoretical costs for 1 ha of spring wheat for 1 year to fertilize are:

By using urine: 560 €;

MAP from urine generated from pilot reactor: 112,000€

Mineral fertilizer: 120 €

The reason for the high cost of MAP in SANIRESCH is because of the pilot scale of the reactor, the operation is highly depend on labor thus the cost of labor is very expensive.

4.4 Utility Analysis

4.2.1 Utility Matrix

The complete matrix of utility analysis is showed in Table 8. To verify the function of utility analysis with all appraisals, estimations, and assumption, the matrix has been discussed with the Ms. Martina Winker (GIZ/Eschborn) and Mr. Enno Schröder (GIZ/Eschborn), before the final utility matrix was created.

Table 8 Assessment criteria for utility analysis of international transferability

Aspect			**Weight (%)**	**Subpoints**	**Proportion (%)**	**Indication**
Health & Hygiene	Micropollutants and pathogen risk		10	1	10	high=1, medium=5, low= 10, not considered=0
	Safe Disposal of Effluent			3	30	high=10, medium=5, low= 1, not considered=0
	Legislative Regulation	wastewater treatment		3	30	highly enforced=10, medium enforced=5, low enforced=1, no requirements=0
		MAP product		3	30	highly enforced=10, medium enforced=5, low enforced=1, no requirements=0
Economic	Investment costs	Treatment plant	30	3	10	low=10, medium=5, high=1, not considered=0

		Pipe system		3	10	low=10, medium=5, high=1, not considered=0
		Price of land		1	3	low=10, medium=5, high=1, not considered=0
	Operating costs	Energy requirement/costs		3	10	low=10, medium=5, high=1, not considered=0
		Personal requirement/costs		3	10	low=10, medium=5, high=1, not considered=0
		Maintenance dost		2	7	low=10, medium=5, high=1, not considered=0
		Chemical Resource(Mg Reserves)		6	20	low=10, medium=5, high=1, not considered=0
		Transportation costs		1	3	low=10, medium=5, high=1, not considered=0
	Utilization profit through resource reuse			4	13	high=10, medium=5, low= 1, not considered=0
	Fund from government or World Bank			4	13	high=10, medium=5, low= 1, not considered=0
Functional and technical	Stability of process		20	4	20	high=10, medium=5, low= 1, not considered=0
	Requirement for person training			4	20	low=10, medium=5, high=1, not considered=0
	Compare to other systematic treatment options	Phosphorus recovery through wastewater treatment plant		6	30	exit=0, not exit=10
		storage and direct usage of urine		6	30	exit=0, not exit=10
Environmental	Eutrophication in the area		30	6	20	high=10, medium=5, low= 1, not considered=0
	Phosphorus import/consumption			16	53	high=10, medium=5, low= 1, not considered=0
	Water scarcity			2	7	high=10, medium=5, low= 1, not considered=0
	Population/Density			3	10	high=10, medium=5, low= 1, not considered=0
	Urbanization			3	10	high=10, medium=5, low= 1, not considered=0

Socio-cultural	General acceptance of users for urine separation	10	4	40	high=10, medium=5, low= 1, not considered=0
	Acceptance of users for MAP fertilizer		4	40	high=10, medium=5, low= 1, not considered=0
	Pioneering spirit		2	20	high=10, medium=5, low= 1, not considered=0
		100%	100%		

4.2.2 Definition of the indicators

The main components and criteria were identified as following aspects:

- **Health and hygiene**
- **Economic**
- **Functional and technical**
- **Environmental**
- **Socio-cultural**

Under the each aspect, the criteria are divided into detailed sub criteria listed:

- **Health and hygiene**
  - Micro pollutants and pathogen risk
  - Safe Disposal of Effluent
  - Legislative Regulation □
- **Economic**
  - Investment costs
  - Operating costs
  - Utilization profit through resource reuse
  - Fund from government or World Bank
- **Functional and technical**
- Stability of process

  - Requirement for person training
  - Compare to other systematic treatment options
- **Environmental**
  - Eutrophication in the area
  - Phosphorus import
  - Water scarcity
  - Population/Density
  - Urbanization
- **Socio-cultural**
  - General acceptance of users for urine seperation
  - Acceptance of users for MAP fertilizer
  - Pioneering spirit

In the following part the criteria of assessment and parameter of the matrix will be described and the categories of the assessment will be defined.

1. Health and Hygiene

One of the main objectives for sanitation systems is to minimize health risk. (Langerbraber, 2004) The hygiene risk of reusing MAP as fertilizer should be also reduced.

Micropollutants and pathogen risk refers to the potential risk of exposure to pathogen through the production and reuse of struvite and pharmaceutical residues in the struvite. The most part of the pathogens is found in the faeces. Human urine contains rarely pathogens that can be transmitted into the environment. (Schönning, 2002) When faeces cross-contamination occurs by misplacement in Non-Mix toilette, it may result in the risk of pathogen-contaminated urine. Yet none of the commonly used indicator of the bacteria can determine the quantity of faeces in the urine. (Schönning, 2002) People may have risk when they have direct contact with urine, eg, clean the urine storage tank, or when operating the reactor. Heavy metals are hardly present in human urine so that the risk of heavy metal will not be considered. (Mauer, 2007) Pharmaceutical residues will not be eliminated during the storage of urine. However, through the struvite precipitation, hormones as well as more than 98% of pharmaceuticals remain in solution. (Ronteltap, M. et al., 2007) If the dry struvite is used which is free of pathogens, a risk of bringing pharmaceuticals in the food chain will be excluded (Schürmann et al., 2011). Since the technology of the struvite production is the same. By reusing struvite is generally free of pathogens and micropollutants. This criterion is considered to be less important. The rating would be given as “high=1, medium=5, low= 10, not considered=0”.

Safe disposal requires that residual water should be disposed in a hygienically and safe manner. The residual water after urine precipitation still contains high concentration of nitrogen (mainly in form of NH_4-N) and micropollutants. Dispose the residual urine in water body will also cause river eutrophication and health risk. A safe disposal will be achieved, if the residual water can be connected to the additional treatment units. One of the solutions maybe uses the exited municipal wastewater treatment. NH_4-N will then be removed by nitrification and denitrification process. If there is an approved access for MAP reactor to the conventional wastewater treatment system is the indicator. That is to say, this system is preferred to be developed in places where advanced wastewater treatment is available. The rating would be given as “access exist =10, partially access=5, little access= 1, not considered=0”.

Legislative Regulation refers to the requirements and standards for wastewater treatment and fertilizer product in the different countries. If there are funding measures for recovery and reuse phosphorus from wastewater, especially MAP product, then it is a strong motivation to develop MAP reactor. A high standard for P-elimination in wastewater treatment effluent may also promote the implementation of the MAP reactor. When it is “highly enforced” the rating will be 10, “medium enforced” will be 5, and “low enforced” will be 1. If there are no requirements, the rate is 0.

2. Economic

Economic efficiency of the treatment is one decisive criterion for the assessment. The investment cost and operating cost are calculated to specific projects, that they cannot be transferred. Cost can vary strongly from countries to countries, even in different location in the same country. (DWA, 2008) In the other hand, reuse the final product MAP can save the cost for fertilizer.

Investment costs include the cost for ***construction of the treatment system*** (UD toilettes, waterless urinal, tank, MAP reactor etc.) and also the special double ***pipe system*** within the building for separate wastewater stream collection. For the different countries, it is assumed that the investment costs are always the same. The difference of investment costs in the different countries is neglected; both of the criteria here will be given as “0” in rating. (Low=10, Medium=5, high=1, not considered=0). The MAP reactor is very compact so that it can be installed within a building where the space is limit. But it needs tanks to store enough urine for the urine precipitation. Thus, if the ***price of land*** is very expensive, it will be less favored to install the treatment system. Generally, the price of land not very important but can still be a supporting indicator for decision making. Rating is given as “low=10, medium=5, high=1, not considered=0”.

Operation costs

Operation costs are subdivided as following items:

Energy costs

This criterion only considers the electric energy. Energy consumption during the operation is one of the key points concerning its economic sustainability. (Van Timmeren, A. et.al. 2007) Electricity is a prerequisite for the process. If there are sufficient and affordable electricity can be provided in the country or region will be evaluated. Since the MAP reactor in SANIRESH is a very low-energy processing system. Energy costs was assessed with 3%, while rating is given as “low expense=10, medium expense=5, high expense=1, not considered=0”.

Personal costs

In a regular production of MAP fertilizer, the personal requirement is high due to its semiautomatic treatment process. The price of operation can be strongly driven by local personal salary standard. Therefore, the criterion is weighted as 3%, while rating is given as “low cost= 10, medium cost= 5, high cost=10, not considered=0”.

