

# The Potential of Nutrient Reuse from a Source-Separated Domestic Wastewater System in Indonesia – Case study: Ecological Sanitation Pilot Plant in Surabaya

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**Abstract** Human excrement (faeces and urine) contribute only small volume in domestic wastewater but are one of the main causes of water pollution. On the other hand, they contain very valuable nutrients to be reused as anthropogenic fertilizer through proper collection, treatment and hygienisation process. To know the potential of nutrient recovery and reuse in Indonesia, a pilot scale source separation domestic wastewater system has been built in Surabaya and has showed so far promising results. Using urine diverting toilets, up to 86 % Nitrogen, 21% Phosphorous and 69 % Potassium from urine and 12 % of Nitrogen, 68 % of Phosphorous and 20 % of Potassium from the faecal matter respectively can be recovered.

The separated urine was stored for 6 months before usage as fertilizer for hygienic reasons, while the separated faecal matter was composted with worms (vermicomposting). In order to investigate the fertilizing effect, a preliminary cultivation experiment has been done on baby rose plant using different fertilizers for two months.

**Keywords** anthropogenic fertilizer; Ecological Sanitation; brownwater; greywater; yellowwater; vermicomposting

## INTRODUCTION

Domestic wastewater constitutes mostly of organic and inorganic matter, pathogenic bacteria and heavy metals. In high concentration, these substances cause problems in surface water. On the other hand, domestic wastewater also contains valuable nutrients that would be valuable for agricultural purpose (Esrey et al., 2001), especially nitrogen (N), phosphorus (P) and potassium (K) that are contained mostly in human urine and faeces (Jönsson et al., 2004). These nutrients would be unrecoverable if they are diluted with large amount of wastewater.

### Case Study in Indonesia

Large-scale municipal (centralized) wastewater treatment is not a feasible option for Indonesia. It is costly and resource-consuming to construct, maintain, and upgrade sewerage systems and treatment plants to satisfy ever increasing requirements for effluent and sludge quality. On-site treatment such as septic tank or pit latrine is also not recommended because of groundwater pollution if it is not properly designed and well managed. It is especially problematic for densely populated areas in Indonesia. The partially-treated or untreated effluent from household sanitation facilities in Indonesia typically flows into open drains or directly into water bodies. Therefore, Indonesia is in urgent need for a new domestic wastewater treatment system.

As a preliminary study to implement Ecological Sanitation concept in Indonesia, a pilot plant with urine diversion toilet was built in a densely populated urban area in Surabaya, Indonesia. Surabaya is the second largest city in Indonesia and has a population of about 3 million people.

In the pilot plant, household wastewater was separated into brownwater, yellowwater and greywater. One unit of squatting pour-flush urine diversion toilet was installed and used to separate the yellowwater and brownwater. The following flowchart shows how the pilot plant works. It has a circular flow of water and nutrients to reuse the nutrients for agricultural purpose.

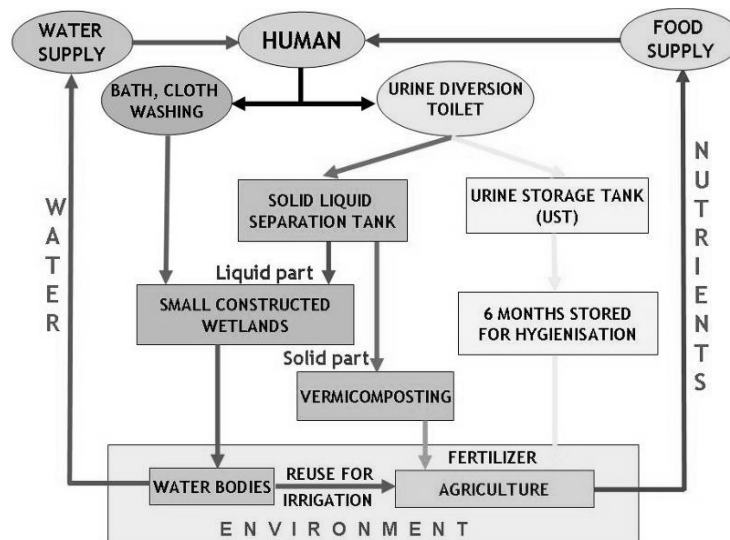


Figure 1. Circular flow of water and nutrient at the pilot plant in Surabaya

The urine diversion toilet was built in an office building with 10-15 employees. It was used daily by the workers during working hours. During the night, it was used by 2-3 workers. Table 1 below shows the nutrient's proportion from the pilot plant based on the assumption that every person produces 107 l greywater, 3 l yellowwater (including washwater) and 0.25 kg brownwater daily.

