Life Cycle Assessment of a Urine Diversion System at Highway Service Area in Japan

Naoko NAKAGAWA[1], Akira KAWAMURA[1] and Hideo AMAGUCHI[1]
[1]*Department of Civil and Environmental Engineering, Tokyo Metropolitan University,*
1-1 Minami-Ohsawa, Hachioji, Tokyo 192-0397, Japan

1 INTRODUCTION

The Great East Japan Earthquake (Its magnitude was 9.0) was occurred on Friday, 11 March 2011 and the water supply and sewage system were also intensely damaged. The water supply systems that exist in inland areas were restored, however, the sewage systems that most of them existed near seashore were extremely disrupted by tunami and their restoration took considerable time. One result was that flush toilets were unusable. Therefore, the toilets that can be used even when the water supply system and sewerage system are cut off are indispensable.

On the other hand, Japanese highway service areas that have the basic facilities, such as car service lots, toilets, and restaurants are required to be comfortable, clean, safe, and environmentally friendly. The Japanese highway management and maintenance company, NEXCO, owns about 300 of these service areas, where, on average a total of 80 toilets are present. They are considering replacing some of these conventional toilets with low environmental load ones not only to save on water and energy usage costs but also to contribute to ecological conservation. To solve this problem, the newly urine diversion system(UDS) such as water recycling urinals and urine diversion toilets that are comfortable to use as pre-existing toilets have been developed. Because it has become more common to view wastewater as a resource and there is increased recognition that water itself is regarded as a limited resource and the nutrients in wastewater can be recycled through agriculture if the material can be properly disinfected. This has led to the development of new wastewater technologies, including source-separating systems in which urine is collected separately. Therefore we have been performing the environmental assessment to estimate environmental load reduction effects by introducing low environmental load toilets into Japanese highway service areas for the first time in Japan (Nakagawa *et al*. ,2009, 2011).

The aim of this paper is to perform the life cycle assessment of a urine diversion system was performed selecting Moriya service area which is one of the large–scale service areas and Minori service area which is the middle–scale one were selected for the case study. In addition, a cost-benefit analysis concerning introducing the UDS was also performed.

2 MATERIALS AND METHODS

2.1 Urine diversion system (UDS)

UDS to be installed in the highway service area are required the following conditions such as having no unpleasant smells, being comfortable to use and being easy to maintain. Therefore, we developed the following UDS consisted of a water recycling urinals and a water recycling urine-diverting toilet that can save water significantly with minimal energy consumption to be installed in the highway service area.

Fig. 1 shows a water recycling urinal. The disposed flushing water was reduced up to 0.25 L per use by the sensitive electromagnet switch, which controls the flushing water for the urine or for washing the toilet bowl. The 1.7 L of the flushing water isn't mixed with the urine and recycled many times. The electricity is 3.3 W at standby and 10 W at flushing. Fig. 3 shows the schematic of it. Fig. 2 shows the newly developed water recycling urine-diverting toilet, which was created by combining the pre-existing urine-diverting toilets with the water recycling toilets (Nakagawa *et. al.*, 2009). The exterior view is the same as the pre-existing water recycling toilet but it has a newly added function of urine diversion. Fig. 4 shows the schematic of it. Urine can be trapped under the toilet bowl by a weight and time sensitive switch. The disposed flushing water was reduced up to 0.6 L per use by the sensitive switch made of electromagnet which controls the flushing water for the black water or for washing the toilet bowl. The 2.2 L of the flushing water for the toilet bowl isn't mixed with the black water and it is recycled many times. The electricity is 3.3 W at standby and 45.3 W at flushing. The captured urine is sent down a separate pipe into a container where it can be collected and stored for further use.

Figure 1. Water recycling urinal.

Figure 2. Water recycling urine-diverting toilet.

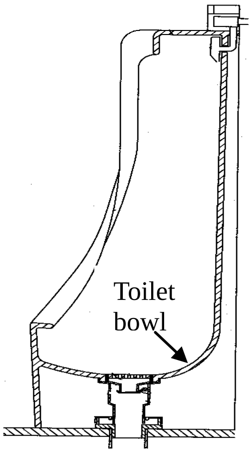

Figure 3. Schematic of water recycling urinal .