Maintenance costs

Maintenance costs including replacement of spare parts in the system repair the reactor or facility, a regular yearly check from the reactor producer or organization. This part of cost is considered to be the same in different countries. It is weighted as 2%, and rated as “low expense=10, medium expense=5, high expense=1, not considered=0”

Chemical resource costs

Operating chemical resource include precipitants (in Eschborn using MgO) and citric acid to clean the reactor. The cost of the struvite production can vary strongly when choosing different magnesium resource. The currently used precipitant magnesium oxide (MgO) is only available through laboratory suppliers. According to the estimation result presented by Etter (Etter, B et.al. 2010), the lowest cost could incur when using the magnesium oxid produced for locally available magnesite. Hence, if there are magnesite resources in the country, the potential price of precipitant could be reduced. For this case, when there are more available magnesium resources in a country, then it is more economical to produce the MAP product. The criterion is weighted as 6%. The rating is higher when the chemical resource costs are lower: low=10, medium=5, high=1, not considered=0.

Transportation costs

When there is no sewer system in the local region. The residual water from the reactor should be transported to farmer land or wastewater treatment plant. It was shown that urine is efficiency to be transported from 30km-40km distance from the site. (Johannson and Nykvist, 2001) The struvite product is very compact and light; it can be stored and transported easily, so the transportation cost for bringing MAP to farmer land can be neglected. Transportation cost totally counted as 1% as a supporting option. Rating for the criterion is “low=10, medium=5, high=1, not considered=0“.

Utilization profit through resource reuse

Comparing to buy produced fertilizer, resource and money could be saved through using the MAP struvite from urine as fertilizer. Though the MAP cannot maintain a self-sustainable production, the profit is still a positive point by assessment. It will be assessed as high profit =10, medium profit=5, low profit=1, not considered=0.

Fund from government or World Bank

Fund from the government or other organization like World Bank can cover the costs for construct and operate the new sanitation system. To accelerate the implementation of the MAP reuse system, one possibility is to apply financial funds from specific supporting program. Rating is “high fund=10, medium fund=5, low fund=1, no fund=0”.

3. Functional and technical

With respect to comparing with other technologies, functional and technical aspect is considered to be important. In international feasibility study, the ***stability of technology*** and ***Requirement for person training*** can be generally neglected, as the process is relative stable and not be influenced by surrounding.

The performance of MAP reactor should be compared to other systematic treatment options. Except P-recovery from MAP, it is already well-known that phosphorus can be recovered in other ways. ***P-recovery through wastewater treatment plant*** or permission from the government for ***direct usage of urine*** on agriculture can infect the implementation of MAP reactor. If the any one option exist, then it is a negative point for assessment, which means “option exist=0, not exist=10” in rating.

4. Environmental

Environmental is considered to be the second important criterion in the matrix assessment. Ecological sanitation aims to protect the environment and optimize the management of nutrients and wastewater. This aspect is weighted as 30% of the total assessment.

Phosphors and Nitrogen in wastewater can lead ***eutrophication*** in water body. By separating collection and treatment of urine, the phosphors concentration in wastewater can be reduced so that the pollution can be prevented. Regions and areas, especially where meet the problem of eutrophication, would be suitable for implementation. If there exist of eutrophication in the area, it will be rated as 10, while regional exist=5, very few exist=1 and no Eutrophication=0.

The quantity of ***phosphate import/consumption*** in a country reflects the demand for phosphate fertilizer. If the demand is huge, then it is a motivation for the implementation of MAP reuse from urine. The demand of phosphate fertilizer is the most important criterion by decision making, so it is weighted with 16% in this group. It will be classified and rated as “high= 10, medium=5, low=1, no=0”

Urine diversion flush toilet (UDT) and waterless urinals not only collect the urine for MAP production but also reduce the use of water. When conventional toilets need about 8-12 L flushing water, UDT only use 0.5-2L water per flushing (von Münch, 2011) Although saving water is not the main purpose of the MAP reuse from urine, ***water scarcity*** is a supporting criterion. Countries without adequate water resource can be potential region for the approach.

Enough urine volume must be ensured in order to produce MAP. High ***population density*** and high ***urbanization’s grad*** is positive for the assessment. Urine is more likely to be collected continuously in a high densely area. In urbanized region, traditional wastewater treatment plant can be integrated with the MAP sanitation system. For these criteria, it was rated as “high=10, medium=5, low=1, not considered=0”.

5. Socio-cultural

Acceptances from the users should always be taken into consideration when making decision. The general acceptance from UDT users and farmers, who will use the MAP fertilizer are important in this group. The option must be comfortable and also affordable for the users. ***Pioneering spirit*** can established while the project is the first model project introduced in the country. If there is no other analogical project in the country then it will be rated as 10.

4.2.3 Identification of global hotspots for phosphorus reuse from source-separated urine through MAP precipitation

To identify the world hotspots for the implementation of phosphorus reuse from source separated urine, the evaluation is based on a simplified version of utility analysis matrix. Environmental factors and also the available source of magnesium are taken into consideration. In the following part, the method of choosing potential feasible countries of the application will be discussed. (Table9)

Table 9 trimmed down version of utility analysis matrix

Criteria	Weight (total 34%)	**Country**	
		Rating	Result
Eutrophication	6		
Phosphate import/comsuption	16		
Chemical Resource(Mg Reserves)	6		
Population/Density	3		
Urbanization	3		
Result			

- **Phosphate import and consumption**

Modern agriculture relies on a regular phosphate fertilization to replenish the phosphorus removal from the soil by growing of crops. Phosphate fertilizers are derived from mined phosphate rocks. The world most phosphate rocks reserves are restricted in few countries, such as Morocco, China and USA. (Cordell et.al, 2007) The world phosphate rock reverses and production based on USGS data are given in Table 10 (Jansinski, 2012).

Table 10 World production and reserves of phosphate rock (in thousand metric tons) (Source: USGS, 2011)

Country	**Mine production**				**Reserves**	**Reserves (%)**
	2010	**2010 (%)**	**2011**	**2011 (%)**		
United States	25,800	14.3%	28,400	14.9%	1,400,000	2.0%
Algeria	1,800	1.0%	1,800	0.9%	2,200,000	3.1%
Australia	2,600	1.4%	2,700	1.4%	250,000	0.4%
Brazil	5,700	3.1%	6,200	3.2%	310,000	0.4%
Canada	700	0.4%	1,000	0.5%	2,000	0.0%
China[a]	68,000	37.6%	72,000	37.7%	3,700,000	5.2%
Egypt	6,000	3.3%	6,000	3.1%	100,000	0.1%
India	1,240	0.7%	1,250	0.7%	6,100	0.0%

Iraq	—	—	—	—	580,000	8.2%
Israel	3,140	1.7%	3,200	1.7%	180,000	0.3%
Jordan	6,000	3.3%	6,200	3.2%	15,000,00	2.1%
Mexico	1,510	0.8%	1,620	0.8%	30,000	0.0%
Morocco and Western Sahara	25,800	14.3%	27,000	14.1%	50,000,000	70.4%
Peru	791	0.4%	2,400	1.3%	240,000	0.3%
Russia	11,000	6.1%	11,000	5.8%	1,300,000	1.8%
Senegal	950	0.5%	950	0.5%	180,000	0.3%
South Africa	2,500	1.4%	2,500	1.3%	1,500,000	2.1%
Syria	3,000	1.7%	3,100	1.6%	1,800,000	2.5%
Togo	850	0.5%	800	0.4%	60,000	0.1%
Tunisia	7,600	4.2%	5,000	2.6%	100,000	0.1%
Other countries	6,400	3.5%	7,400	3.9%	500,000	0.7%

World total (rounded)	181,000	100.0%	191,000	100.0%	71,000,000	100.0%

Production data for China do not include small artisanal mines.

Based on the data from table 10, distribute of major P-resource in the world is shown on the Figure 26.