Table 1. Characteristics of different wastewater streams at the Surabaya pilot plant, Indonesia

Volume Flow	Greywater	Urine	Faeces
Nitrogen (N)	2 %	86 %	12 %
Phosphorous (P)	11 %	21 %	68 %
Potassium (K)	11 %	69 %	20 %

Under the urine diversion toilet, the separated yellowwater was put in a tightly closed storage tank at room temperature for 6 months for hygienic reasons. Before using the urine as fertiliser, it has to be guaranteed that the urine is free from harmful microorganisms. From microbiological aspects, the remaining pathogenic organisms in urine is caused by a faecal cross-contamination (e.g., Jönsson et al., 1999; Esrey et al., 2001), which are found to die off during 6 months of storage (Höglund, 2001; Vinnerås, 2002).

The separated brownwater was collected in a solid-liquid separation tank, where the liquid and solid part of the brownwater will be separated by a fish net hanging in the tank. The liquid part flows through towards a small constructed wetland for further treatment. The remaining solid part was vermicomposted to produce a relatively safe anthropogenic fertilizer. For safe re-use of human faeces, the destruction of pathogens is compulsory (Peasey, 2000; Esrey et al., 2001) and one of the methods for pathogen removal is vermicomposting.

## MATERIALS AND METHODS

### Vermicomposting

A small-scale vermicomposting experiment has been done on the separated brownwater from the urine diversion toilet. The remaining solid part of the brownwater were taken out from the solid-liquid separation tank and put into a small bucket. Then worms were put into the buckets for vermicomposting process. Two worm species were used: *Lumbricus rubellus* and *Eisenia foetida*. Samples were taken on the 30<sup>th</sup> day of the composting process for nutrient content and microorganism analysis.

### Cultivation experiment

To assess the fertilizing effect from nutrients contained in urine and faecal matter, a preliminary cultivation was done on baby rose (*Rosa multiflora*). This plant was chosen because of its rapid growth (2-3 month) and it can be planted in every season (rainy and dry season).

In this experiment, three plants were fertilized with different fertilizers:

#### 1. Urine

The urine dose was calculated based on the experience of Singh (2003) in India. He planted tomato and chillies with 200 ml urine without dilution, which was given to the plant once at the beginning. Since the users of urine diversion toilet in this research use cleansing water, it is assumed that the collected urine is 8 times diluted, which makes a total dose of 1600 ml. As the planting time is 8 weeks, the urine dose of 200 ml/week was applied.

#### 2. Compost from faecal matter

The amount of faecal compost added should be based on the current recommendation for the use of phosphorous-based fertilizers (Vinneras et al., 2003), which is the same dose as the phosphate content in synthetic fertilizer (14%). The normal dose for Indonesian synthetic fertilizer is 1000 kg/ha or 0.1 kg/m<sup>2</sup> (Wiryanta, 2002). Since the small pot used in this experiment has an area of about 0.018 m<sup>2</sup>, the total synthetic fertilizer dose is equal to 1.8 gram. Thus, the compost from vermicast that should be added to the pot will be 1.8 grams multiplied by 14%, which is equal to 0.252 gram. Hence, a dose of 140 kg/m<sup>2</sup> of faecal compost are added to the soil. In addition, the plant were watered with tap water regularly.

#### 3. Combination of urine and vermicast

The fertilizer dose was a mixture of 200 ml/week for urine and 140 kg/m<sup>2</sup> for faecal compost.

Growth of babyrose plants was analysed based on two parameters: plant's height and number of leaves.

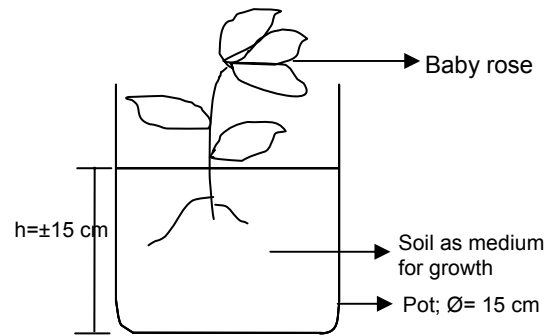


Figure 2 – Pot for planting

## RESULTS AND DISCUSSIONS

### Converting pathogenic faecal matter into valuable compost

After 1 month of vermicomposting for wet faecal matter without toilet paper, a good quality of compost was produced, which has already complied with the Indonesian National Compost Standard. It had a C/N ratio of 11-12 and contained very low amounts of E.coli (100-200 MPN/gr). The smell was already similar to soil and it has no faecal appearance anymore. The final compost characteristics were shown in the following table and visualised in figure 3 (a) and (b).