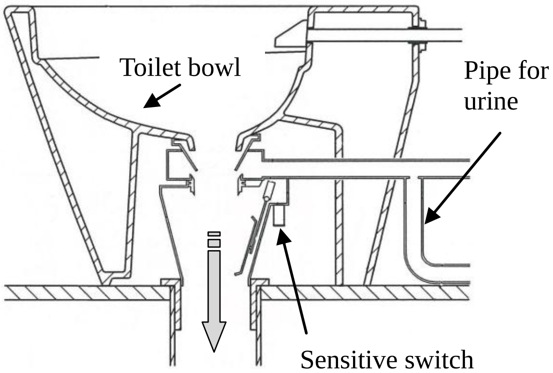

Figure 4. Schematic of water recycling urine-diverting toilet .

2.2 The Minori and Moriya Service Area in Ibaraki prefecture

The feature of the Moriya and Minori service areas are shown in Table 1. The Moriya service area (Fig. 5) is located about 30 km northeast of Tokyo, Japan and is one of the large–scale service areas. The number of the users is 8,080,000 people in a year. The effluent from this service area is treated by the sewage treatment system. Fig. 6 shows one of the existing toilets at the Moriya Service Area. The toilets are 8 L-type flush toilets with a bidet and a fountain of warm water. Number of the urinals and the standard toilets is 64 and 108, respectively.

The Minori service area (Fig. 7) is located about 100 km northeast of Tokyo, Japan and is one of the middle–scale service areas. The number of the users is 560,000 people in a year. The effluent from this service area is treated by the domestic wastewater treatment system (Fig. 8). Number of the urinals and the standard toilets is 30 and 40, respectively.

As shown in Table 1, water use for the toilets occupies 53.4 % and 43.8 % of the total water used in the Moriya and Minori service area, respectively. The water used by the toilets in the Moriya service area totals to a huge amount of 70,000 m^3 per year and costs 170,862 dollars per year. Electricity for the water treatment occupies 1.2 % and 40.1 % of the total electricity used in the Moriya and Minori service area, respectively. Because the wastewater from the Moriya service area is treated by the sewage system, the electricity for water treatment is dedicated just to the water supply, however, the cost for the sewage system is large in the Moriya service area.

Table 1. Feature of Minori and Moriya Service Area.

Case Study			Moriya SA	Minori SA
Size of service area			Large	Medium
Wastewater treatment			Sewage	*DWTF
Number of Users		/ Year	8,080,000	560,000
	Men	/ Year	4,202,000	351,000
	Women	/ Year	3,878,000	214,000
Number of Toilets	For Men		*U 64/ R 28	U 30/ R 10
	For Women		For kids 5/ R 80	For kids 0/ R 30
	For Handicapped		2	2
Amount of Water Use	Total Amount	m^3/Year	132,670	16,138
	Total Cost	Dollar/Year	320,200	37,200
	For toilets	m^3/Year	70,794	7,063
	Cost for toilets	Dollar/Year	170,862	16,281
	Ratio of toilet water use for entire facility	%	**53.4%**	**43.8%**
Amount of Effluent		m^3/Year	134,249	16,548
Cost for sewage system		Dollar/Year	219,800	--
Electricity	Total	kWh/Year	3,250,368	233,681
	Total Cost	Dollar/Year	426,900	35,200
	For water treatment	kWh/Year	39,192	93,641
	Cost for water treatment	Dollar/Year	5,200	14,100
	Ratio of water treatment for entire facility	%	**1.2%**	**40.1%**

* DWTF : Domestic Wastewater Treatment Facility

*U 64/ R 28 : Number of Urinals is 64,Number of Regular Toilets is 28.

Figure 5. Moriya service area in Ibaraki prefecture.

Figure 6. Existed Toilet in Moriya service area.

Figure 7. Minori service area in Ibaraki prefecture.

Figure 8. Domestic wastewater treatment facility in Minori service area.

2.3 Life cycle assessment(LCA) of the urine diversion system(UDS)

The change in energy load and cost that occurred, when the existed toilets were replaced with low environmental load toilets, were calculated. To calculate the energy load, a life cycle assessment (LCA) was adopted. In process analysis, the LCA support software named JEMAI-LCA Pro was used. For input-output analysis was collected from the $(I\text{-}A)^{-1}$ type data for the year 2005 without considering imports. Table 2 shows the energy consumption rate used for the LCA. Other data used for the LCA were obtained from Reinforce LTD. Table 3 shows the cost for introducing the low environmental load toilets for performing the cost-benefit analysis. Fig. 9 shows the schematic of the existing and new system at Minori service area.

Table 2. Energy consumption rate used for the LCA.