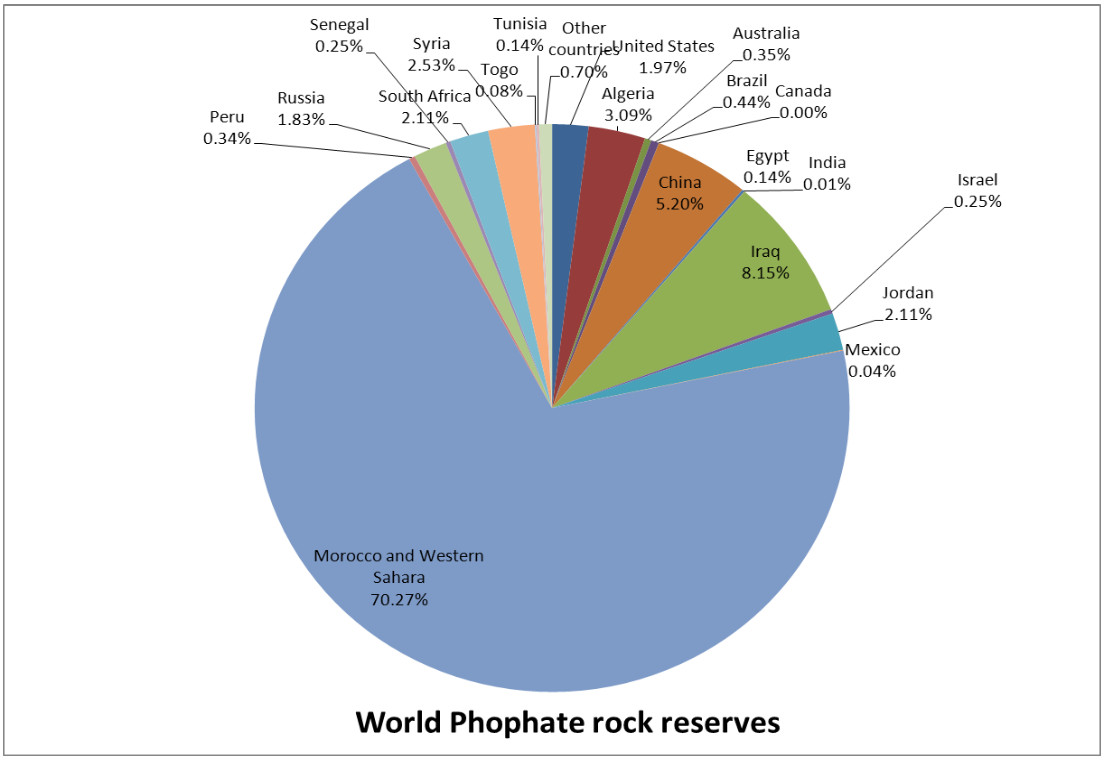


Figure 33 Distribution of world phosphate rock reserves

As we can see from Figure 33, the large part of the world including Europe, India and Australia are almost totally dependent on the import of phosphate from limited countries. The world phosphate supply is expected to increase by 3.2 percent per year between 2011 and 2015. (FAO, 2011)

According to the research from FAO, the world and regional potential phosphate balance was calculated and estimated. Potential balance means the difference between supply-non-fertilizer demands minus fertilizer demand. This is a medium-term indicator of potential changes in fertilizer nutrient demand and supply. (FAO, 2011)The result is shown in the Figure 34:

Among the regions, South Asia will continue to remain a phosphate deficit during the forecast years. Its import of phosphate would rise in the forecast period, so that it might be most ideal region to reuse MAP from separated urine in the view of phosphate demand; Latin America is also a big importer of phosphate fertilizer. The phosphate import would slightly decline from 2012. South America still has the second largest import demand in the world. Europe and Oceania will continue to remain phosphate deficit. While Africa remains a major exporter of raw phosphate. However, Africa produces more fertilizer than it uses. About 75% of production is from North Africa while 17% is from South Africa. Some countries like Senegal even export more fertilizer than its own use. (Wallace, 1997)

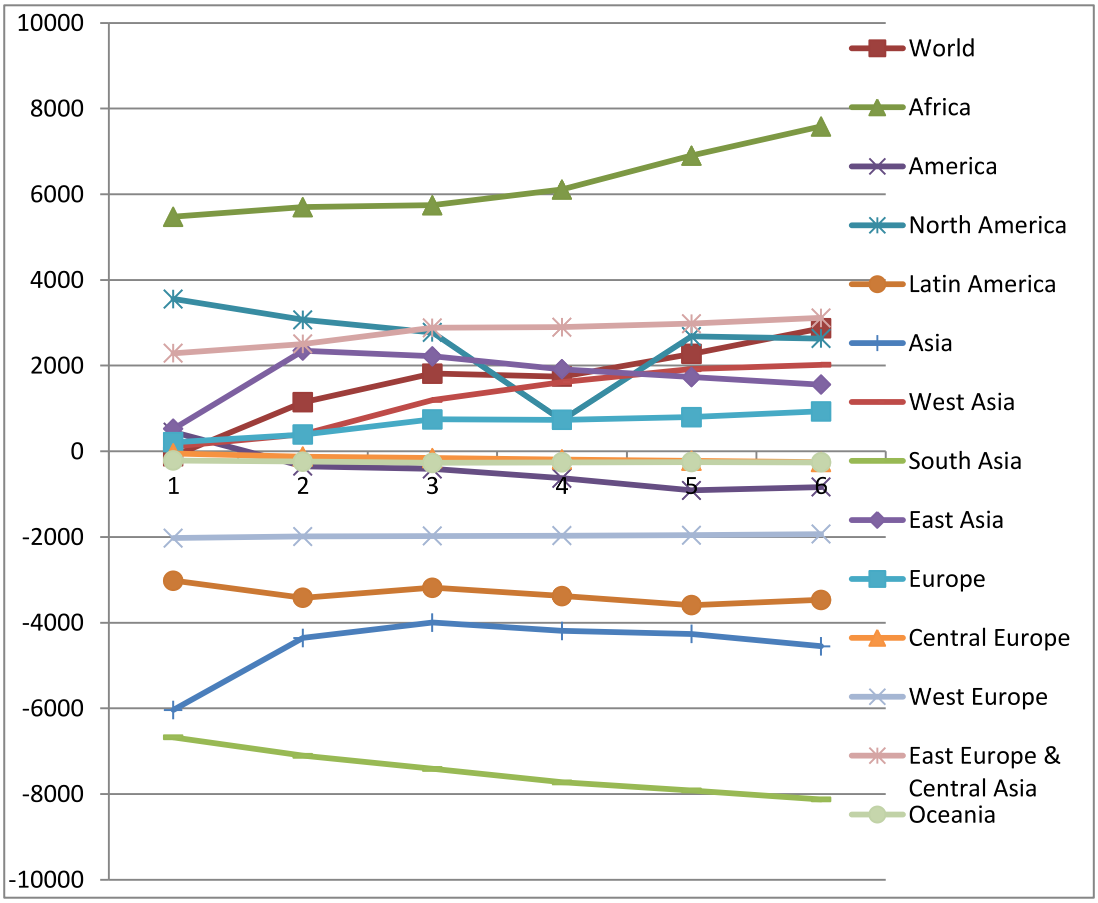


Figure 34 potential phosphate balance based on data from FAO, 2011

As against the increase rate of world consumption of P_2O_5 contained in fertilizers was estimated to be at 2.5% per year during the next 5 years, with the largest increases in Asia and South America. (Jansinski, 2012) “Among the Asia countries, about 28 percent of the growth in world demand of phosphate is expected in India, 9 percent in China, 5 percent in Pakistan, 3% in Vietnam and 2% in Indonesia. Among America countries, 15% of the growth in world demand is projected to be in Brazil and 4 percent in USA. The share of East Europe & Central Asia is expected to be 5 per cent and of Central Europe to be 4 per cent." (FAO, 2011) Countries with huge demand for imports phosphate fertilizer, especially when the demand has an increasing tendency, will be ideal for the implementation of reuse MAP from urine.

Figure 35 shows the regional and sub-regional share of world increase in phosphate consumption from 2011 to 2015. (FAO, 2011)

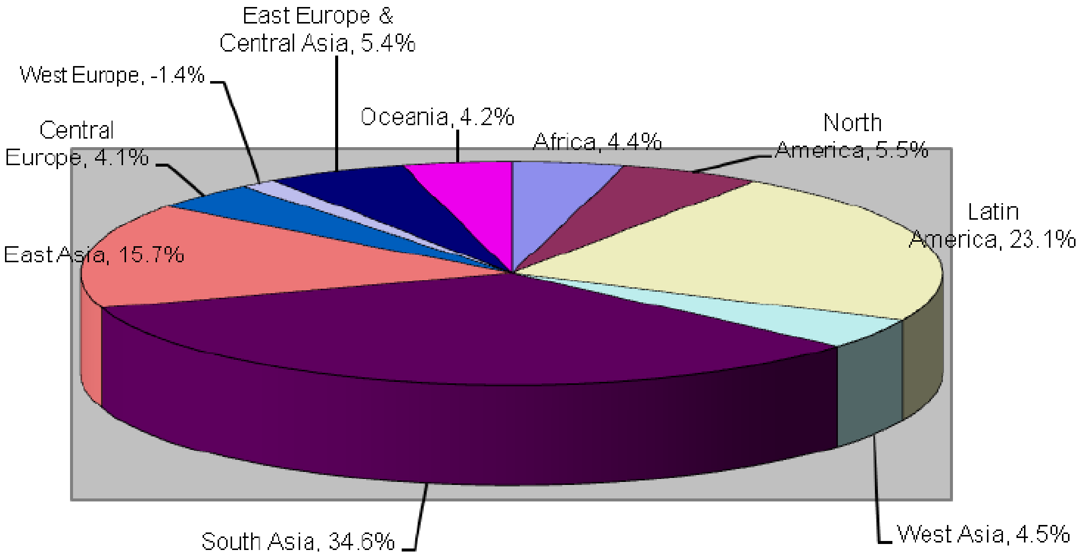


Figure 35 Regional and sub-regional share of world increase in phosphate consumption between 2011 and 2015 (Source: FAO, 2011)

Africa uses the least amount of inorganic fertilizer in the world, especially in Sub-Saharan Africa. The world average fertilizer use rate from is 118 kg nutrient including nitrogen, phosphorus, and potassium (N, P, K) per hectare while the average fertilizer use rate is only 24kg nutrient (N, P, K) per hectare. The rate varies huge between different regions from 76kg/ha in North Africa to 44kg/ha in South Africa and only 9kg/ha in Sub-Saharan Africa. (Roy, 2009) The fertilizer use is very concentrated in five countries −Nigeria, Zambia, Zimbabwe, Kenya, and Ethiopia. These five countries use two-thirds of fertilizer in Sub-Saharan Africa. Many African countries use compound and complex fertilizers that imported from abroad in small quantities and with high costs. Hence, regions with extremely low fertilizer application rates such as Sub-Saharan Africa and South Africa can also be potential place to use MAP reuse from urine. On the other hand, some countries have relatively higher fertilizer consumption than world average standard. Some top phosphate fertilizer producer is at the same time the top consumer.