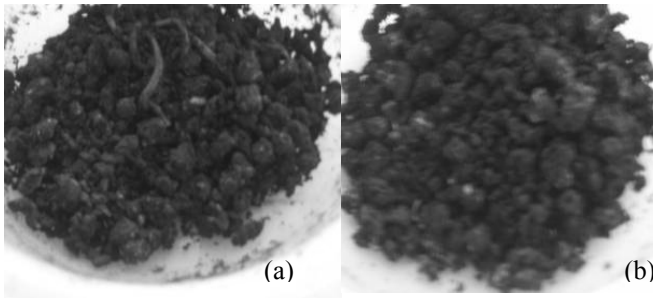


Figure 3.  
 (a) Faecal matter (without toilet paper) + *Eisenia foetida* after 30 days composted  
 (b) Faecal matter (without toilet paper) + *Lumbricus rubellus* after 30 days composted

Table 2. Compost characteristic from the Ecosan pilot plant in Indonesia after vermicomposting treatment

Parameter	Indonesian Compost National Standard	<i>Eisenia foetida</i>	<i>Lumbricus rubellus</i>
C (% C)	Min. 9.8	17.11	14.6
N (%Kjeldahl)	Min. 0.40	1.48	1.22
P (%P <sub>2</sub> O <sub>5</sub> )	Min. 0.10	3.36	3.08
K (%K <sub>2</sub> O)	Min. 0.20	3.51	2.98
<i>E.coli</i> (MPN/gr)	Max. 1000 MPN/gr	120	230
C/N	Min. 10	11.56	11.97

Because Indonesian people use wet anal cleansing instead of toilet paper, the compost product contains less C/N ratio compared to other composting studies done in developed countries. A laboratory analysis of carbon content in toilet paper revealed that it contains 42 % of Total Carbon. Therefore, the absent of toilet paper and other bulk material in this research could be the reason for the low C/N ratio.

Table 3. Comparison of compost characteristic with other researches

Parameter	Other investigations on composting with faecal matter		
	Naudascher, 2001	Gajurel, 2003	Shalabi, 2005*
C (% C)	48.6 – 50.2	39.5 – 45.8	46 – 52
N (%Kjedahl)	1.60 – 2.24	2 – 2.8	1,8 – 4
C/N	22.2 – 31.9	16.4 - 19.75	20 - 22

\* = not published yet

### Reusing human urine as fertilizer and faecal compost as soil conditioner

Planting baby rose with different fertilizers showed significant differences in plants given urine fertilizer (figure 4 and 5).

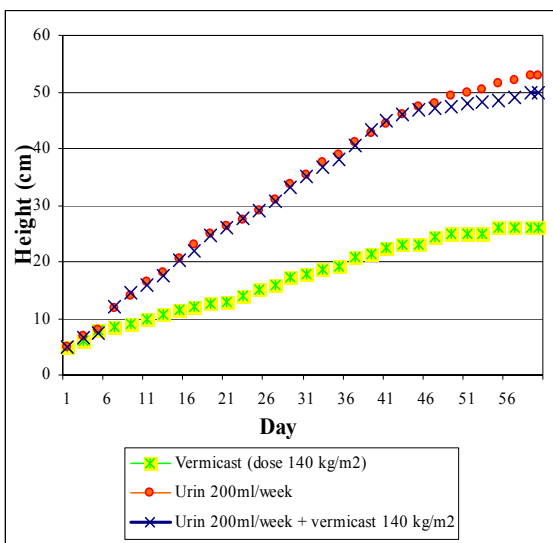


Figure 4 Height of tomato's stalk

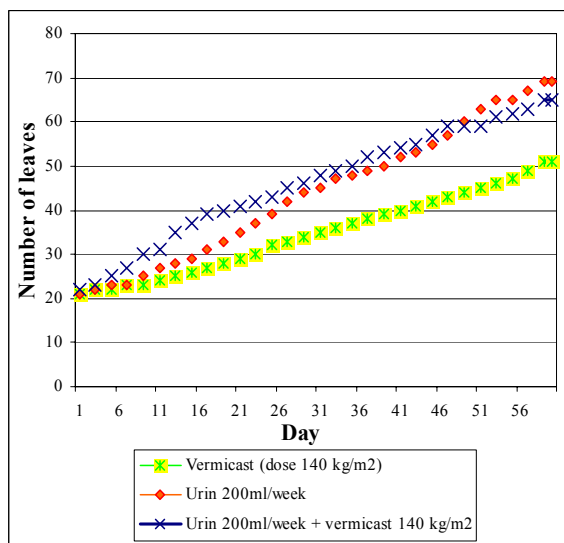


Figure 5 Number of leaf of tomato

Figure 6 below shows that after two months, urine application gave better and faster growth to baby rose. In this experiment, only baby rose fertilized with urine had flowers. Possible reason for this is because urine is a quick-acting fertilizer (Jönsson et al. 2004) and has higher nitrogen content compared to other fertilizers. Nitrogen found in abundance in urine is good for plant growth because it helps to build protoplasm, protein, promotes leaf and other components of plant growth (Morgan, 2004).