Item	Energy consumption rate	Data source
Demolition and removal work	Disposal of waste matter 34,500 (MJ/mill.)	(Nansai,K. *et al.*,2010)
Installation work	Civil engeering & Construction 18,400 (MJ/mill.)	
	Non-wood building construction 39,400 (MJ/mill.)	
	Repair & Maintenance works (MJ/mill.)	
Polypropylene	55.55 (MJ/kg)	NIAIST,JEMAI-LCA software
ABS resin	81.12 (MJ/kg)	
Stainless steel plate	52.38 (MJ/kg)	
Plain steel	20.21 (MJ/kg)	
Styrene-btadiene rubber	83.17 (MJ/kg)	
Vinyl chloride monomer	32.89 (MJ/kg)	
Sheet copper	28.62 (MJ/kg)	
Glass	15.04 (MJ/kg)	
Electric power	8.14 (MJ/kwh)	

(MJ/mill.) : (MJ/million yen)
NIAIST:National Institute of Advanced industrial Science and Technology

Table 3. Cost for introducing the low environmental toilets.

Case Study		Moriya SA	Minori SA
Cost for introducing the urine diversion system (dollar/Year)	Water recycling Urinals	276,500 (64 units)	107,500 (30 units)
	Water recycling urine-diversion toilets	106,200 (108 units)	49,800 (42 units)
	Urine storage tanks	7,000 (21 units)	6,600 (20 units)

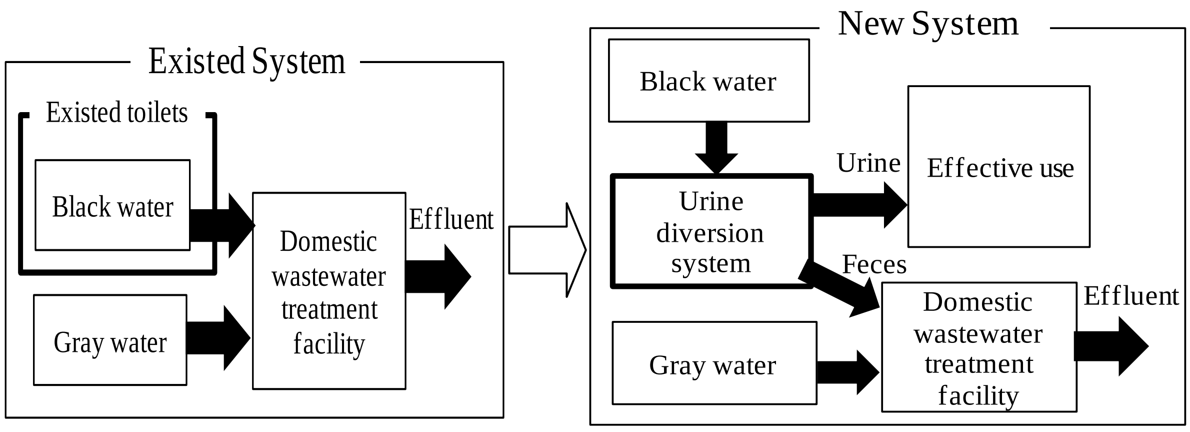

Figure 9. Schematic of the existed system and new system at Minori SA.

3 RESULTS AND DISCUSSION

Fig. 10 and Fig. 11 show the energy and cost, respectively, for introducing of the UDS and the reduced energy per year after introducing it. Regarding the part of the introduction, the ration of the energy and cost for manufacturing and installation were large. Regarding the reduced energy after introducing the UDS, the energy reduction of water supply system and sewer system were large because the amount of the water use and effluent were reduced greatly in Moriya SA. On the other hand, in case of the Minori SA, which fewer UDS were installed compared with the Moriya SA, the amount of the energy reduction was small. Regarding the cost, as shown in Fig. 6, the reduction of the cost for water use and effluent charge were large in case of the Minori SA as the effluent from this service area is treated by the sewage treatment system.

In order to consider the advantage of introducing the UDS, the required period for the cost generated by the introduction of those of UDS to be paid back, by reduction of water and energy consumption, was calculated in energy and cost aspect. Consequently, it was demonstrated that the payback period by introducing the UDS was 0.3 and 0.8 years regarding the burden of the energy, and 2.8 and 12.6 years regarding the cost for the Moriya and Minori service area, respectively. This result of the estimation is valuable for considering the cost of treatment for the removed urine in this system. Concerning the treatment for removed urine, so far, using it as a fertilizer in the rape blossoms field in the vicinity is considered, without neither the cost nor energy as possible, for recycling nutrients back into the environment.