Phosphate import quantity cannot interpret phosphate demand aggregately; it should be calculated into phosphate import per arable land based on the data from FAO. Furthermore, if the percentage of import to consumption is high, it shows that there is a considerable dependence on phosphate imports. The phosphate fertilizer use rate (consumption per arable land) is also taken into consideration; both countries with low fertilizer use rate and very high rate are considered to be positive for the result; Countries with high import quantity per arable land will be given a high rate. The selection is based Consumption and Import Quantity in nutrients Phosphate Fertilizers (P_20_5 total nutrients) published by FAO from 2002 to 2009. Key regions would be Sub-Saharan Africa, South Asia and Latin America. The following countries are chosen as hotspots for the implementation of MAP reuse (Table 11):

Table 11 Countries chosen as hotspots for MAP transferability analysis

No	Country
1	Argentina
2	Australia
3	Bangladesh
4	Bhutan
5	Brazil
6	Cambodia
7	Cameroon

8	Canada
9	Chile
10	China
11	Colombia
12	Cuba
13	Ethiopia
14	Iceland
15	India
16	Indonesia
17	Iran
18	Israel
19	Japan
20	Jordan
21	Kazakhstan
22	Kenya
23	Luxembourg
24	Malaysia
25	Mexico
26	Namibia
27	Netherlands
28	New Zealand
29	Niger

30	Oman
31	Pakistan
32	Philippines
33	Senegal
34	Singapore
35	Slovenia
36	South Africa
37	Spain
38	Thailand
39	Uganda
40	Ukraine
41	United Arab Emirates
42	USA
43	Viet Nam
44	Zimbabwe

__Calculation methods:__

Score for phosphate import is classified as following:

Score.1	Import quantity per arable land (kg/ha)*
10	≥ 100
5	100 - 50
1	≤50

*P_2O_5 Import Quantity per arable based on FAO STAT from 2002-2009

The score for phosphate consumption is classified as following:

Score. 2	Consumption quantity per arable land (kg/ha)*
10	≥ 200 and ≤ 30
5	200 - 50
1	30 - 50

**P_2O_5 Consumption Quantity per arable based on FAO STAT from 2002-2009*

The average score of consumption per arable land and import quantity per arable land will be then calculated and used in utility analysis.

The rating for phosphate import / consumption in utility analysis is classified as following:

	Rating	Average score of consumption and import
High	10	8-10
Medium	5	5-6
Low	1	1-3

Calculate Example:

Take an example of Singapore: The phosphate consumption rate is 1830 kg/ha is in the range of > 200kg/ha. The score for consumption (score 1) is 10. The import quantity is 3976kg/ha, then the score for import (score 2) is 10. Average score for import and consumption will be 10. According to the average score, the rating for Singapore will be given as 10. (Table 12)

Table 12 Calculation example for P import/consumption indicator

Country	Consumption kg/ha	Score 1	Import kg/ha	Score 2	AVG Score	Rating
Singapore	1830	10	3976	10	10	10

Eutrophication

Eutrophication is an enrichment of nutrient especially nitrate and phosphate in the bodies of fresh water. It results in an excessive growth of algae and an oxygen deficit in the water, so that causing the death of other organisms. Eutrophication can occurs naturally but human activity speed up the process greatly (Art, 1993). Since it is considered as water pollution and exists in many countries as a great environmental problem, a control of emission of phosphate into water can reduce the eutrophication. In the urine separation system, the load of phosphate and nitrogen on the wastewater treatment plant can be decreased. Even in places where wastewater treatment is efficient and has good function, urine separation leads to decrease the eutrophic effect; in the region where sewage treatment it not so efficient a great effect can be achieved (Jössen et.al., 1999). Hence, the MAP reactor is more suitable to be installed where Eutrophication exit. This is a specific condition that is varying from project to project. In this part, if country is facing with eutrophication problem is only generally evaluated, because the situation can be different even in a same country. A lack of reliable data can also hinder the assessment of eutrophication, making it difficult to assess the number and scale eutrophic water in specific country.

Eutrophication problems are more apparent in coastal areas. According to the data provided by World Resource Institute, more than 415 coastal areas in the world that are experiencing symptoms of eutrophication (Selman et al., 2008). (Figure 36)

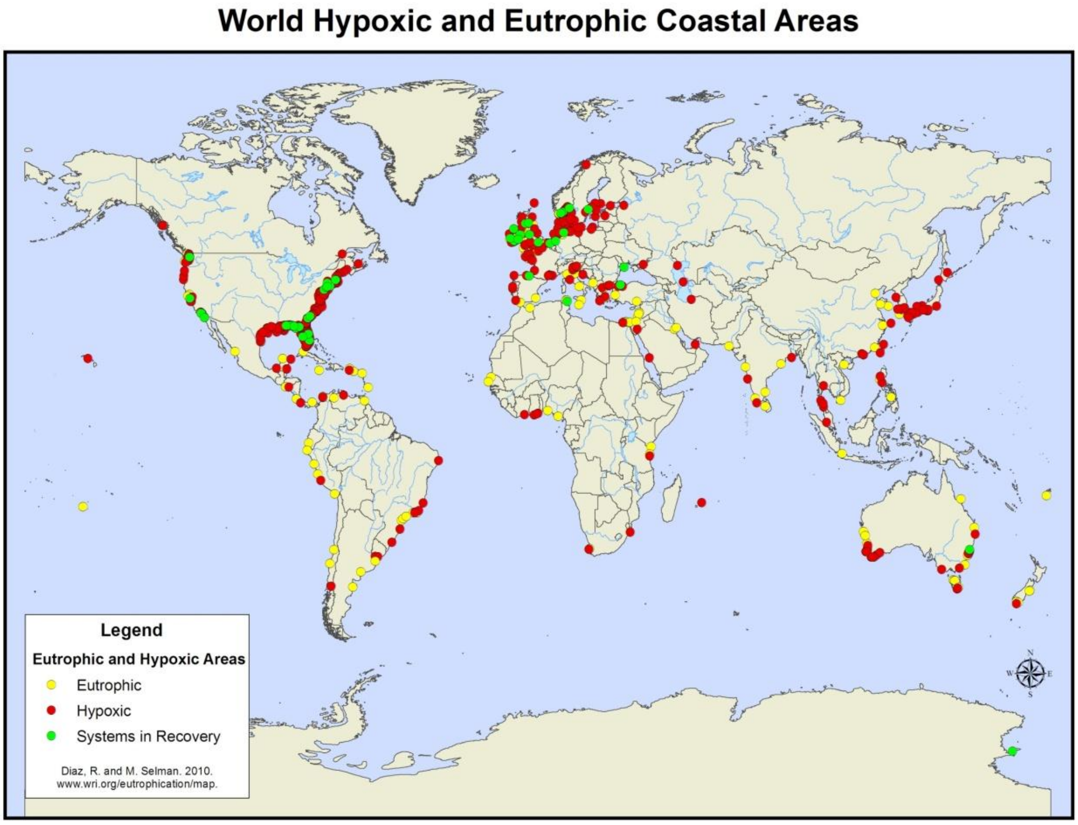


Figure 36 World eutrophic and hypoxic areas (Source: WRI, 2008)

According to the research from the UNEP (United Nation Environmental Protection) about 30%~40% of the lakes and reservoirs have been affected more or less by water eutrophication around the world.(Yang, 2008) Eutrophication occurs in river and lakes worldwide. Agriculture and wastewater effluent is the major source of nutrients in the lake. 50-80% of Nitrogen comes from run-off from Agriculture land, while phosphors pollution is mainly caused by household and industry. The total area-specific load of nutrient (kg N or P/ha per year) can be the indicator to possible eutrophication situation. Increased population density and agriculture land can increase the area-specific load of nutrient. (EEA, 2005)