Figure 6. Different growth rate of baby rose

Plant given faecal compost had approximately similar number of leaves with plant given a mixture of urine and faecal compost. But the former did not have any flower. Possible reason for this is because urine and faecal matter supplement each other and because faecal matter is a slower acting fertilizer. Nutrient content of faecal matter is considerably lower than urine, especially the amount of plant-available nitrogen. Main contribution from faecal matter is the content of phosphorus and potassium and increase in buffering capacity of the soil (Vinneras et al, 2003).

#### Potential of nutrient reuse from human excreta on agriculture

Nutrients collected from the urine diversion toilet proved that the majority of potential fertilizer was found in urine.

Table 4. Estimated calculation of yearly nutrient excretion per person in different countries (adapted from Langergraber and Muelleger, 2004)

Country	Nutrient					
	Nitrogen		Phosphorus		Potassium	
	% in urine	% in faeces	% in urine	% in faeces	% in urine	% in faeces
China	87.5	12.5	66.7	33.3	72.2	27.8
Haiti	90.5	9.5	66.7	33.3	75.0	25.0
India	85.2	11.1	75.0	25.0	73.3	26.7
South Africa	88.2	11.7	60.0	40.0	75.0	25.0
Uganda	88.0	12.0	75.0	25.0	71.4	28.6
Sweden*	88.0	12.0	66.7	33.3	71.4	28.6
Indonesia**	87.6	12.3	23.5	76.5	77.3	22.7

\* = Jönsson and Vinnerås, 2003

\*\* = data obtained from the Ecosan Pilot-Plant in Surabaya, Indonesia

The nutrient content of collected urine and faecal matter in this study were similar to other investigations, except for phosphorous content. In this study, urine contains less phosphorous than faecal matter, while the others had contrary condition. Different diet behaviors are considered as the reason for this difference. Dairy products (including yoghurts and milk), meat, and fish are particularly rich sources of phosphorus. These kinds of food are not very common to low-income population in Surabaya because they simply can not afford it. People living in the case-study area

mostly eat tofu, tempeh (both are made from soybean which have a high protein content), and sometimes eggs or fish. Proteins from these foods contain high amounts of amino acids which are the biggest source of Nitrogen.

Assuming that the entire Indonesian population separates their domestic wastewater and nutrients are collected, high amounts of fertilizers could be produced. However, the estimated total nutrient content of urine and faecal matter from Indonesia total population could not fulfill the corresponding fertilizer demand, in particular for phosphorous and potassium fertilizer (see table 5) due to less phosphorous and potassium content in the anthropogenic fertilizer from the Surabaya pilot plant.

Table 5. Average consumption and estimated production of fertilizer in Indonesia

Fertilizer (1000 tonnes/year)	Estimated production from separation wastewater system	Average consumption (data from 1995-1999)*
Nitrogen	2842,62	1690,58
Phosphorous	136,51	280,11
Potassium	176,67	187,31
TOTAL	3155,8	2158

\* = after Suhadi, 2002

## CONCLUSIONS

Although produced in a small daily amounts, human excreta contains high amount of nutrients which can be recovered as valuable resources for agriculture. By using a urine diversion toilet, urine and faecal matter were collected and treated separately in a pilot-plant scale in Surabaya, Indonesia. Small-scale cultivization experiments with baby rose plants have been carried out, and it revealed that human excreta (urine and faecal) which has undergone hygienization process showed a good potential to be reused as anthropogenic fertilizer.

In this case study, urine contained up to 31 kg Nitrogen, 0.4 kg Phosphorous and 1.7 kg Potassium per person annually. The second largest nutrient content was found in faecal matter which contained 4.4 kg Nitrogen, 1.3 kg Phosphorous and 0.5 kg Potassium per person annually. The vermicomposting experiment on wet faecal matter without toilet paper produced good quality of compost, which has already complied with Indonesian National Compost Standard.

If human excreta could be used as nutrient source for agricultural purposes, then it is possible to substitute the use of synthetic fertilizers. However, more research is still needed to optimize the implementation of Ecological Sanitation Concept in Indonesia.