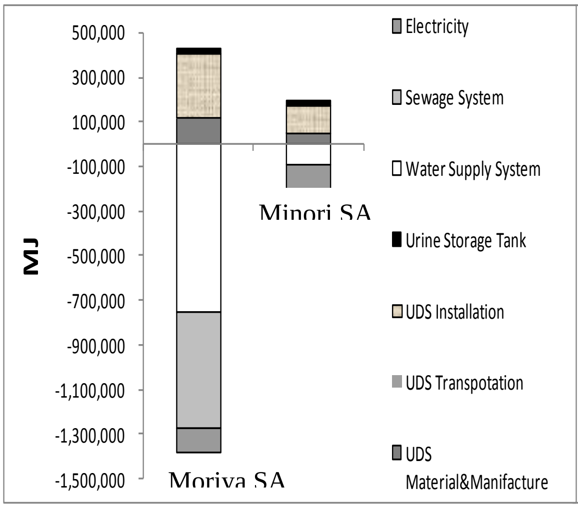

Figure 10. Energy for introducing of the UDS and the reduced energy per year.

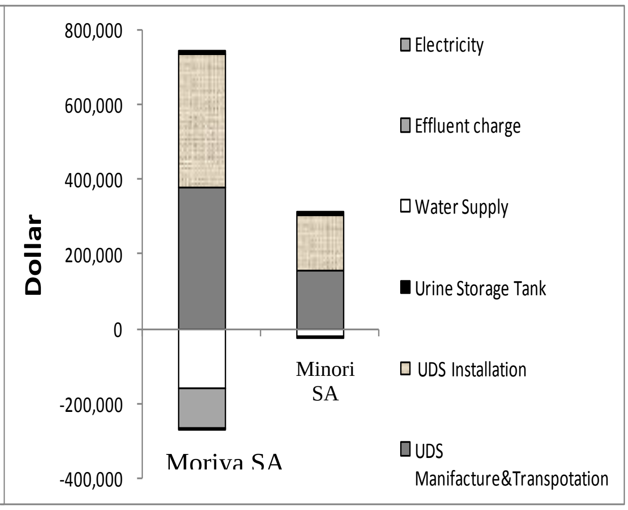

Figure 11. Cost for introducing of the UDS and the reduced cost per year.

4 CONCLUSIONS

In this study, the life cycle assessment of a urine diversion system that is useful after catastrophic earthquakes was performed. Moriya service area which is one of the large–scale service areas and Minori service area which is the middle–scale one were selected for the case study. In addition, a cost-benefit analysis concerning introducing the urine diversion system was performed. As for the results, the payback period by introducing the urine diversion system was 0.3 and 0.8 years regarding the burden of the energy, and 2.8 and 12.6 years regarding the cost for the Moriya and Minori service area, respectively. These results of the estimation are valuable for considering the cost of treatment for removed urine in this system.

ACKNOWLEDGEMENTS: This research presents the results of the research project “Solutions for the water-related problems in Asian metropolitan areas” (Represented by Akira KAWAMURA) supported by the Tokyo Metropolitan Government and the research project “Establishment of resources recycling and low emission type waste water treatment system by urine diversion system “(Represented by Naoko NAKAGAWA) supported by JSPS KAKENHI (23560649). The authors are grateful to NEXCO LTD. and Reinforce LTD for providing valuable data.

REFERENCES

Imura,H., K.Zenitani, Y.Nakajima, K.Morishita, and H.Ikeda(1996),Life cycle assessment of urban sewage treatment systems: a case study in term of LCE and LC-CO_2 , *Journal of Japan Society and Civil Engineering* No.552/VII-175-84 (in Japanese).

Nakagawa.N., A.Kawamura,H. Amaguchi,(2011).”Environmental Assessment Concerning Environmental Load Reduction at Highway Service Areas in Japan by Introducing Low Environmental Load Toilets”, *Proc. of the World Environmental &Water Resources Congress 2011*,Palm Springs, U.S.A., pp.3529-3538.

Nakagawa,N., A.Kawamura,H. Amaguchi (2009).”Estimation of Environmental Load Reduction at Highway Service Area in Japan by Introducing Low Environmental Load Toilets”,*Proceedings of International Conference on Hydrology and Disaster Management*, UNESCO-IHP, 198-203.

Nansai,K.,Y. Moriguchi (2010) Embodied energy and emission intensity data for Japan using input-output tables (3EID): For 2005 IO table (Beta+ version), CGER, National Institute for Environmental Studies, Japan, http://www.cger.nies.go.jp/publications/report/d031/index.html Accessed: July 21, 2011.

Sustainable Water System Association (1993), Water supply system in the age of the global environment, *Gihodo Shuppan Co.,Ltd.*, 109 (in Japanese).