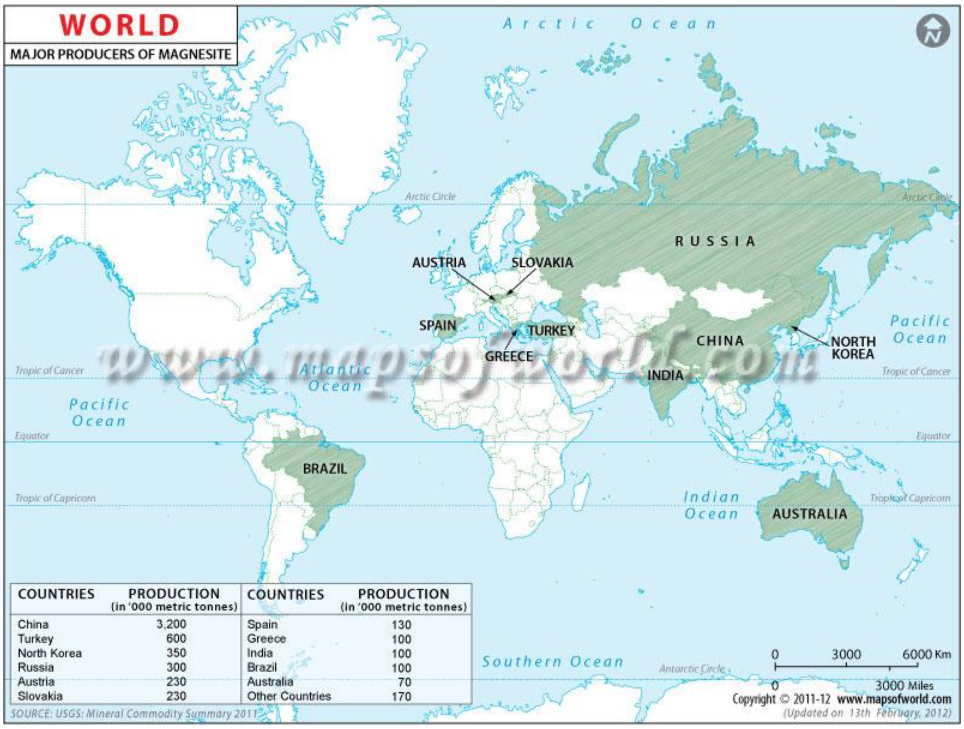
Rate for Eutrophication situation in utility analysis to following class:

Eutrophication problem	Rating
Generally Exist (High)	10

Partly Exist (Medium)	5
Fare Exist (Low)	1

Chemical resource (Mg resource production)

As it was mentioned in last section, the potential cost of MAP can be reduced if there is magnesite resource available in the local the country, because magnesium is cheaper if there is own magnesite resource in a country, and magnesium is an essential chemical that should be added in to the precipitation process. MgO can be produced from Magnesite ($MgCO_3$). The world major magnesite producer is shown on the figure 37:



COUNTRIES	PRODUCTION (in '000 metric tonnes)	COUNTRIES	PRODUCTION (in '000 metric tonnes)
China	3,200	Spain	130
Turkey	600	Greece	100
North Korea	350	India	100
Russia	300	Brazil	100
Austria	230	Australia	70
Slovakia	230	Other Countries	170

SOURCE: USGS: Mineral Commodity Summary 2011

Figure 37 World Magnesite production (Source: USGS 2011)

Among all countries, China is the largest producer of Magnesite and has two-thirds of magnesite in the world. Magnesium price (primary China FOB) was 1500USD/t in 2005 and was risen to 600 USD/t in 2008 and fall again in currenty pricing 3000USD/t (Abbott, 2009) Since the Magnesium price changes all the time, it is hard to evaluated by price. The world production of magnesite according to USGS is shown in Table 5. The rating is based on Magnesite production. (Table 13)

Table 13 Average annual production of magnesite in the world from 2007 to 2011, (in thousand metric tons) (Source: 2011 Minerals Yearbook, USGS, 2011)

Country	Production
United States	N.A.
China ^{e}	14220
Russia ^{e}	1160
Turkey,	868
Austria, crude	742
Slovakia	698
Spain ^{e}	460
Brazil	440
India ^{e}	349
Greece	313
Australia	298
Canada ^{e}	144
Korea, North ^{e}	131
Iran ^{e}	115
South Africa	68
Poland	54
Colombia ^{e}	40
Guatemala	14

Pakistan	4
Zimbabwe	3

^{e}Estimated. W Withheld to avoid disclosing company proprietary data; not included in "Total." -- Zero.

Rate for Magnesite resource in utility analysis to following class:

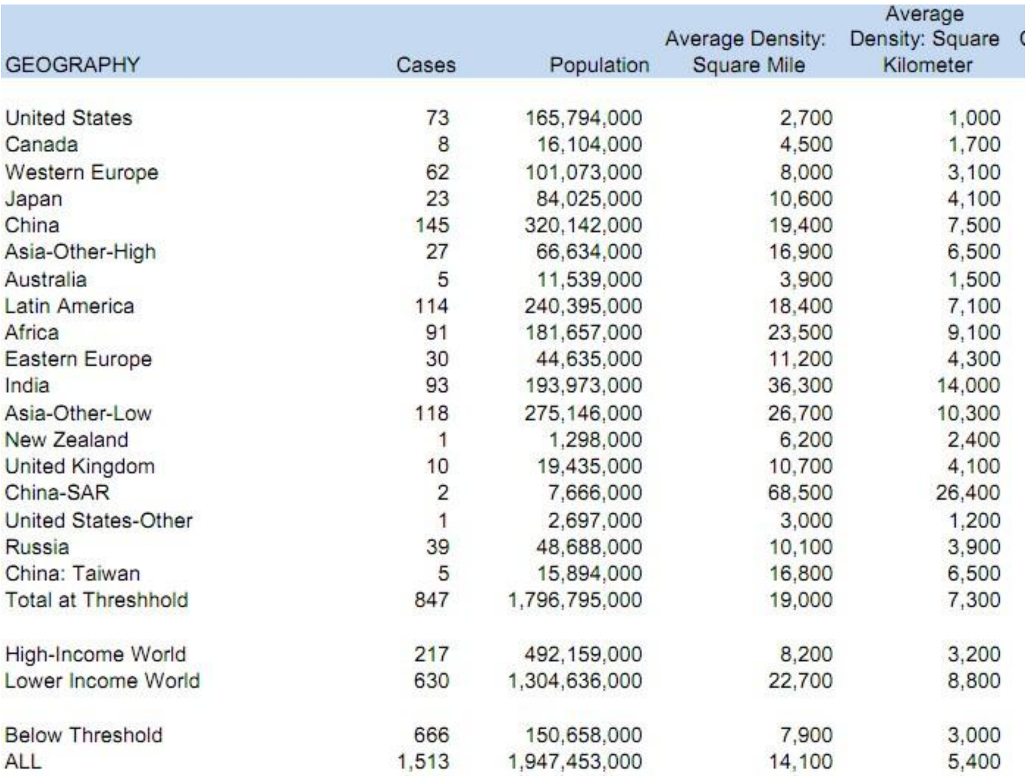
Magnisite Production (in 10^3 t)	**Rating**
>200	10
1-200	5
Other Countries	1

Population density

MAP precipitation system requires a sufficient supply of urine. Urine is more easily to be collected in a high population density area. On the other the approach combines decentralized and centralized systems; which is a good option for those with medium to high population density. A rapid population growth will essentially take place in developing countries in urban or peri-urban. (UN, 2010) Physiology density (total population/ arable land) is an indicator that more interested by agriculture and indicates the average arable land per person. It cannot reflect the world agglomeration situation that most people live in urban area and the high density in cities. For this reason, urban population density will be considered for the assessment. The report of demographia in 2012 provides population density data in over 1000 cities in the world. (Demographia, 2012) The average urban population density for urban with over 500,000 will be taken into consideratin in utility analysis. (Table 14)

Table 14 SUMMARY: URBAN AREAS 500,000 & OVER (Threshold Population for Ranking 500,000)

(Source: Demographia World Urban Areas: 8th Annual Edition: Version 2, 2012.07)



GEOGRAPHY	Cases	Population	Average Density: Square Mile	Average Density: Square Kilometer
United States	73	165,794,000	2,700	1,000
Canada	8	16,104,000	4,500	1,700
Western Europe	62	101,073,000	8,000	3,100
Japan	23	84,025,000	10,600	4,100
China	145	320,142,000	19,400	7,500
Asia-Other-High	27	66,634,000	16,900	6,500
Australia	5	11,539,000	3,900	1,500
Latin America	114	240,395,000	18,400	7,100
Africa	91	181,657,000	23,500	9,100
Eastern Europe	30	44,635,000	11,200	4,300
India	93	193,973,000	36,300	14,000
Asia-Other-Low	118	275,146,000	26,700	10,300
New Zealand	1	1,298,000	6,200	2,400
United Kingdom	10	19,435,000	10,700	4,100
China-SAR	2	7,666,000	68,500	26,400
United States-Other	1	2,697,000	3,000	1,200
Russia	39	48,688,000	10,100	3,900
China: Taiwan	5	15,894,000	16,800	6,500
Total at Threshhold	847	1,796,795,000	19,000	7,300
High-Income World	217	492,159,000	8,200	3,200
Lower Income World	630	1,304,636,000	22,700	8,800
Below Threshold	666	150,658,000	7,900	3,000
ALL	1,513	1,947,453,000	14,100	5,400