## ACKNOWLEDGMENT

The authors would like to express their gratitude to German Ministry of Education and Research (BMBF), who is the funder of the IPSWAT program, and German Academic Exchange Service (DAAD) for providing the scholarship and funding for this research.

## REFERENCES

- (i). Austin LM, and Vuuren SJ, 2002, *Sanitation, Public Health and the Environment: Looking Beyond Current Technologies*.
- (ii). Drangert, JO, 1998, Fighting the urine Blindness to provide more sanitation options, ISSN 0378-4738, *Water SA*, Vol. 24 No. 2.

- (iii). Edwards C.A, 1995, Commercial and environmental potential of vermicomposting, a historical overview, *Biocycle*, June 1995, 62-63.
- (iv). Esrey S, Andersson I, Hillers A, Sawyer R, 2001, *Closing the loop Ecological sanitation for food security*, SIDA, Stockholm, Sweden.
- (v). Gajurel, DR 2003, Evaluation of Decentral Physico-Biological Systems for Pre-treatment of Household Wastewater and their Potential for Ecological Sanitation, *Dissertation Report*, Hamburg University of Technology (TUHH).
- (vi). Höglund C, 2001, Evaluation of microbial health risks associated with the reuse of source separated human urine, *PhD thesis*, Department of Biotechnology, Royal Institute of Technology, Stockholm, Sweden.
- (vii). Jönsson H., Stintzing AR, Vinnerås B, Salomon E, 2004, Guidelines on the Use of Urine and Faeces in Crop Production, *Ecosanres Publication Series*.
- (viii). Jönsson, H. and Vinnerås, B., 2003, Adapting the nutrient content of urine and faeces in different countries using FAO and Swedish data, *Proceedings of the 2<sup>nd</sup> International Symposium on ecological sanitation*, Lübeck, Germany, pp 623-626.
- (ix). Jönsson, H. 2001, *Urine separation – Swedish experiences*, Swedish University of Agricultural Sciences.
- (x). Jönsson H., Vinneras B., Höglund C, Strenström T-A, 1999, Source separation of urine, *Wasser Boden*, 51 (11): 21-5.
- (xi). Langergraber G, and Muelleger E, 2005, Ecological Sanitation - a way to solve global sanitation problems?, *Environmental International* 31 (433-444).
- (xii). Li, Z. 2004, Grauwasserbehandlung und – wiederverwendung Untersuchungen zur höherwertigen Wiederverwendung von Grauwasser in Verbindung mit teilstromorientierten ökologischen Sanitätskonzepten (Greywater treatment and reuse - Investigations for an upgraded reuse of greywater in relation to source separation ecological sanitation concept), *Dissertation Report*, Hamburg University of Technology.
- (xiii). Morgan, P. (2004), The usefulness of urine, *An Ecological approach to sanitation in Africa*.
- (xiv). Naudascher, I., 2001, Kompostierung menschlicher Ausscheidungen durch Verwendung biologischer Trockentoiletten – mit besonderer Berücksichtigung des Kleingartenbereichs (Composting human faeces through the application of biologically dry toilet – with special regards towards the field of allotments), *PhD Dissertation*, Universität Fridericiana zu Karlsruhe (TH).
- (xv). Palmquist, H., Jonnsson, H., 2004, Urine, faeces, greywater and biodegradable solid waste as potential fertilizers, *Proceedings of the 2<sup>nd</sup> International Symposium on ecological sanitation*, Lübeck, Germany, p.828.
- (xvi). Singh, RD, 2003, Urine-separating toilet in popularizing ecological sanitation in the peri-urban areas of Manipur, India, *Proceedings of the 2<sup>nd</sup> International Symposium on ecological sanitation*, Lübeck, Germany.
- (xvii). Suhadi, 2002, Development of Balanced Fertilization in Indonesia, *IFA Regional Conference for Asia and the Pacific*, Singapore.
- (xviii). Vinnerås B, Jönsson H., Salomon E, Stintzing AR, 2003, Tentative guidelines for agricultural use of urine and faeces, *Proceeding of the 2<sup>nd</sup> International Symposium on ecological sanitation*, Lübeck, Germany, p. 101-108.
- (xix). Vinnerås B., 2002, Possibilities for sustainable nutrient recycling by faecal separation combined with urine diversion, *PhD thesis*, Agraria 353, Swedish University of Agricultural Sciences, Uppsala, Sweden.
- (xx). Wiryanta, BTW, Marianto, LA, 2002, Kiat mengatasi permasalahan praktis - Bertanam tomat (Practical Methods in Cultivation of Tomatoes), *Agromedia Pustaka*, Jakarta.