Rate for population density in utility analysis to following class:

population density(cap/km^2)	Rating
>5000	10
5000-2000	5
<2000	1

Urbanization

Urine diversion can both be installed in rural as well as urban areas. However, it would be more economic when directly use urine instead of precipitant MAP as fertilizer in rural areas. MAP is very compact; the transportation cost for MAP is than cheaper than urine fluid. Rest water from MAP reactor can be treated in centralized wastewater plant, a combination of decentralized urine treatment and centralized system is ideal for the implementation. In urban area, there is more access to improved sanitation facilities than in rural area, ranging from flush toilet to pit latrine with a sewage connection. Hence, it is more suitable to bring the approach to urban areas. Urbanizations grad in a country can be reflect by percentage of urban population to total population. Urban population refers to people living in urban areas as defined by national statistical offices. It is calculated using World Bank population estimates and urban ratios from the United Nations World Urbanization Prospects. (World Bank) Table 15 shows urban population in 2011 in candidate countries:

Table 15 Urban population (% of total)(Source: World Bank database, 2012)

No	Country	Urban population (% of total)
1	Argentina	92
2	Australia	89
3	Bangladesh	28
4	Bhutan	36
5	Brazil	85
6	Cambodia	20
7	Cameroon	52
8	Canada	81

9	Chile	89
10	China	51
11	Colombia	75
12	Cuba	75
13	Ethiopia	17
14	Iceland	94
15	India	31
16	Indonesia	51
17	Iran	69
18	Israel	92
19	Japan	91
20	Jordan	83
21	Kazakhstan	54
22	Kenya	24
24	Luxembourg	85
25	Malaysia	73
26	Mexico	78
27	Namibia	38
28	Netherlands	83
29	New Zealand	86
30	Niger	18

31	Oman	73
32	Pakistan	36
33	Philippines	49
34	Senegal	43
35	Singapore	100
36	Slovenia	50
37	South Africa	62
38	Spain	77
39	Thailand	34
40	Uganda	16
41	Ukraine	69
42	United Arab Emirates	84
43	USA	82
44	Viet Nam	31
45	Zimbabwe	39

Rate for urbanization in utility analysis to following class:

Urban population (% of total)	**Rating**
>70	10
70-40	5
<40	1

4.2.4 Result of identification of ideal international application of MAP reactor by utility analysis

The identification of ideal applications of MAP reactor was accomplished by utility analysis. An assessment of phosphate consumption and import quantity, Eutrophication, Magnesium resource, population density and urbanization was made by a trimmed-down utility matrix and is presented in Table 16, the description of the rating procedure is assorted in last section and the utility analysis has a maximum rating of 34 scores. In appendix the complete tables of utility matrix are available to see. Here the results are presented, sorted in descending order.

Table 16 Ranking of countries ideally fitting for international transfer according to an assessment by utility analysis

Rank	Country	Rating
1	Colombia	26.5
2	Brazil	26.0
3	Bangladesh	25.9
4	Malaysia	25.6
5	China	24.5
6	New Zealand	24.4
7	Oman	24.1
8	Chile	24.1
9	India	23.3
10	Singapore	23.2

11	Japan	23.2
12	Jordan	22.9
13	Bhutan	22.9
14	Netherlands	21.7
15	Luxembourg	21.7
16	Israel	21.7
17	Thailand	20.5
18	Iceland	20.5
19	Slovenia	20.2
20	Pakistan	20.0
21	Indonesia	19.1
22	Iran (Islamic Republic of)	18.5
23	Cambodia	17.9
24	Zimbabwe	17.6
25	Spain	16.1
26	Cuba	16.1
27	Mexico	15.2
28	Namibia	13.7
29	South Africa	13.6
30	Niger	13.4
31	USA	12.9
32	Viet Nam	12.5

33	United Arab Emirates	12.5
34	Cameroon	12.2
35	Australia	11.5
36	Ukraine	11
37	Senegal	11
38	Philippines	11.0
39	Kazakhstan	11
40	Ethiopia	11.0
41	Uganda	9.8
42	Argentina	9.7
43	Canada	8.5
44	Kenya	3.4

With a maximum rating of 34 being scored by Colombia it is identified as an ideal country for the implementation of MAP crystallization from urine, due to a correlation of all rated criteria. An installation of urine separating collected system in a building with MAP reactor can be implemented ideally.

Further ideal international applications for MAP recuse from urine are in south America, south Asia and regions as well. The countries are all characterized by phosphor demand deficit and high urbanization rate in combination with high population density. The overview of the results is shown in the map (Figure 38).

This is a rough estimation of ideal application areas for MAP reactors for urine by utility analysis. Due to the limited time of this work, a detailed evaluation of worldwide regions divided into small sections was not possible. In a further study, an investigation based on geographic information systems (GIS) could supply more detailed results. It is conceivable, to utilize cartographic modeling, where several thematic layers, such as phosphor scarcity, phosphor reserves etc. could be put on top of each other to evaluate the best compliance with the conditions of utility analysis.

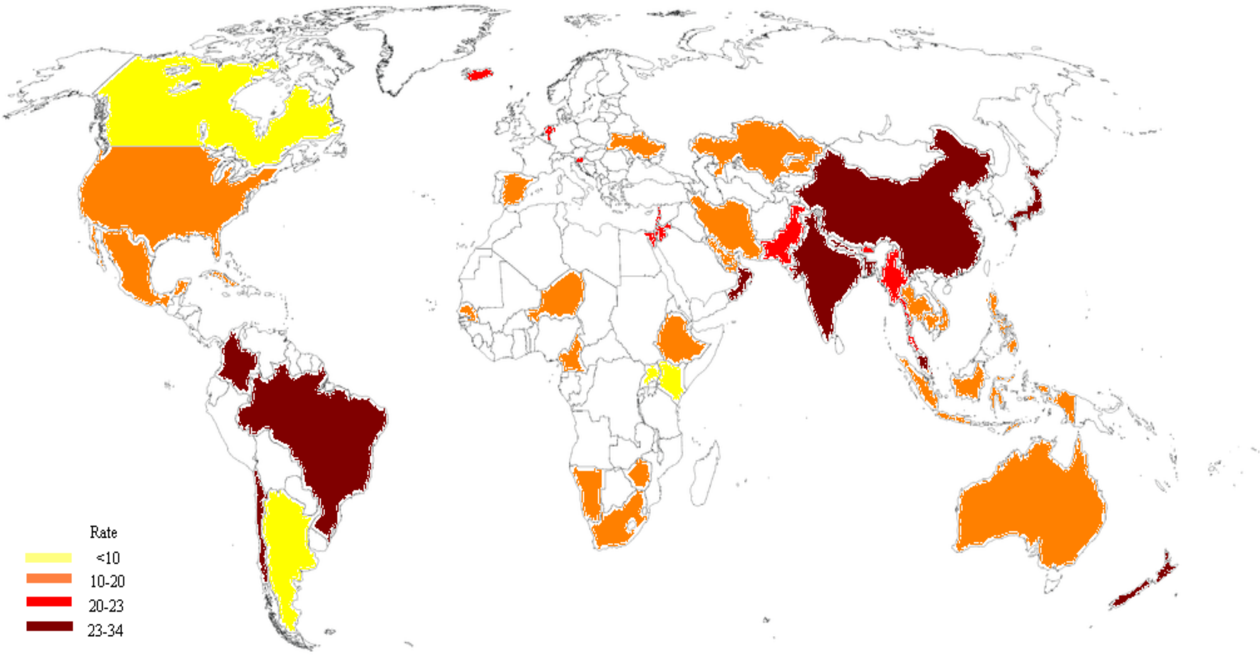


Figure 38 International adaptability of MAP-crystallization from urine

This approach, to assess four environmental aspects, can only outline a rough estimation of global hotspots, due to regional differences. This analysis has a maximum rating of 34 scores or weighting of 34 %, based on the trimmed-down version of utility matrix.

By identification of water scarcity as an indicator criterion, a pre selection within the assessment was made. Phosphorus demand and consumption is the strongest criterion within the whole analysis and thus it provides a good base to identify countries which are rewarding for the examination of the international transferability. This strategy aims to exclude incorrect influences from the analysis. Within the given time of this work it was not possible to assess all countries according the four criteria, but by starting with the most influencing criterion is a simple way to start. The worldwide view on all four assessed environmental criteria without any pre-selection may show a slightly different result, but this was not possible within the limited time of this work.

On top, the estimation is based on the trimmed-down analysis with a maximum rating of 34 % of 100 % within the utility analysis, which contributes only one-third to the analysis. Hence, it must be taken into consideration that further aspects, apart from environmental criteria, can add a serious weight into assessment as well.

This approach can only outline a rough estimation of global hotspots, due to regional differences. The regional distinctions and conditions of a project may vary widely within narrow spaces, hence it is only possible to make suggestions and give directions. Here, only estimations based on environmental aspects are possible. For practical projects all the criteria including legal, economic, socio-cultural, and building specific criteria. A detailed consideration of each criterion is required to identify reasonable applications. For the investigation of a proposed project, accurate data from local condition must be used to estimate the transferability of MAP technology.

Conclusion

The MAP reactor can recover 70% of phosphorus from urine. The precipitation product MAP can be applied for fertilizer in agriculture. The function of MAP precipitation has been proven to work out through the experiment. The positive aspects of this technology have been shown on environmental advantages – closing the nutrient loop and provide the opportunity of alternative phosphor source.

Yet, precipitation of struvite from urine is not economically reasonable in the context of this system. The amount of excreted MAP from urine is not comparable to investment cost for the treatment component. Further researches to reduce the cost of MAP production or to find alternative methods for phosphor recovery is required. To achieve marketable plants on a serial scale, the dispersal of ready-made systems which can be offered cheaply, is a step required in the future.

The evaluation to locate global hotspots for phosphor recycling from urine applications was based on phosphor demand and consumption, defined as the indicator criterion to identify the most meaningful countries. In total 44 countries, which are facing with problem of phosphor deficit was assessed by a trimmed-down utility analysis. According to the five rating criteria: phosphor demand/consumption, eutrophication, population density and urbanization rate, Mg resource, an appraisal based on environmental aspects was conducted.

Estimation of global hotspots is only a rough outline concerning the environmental aspects. This estimation is based on a maximum rating of 34 % of 100 % within the utility analysis, which contributes only one-third to the analysis. Therefore, further aspects like economic, socio-cultural and legal criteria, must be taken into consideration when evaluate the specific application.

The ideal applications for the implementation of MAP precipitation are in the Middle East, South America region and South Asia and part of Sub-Saharan region, due to a correlation of all assessed criteria. In addition, a main focus can be on existing or emerging megacities in those countries.

In regions where exist a low urbanization rate, a low-tech approach could be more suitable as MAP reactor, such as collecting and reusing urine directly as fertilizer. A calculation for the transportation cost should be therefore conducted. Compared to urine, MAP is more compacted and cheaper for transportation, but has more expensive production cost.

Finally, a general paradigm shift must take place, as today's water and sewage systems are no longer acceptable in respect to sustainability aspects. In particular, it is not an exportable solution to emerging and developing countries, where phosphorus fertilizer demand is increasing as well as the scarcity of water. The well-known conventional method with centralized treatment plants is very cost intensive, due to the expensive sewer systems and high operation costs of the sewage treatment plants. These systems are hardly affordable in emerging and low-income economies; hence they should not be promoted as a sanitation solution in such contexts. Additionally, the conventional wastewater treatment methods are only disposal oriented and the potential of recycling and reuse is not taken into consideration. Based on a holistic approach, by “closing the loop” a recirculation of water within the building without any wastewater production is a conceivable future.

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Appendix

Data from experiments

Phosphor in MAP

Nr.		MAP Weight (g)	Total P in MAP (g)	Total P in influent (g)	Recovery rate
1		108.15	11.56	15.60	74.10%
2		115.84	11.22	16.20	69.26%
3		101.34	11.10	14.97	74.15%
	Avg	**108.44**	**11.29**	**15.59**	**72.50%**
	MAP (g/l urine)	1.45			
	Total P (g/g MAP)	0.10			

Phosphor in urine

	Masses Total P reduced (mg)		
Cycle 1	3163.4	2903.4	3163.15
Cycle 2	2021	4343.35	3174
Cycle 3	3103.25	4210.05	3104.38
Sum Reduce	8287.65	11456.8	9441.53
P-Reduce %	**53.18%**	**70.72%**	**63.07%**
	Masses ortho-P (mg)		
Cycle 1	2435.65	3003.915	3372.53
Cycle 2	2152.4	4556.985	4092.93
Cycle 3	3217.6	4510.44	4565.96
Sum Reduce	7805.65	12071.34	12031.42
P-Reduce %	**55.95%**	**75.45%**	**76.61%**

b

NH_4 in urine

Inflow		Outflow		
NH4 (mg)	**NH4 (mg/l)**	**NH4 (mg)**	**NH4 (mg/l)**	**NH4 reduce rate**
74500	2980	70860	2834.4	4.89%
73250	2930	70665	2826.6	3.53%
75750	3030	69935	2797.4	7.68%
72750	2910	67625	2705	7.04%
65750	2630	64665	2586.6	1.65%
71750	2870	69325	2773	3.38%
84500	3380	77640	3105.6	8.12%
70000	2800	68715	2748.6	1.84%
Avg.	2933		2786	4.21%

Total-N in urine:

Inflow		Outflow		
Total N (mg)	**N (mg/l)**	**Total N (mg)**	**N (mg/l)**	**Total N reduce rate**
77500	3100	75265	3010.6	2.88%
75000	3000	70850	2834	5.53%
72625	2905	69357.5	2774.3	4.50%
73750	2950	72330	2893.2	1.93%
78250	3130	74090	2963.6	5.32%
Avg.	2974		2869	3.36%

c

K in urine and MAP

	K (mg/l)			K (mg)		
1. Inflow unfillted	1450	1463	1457	36247	36568	36426
1. Outflow 1 unfillted	1462	1457	1439			
1. Outflow 1 fillted	1457	1491	1450			
1. Outflow 2 unfillted	1431	1477	1439			
1. Outflow 2 fillted	1419	1491	1479			
2. Inflow unfillted	1452	1448	1471	36292	36199	36784
2. Outflow 1 unfillted	1474	1444	1459			
2. Outflow 1 fillted	1464	1448	1435			
2. Outflow 2 unfillted	1447	1464	1474			
2. Outflow 2 fillted	1460	1460	1489			
3. Inflow unfillted	1446	1445	1547	36144	36130	38687
3. Outflow 1 unfillted	1471	1424	1482			
3. Outflow 1 fillted	1463	1461	1451			
3. Outflow 2 unfillted	1470	1442	1499			
3. Outflow 2 fillted	1460	1446	1486			
			SUM	108683	108897	111897
Avg. Concentration inflow (mg/l)	1464		**K in MAP (mg)**	964	730	488
Avg. Concentration outflow (mg/l)	1460		**K-Reduce (%)**	0.89%	0.67%	0.44%

d

Composition in MAP

	Ca 315.887 (mg) mittelwert	K 766.490 (mg)	Mg 285.213 (mg)	P 213.617 (mg)	Weight (g)
MgO	59.388	0	8080.058	0	14
08.05_2.Kugelhahn	97.7688	26.79392	845.7016	373.58752	5.92
23.05_2.Kugelhahn	30.73251	10.61859	399.43242	209.82264	2.91
24.05_2.Kugelhahn	24.29202	10.93602	448.7298	260.67732	3.18
08.05_1.Mag	1523.8872	963.91872	9570.37968	11188.32768	102.24
23.05_2. Mag	2834.76886	729.5278	9945.29338	11007.2871	112.93
24.05_2.Mag	1011.44064	487.75704	9487.75296	10835.19528	98.16

e

Utility analysis (trimmed-down version) to identify ideal international applications for MAP crystallization from urine

Criteria	Weight (total 34%)	**Argentina**		**Australia**		**Bangladesh**		**Bhutan**		**Brazil**	
		Rating	Result	Rating	Result	Rating	Result	Rating	Result	Rating	Result
Eutrophication	6	5	3	1	0.6	10	6	5	3	10	6
Phosphate import/comsuption	16	1	1.6	1	1.6	10	16	10	16	5	8
Chemical Resource(Mg Reserves)	6	1	0.6	10	6	1	0.6	1	0.6	10	6
Population/Density	3	5	1.5	1	0.3	10	3	10	3	10	3
Urbanization	3	10	3	10	3	1	0.3	1	0.3	10	3
Result	**34**		**9.7**		**11.5**		**25.9**		**22.9**		**26**

Criteria	Weight (total 34%)	**Cambodia**		**Cameroon**		**Canada**		**Chile**		**China**	
		Rating	Result	Rating	Result	Rating	Result	Rating	Result	Rating	Result
Eutrophication	6	10	6	1	0.6	1	0.6	5	3	10	6
Phosphate import/comsuption	16	5	8	5	8	1	1.6	10	16	5	8
Chemical Resource(Mg Reserves)	6	1	0.6	1	0.6	5	3	1	0.6	10	6
Population/Density	3	10	3	5	1.5	1	0.3	5	1.5	10	3
Urbanization	3	1	0.3	5	1.5	10	3	10	3	5	1.5
Result	**34**		**17.9**		**12.2**		**8.5**		**24.1**		**24.5**

f

Criteria	Weight (total 34%)	**Columbia**		**Cuba**		**Ethiopia**		**Iceland**		**India**	
		Rating	Result	Rating	Result	Rating	Result	Rating	Result	Rating	Result
Eutrophication	6	5	3	5	3	1	0.6	1	0.6	10	6
Phosphate import/comsuption	16	10	16	5	8	5	8	10	16	5	8
Chemical Resource(Mg Reserves)	6	5	3	1	0.6	1	0.6	1	0.6	10	6
Population/Density	3	5	1.5	5	1.5	5	1.5	1	0.3	10	3
Urbanization	3	10	3	10	3	1	0.3	10	3	1	0.3
Result	**34**		**26.5**		**16.1**		**11**		**20.5**		**23.3**

Criteria	Weight (total 34%)	**Indonesia**		**Iran**		**Israel**		**Japan**		**Jordan**	
		Rating	Result	Rating	Result	Rating	Result	Rating	Result	Rating	Result
Eutrophication	6	10	6	5	3	1	0.6	1	0.6	5	3
Phosphate import/comsuption	16	5	8	5	8	10	16	10	16	10	16
Chemical Resource(Mg Reserves)	6	1	1	5	3	1	0.6	1	0.6	1	0.6
Population/Density	3	10	3	10	3	5	1.5	10	3	1	0.3
Urbanization	3	5	2	5	1.5	10	3	10	3	10	3
Result	**34**		**19**		**18.5**		**21.7**		**23.2**		**22.9**

g

Criteria	Weight (total 34%)	**Kazakhstan**		**Kenya**		**Luxembourg**		**Malaysia**		**Mexico**	
		Rating	Result	Rating	Result	Rating	Result	Rating	Result	Rating	Result
Eutrophication	6	1	0.6	1	0.6	1	0.6	5	3	1	0.6
Phosphate import/comsuption	16	5	8	1	1.6	10	16	10	16	5	8
Chemical Resource(Mg Reserves)	6	1	0.6	1	0.6	1	0.6	1	0.6	1	0.6
Population/Density	3	1	0.3	1	0.3	5	1.5	10	3	10	3
Urbanization	3	5	1.5	1	0.3	10	3	10	3	10	3
Result	**34**		**11**		**3.4**		**21.7**		**25.6**		**15.2**

Criteria	Weight (total 34%)	**Namibia**		**Netherlands**		**New Zealand**		**Niger**		**Oman**	
		Rating	Result	Rating	Result	Rating	Result	Rating	Result	Rating	Result
Eutrophication	6	1	0.6	1	0.6	10	6	5	3	5	3
Phosphate import/comsuption	16	5	8	10	16	10	16	5	8	10	16
Chemical Resource(Mg Reserves)	6	1	0.6	1	0.6	1	0.6	1	0.6	1	0.6
Population/Density	3	5	1.5	5	1.5	1	0.3	1	0.3	10	3
Urbanization	3	10	3	10	3	5	1.5	5	1.5	5	1.5
Result	**34**		**13.7**		**21.7**		**24.4**		**13.4**		**24.1**

h

Criteria	Weight (total 34%)	**Pakistan**		**Philippines**		**Senegal**		**Singapore**		**Slovenia**	
		Rating	Result	Rating	Result	Rating	Result	Rating	Result	Rating	Result
Eutrophication	6	5	3	5	3	1	0.6	1	0.6	1	0.6
Phosphate import/comsuption	16	5	8	5	8	5	8	10	16	10	16
Chemical Resource(Mg Reserves)	6	5	3	1	0.6	1	0.6	1	0.6	1	0.6
Population/Density	3	10	3	10	3	1	0.3	10	3	5	1.5
Urbanization	3	10	3	1	0.3	5	1.5	10	3	5	1.5
Result	**34**		**20**		**11**		**11**		**23.2**		**20.2**

Criteria	Weight (total 34%)	**South Africa**		**Spain**		**Thailand**		**Uganda**		**Urkraine**	
		Rating	Result	Rating	Result	Rating	Result	Rating	Result	Rating	Result
Eutrophication	6	10	6	5	3	1	0.6	1	0.6	1	0.6
Phosphate import/comsuption	16	1	1.6	5	8	10	16	5	8	5	8
Chemical Resource(Mg Reserves)	6	5	3	1	0.6	1	0.6	1	0.6	1	0.6
Population/Density	3	5	1.5	5	1.5	10	3	1	0.3	5	1.5
Urbanization	3	5	1.5	10	3	1	0.3	1	0.3	10	3
Result	**34**		**13.6**		**16.1**		**20.5**		**9.8**		**11**

Cost calculation for MAP production

MAP Produktion im jetzigen Betrieb (Mittelstrang)		
Urinproduktion		
Nutzer	328	*Wasseranfall Tabelle*
Urinanfall pro Werktag (l)	178	Gemessene Werte September bis Februar 2012
Urinlagerung		
Urintanks	*1 Tank für 1 Charge, 1 Tank füllt*	
Tankvolumen [l]	8000	
theoretische Auslastung [%]	0	
Investitionskosten Tanks	*45000*	
Installationskosten Tanks	30 % vom Investitionspreis	30 % vom Investitionspreis
Lebensdauer	25	
Stromkosten Belüftungsanlage [€/a]	2397.3	
Investitionskosten Belüftungsanlage		
Installationskosten	*5955.52*	*Rechnung 22./23.6.2010*
Lebensdauer [a]		
MAP-Produktion		
MgO-Päkchen		
Reichweite [Päkchen/l]	40	
Kosten pro Päkchen	0.31 €	
Kosten MgO/L Urin	0.0075 €	
Kosten MgO pro Jahr [€/a]	347.1000 €	
Nährstoffe		*gemessen*

		https://dms.gtz.de/livelink-ger/livelink.exe?func=ll&objaction=overview&objid=55897772
Phosphor (Zulauf) [mg/l]	176	
P removal	60 - 80 %	
Stickstoff (Zulauf) [mg/l]	2879	*gemessen https://dms.gtz.de/livelink-ger/livelink.exe?func=ll&objaction=overview&objid=55897772*
N removal	60 - 80 %	
MAP-P, gewaschen [g/kg]	91,4 g/kg MAP	
MAP-N, gewaschen [g/kg]	38,9 g/kg MAP	
MAP-Mg, gewaschen [g/kg]	140 g/kg MAP	
Reaktorbetrieb		
Investitionskosten für MAP-Reaktor [€]	28,000	
Installationskosten für MAP-Reaktor [€]		
Lebensdauer [a]	25	
Kosten Schmutzfilter [€]	617.13	
Lebensdauer [a]	10	
Stromverbrauch pro Stunde im Betrieb [kWh/h]	0	
Stromverbrauch pro Liter Urin [kWh/l]	0	
Wartungskosten (Material, Personal) pro Jahr		
Zyklusgröße [l]	40	
Zykluslänge [min]	135	
Rüstzeit pro Zyklus [min]	3	
Gesamtzeit pro Zyklus [min]	138	
Maximales tägliches Volumen theor. möglich [l/d]	419	
Filtersäcke		

Kosten Needle felt filter [€/Filter]	3
Lebenszeit [Zyklen; Liter Urin]	4
MAP-Verlust [%]	21.5
MAP-Produktion	
MAP recovery [%]	50 - 65
theoret. MAP(trocken)/ Urin [g/l]	0.8
prakt. MAP (getrocknet) pro l Urin [g/l]	0.63
MAP(trocken) pro Tag theoret. möglich [g/d]	263.07
MAP(trocken) pro Tag bei 178 l [g/d]	111.78
MAP(trocken) pro Jahr theoret. möglich [kg/a]	68.40
MAP(trocken) pro Jahr bei 178 l/wd [kg/a]	29.06
Weltpreis MAP [€/kg]	0.48
Wert jährlich produziertes MAP theoret. möglich [€/a]	32.83
Wert jährlich produziertes MAP bei 178 l/wd [€/a]	13.95
Dichte MAP(trocken) [g/cm³]	*1.711*
MAP-Trocknung	
Trocknungsvorgang	
Trocknungsgrad	Gewichtskonstanz (0% Wassergehalt)
Trocknungstemperatur [°C]	39
Trocknungsdauer Trockentruhe [d]	3
max. Filtersäcke Trockentruhe	5
Trocknungsdauer Trockenschrank [h]	240
Filtersäcke Trockenschrank	10
MAP (trocken) pro Filtersack g	100.48
Trockentruhe	
Investitionskosten	1,280 €
Lebensdauer [a]	25

Trockenschrank		
Investitionskosten	1,125 €	
Lebensdauer [a]	25	
Volumen [l]	54.4	*nachgemessen*
Trockenvariante	keine Umluft	
Nennleistung [kW]	1.4	
Stromverbrauch bei 70°C [W]	70	
Strompreis Basis 2010 €/kWh	0.25	
Stromkosten pro getrocknetem Filtersack [€]	0.42	
Stromkosten Trocknung pro g MAP [€]	0.004179936	

Zusammenfassung Kosten MAP-Produktion	
Arbeitskosten pro Jahr [€/a]	8,064.29 €
Summe Stromkosten [€/a]	8,467.25 €
Stromkosten Trocknung pro Jahr	467.25 €
Stromkosten Belüftung pro Jahr	8,000.00 €
Summe Materialkosten [€/a]	1,214.85 €
MgO [€/a]	347.10 €
Filtersäcke [€/a]	867.75 €
Summe Wartungskosten pro Jahr [€/a]	17,746.39 €