# Life Cycle Analysis of Environmental Load from Small-scale Wastewater Treatment Systems in Japan

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## INTRODUCTION

The aim of this study was to perform life cycle assessment (LCA) of Japanese small-scale wastewater treatment systems (Johkasou), which serve fewer than 10 people and are widely used as decentralized wastewater treatment systems in Japan. Many types of Johkasou systems exist nowadays, for example, the standard structure type, BOD removal type, nitrogen removal type, phosphorus removal type, and very compact type. However, few studies have focused on the LCA of Johkasou systems thus far compared with the numerous studies on large-scale wastewater treatment systems. Moreover, LCA studies of wastewater treatment have mainly evaluated the total cost or CO2 emission. The integrated environmental load under two conditions in wastewater treatment has been evaluated and compared using the life cycle impact assessment method based on endpoint modelling ver. 2 (LIME2; Itsubo et al., 2012) and the ecotoxicity estimation model (Mishima et al., 2016). This procedure is very useful in evaluating the integrated environmental load against global warming, eutrophication, and biodiversity in the atmosphere and water environments. Therefore, LCA evaluating the integrated environmental load, including effluent discharge to water environments from various Johkasou systems, should be performed to quantify the environmental performances of the systems. The objective of this study was to determine the integrated environmental performances of actual Johkasou systems and consider the feature of each Johkasou system quantitatively using the LCA procedure.

## METHODS

The water quality of wastewater treated by the Johkasou systems, as classified in one of six categories shown in Table 1, was investigated. To study Johkasou systems with normal influent load, 5 p.e. (population equivalent) Johkasou systems that were used by two to four people and 7 p.e. Johkasou systems that were used by three to five people were selected for investigation. Because only a few C3 Johkasou systems were installed, two 5 p.e. C3 Johkasou systems were selected and investigated once per month for about a year each. The life cycle system boundary and analysis for the Johkasou systems in this study were set as shown in Fig. 1. Environmental load was calculated by multiplying the mass associated with an activity in a process in each stage by the discharge rate of the environmental load. Discharge rate of the environmental load was obtained from the Inventory Database for Environmental Analysis (IDEA) included in the LCA support system MiLCA. In the operation stage, not only the environmental load of power consumption, consumables, greenhouse gas emissions, maintenance, and sludge disposal, but also the environmental load of COD, T-N, T-P, and NH4-N in the effluent were calculated. Finally, in accordance with LIME2 and ecotoxicity estimation model, each environmental load was converted into a monetary value (yen) by multiplying it by conversion factors.


Table 1 – Classification of Johkasou systems to six categories.

| Classification | Targeted wastewater | Type | Effluent water quality (mg/L) | Remarks | n |
|---|---|---|---|---|---|
| M | Night soil only | - | BOD 90 | | 26 |
| K | All of domestic wastewater | Standard structure | BOD 20 | | 89 |
| C1 | | Certified structure | BOD 20<br>T-N 20 | | 26 |
| C2 | | | BOD 10<br>T-N 20 | | 43 |
| C3 | | | BOD 10<br>T-N 10<br>T-P 1 | Phophorus removal | 29 |
| C4 | | | BOD 20<br>T-N 20 | Very compact type | 20 |

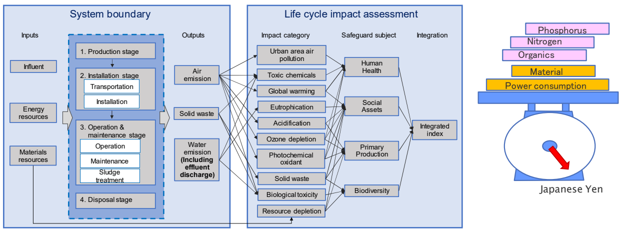



Figure 1 – The life cycle system boundary and analysis for the Johkasou systems.

## RESULTS AND DISCUSSION

The box-and-whisker plots in Fig. 2 shows the water quality for all the categories. Because the mean value of BOD was lower than the standard value, 20 mg/L, the Johkasou systems investigated seemed to have been operated appropriately as a whole. As for C2 and C3, the BOD and T-N were consistently lower than 10 mg/L. For C3, which can remove phosphorus, T-P was overwhelmingly lower than the other five categories. As for C2 and C3, NH4-N was lower than that of the other categories. This was because nitrification was further promoted.

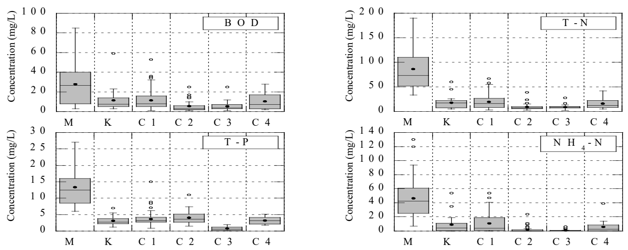



Figure 2 – Effluent water quality for all the categories.

The environmental load of the effluent discharge in the operation stage was calculated based on the mean values of the effluent water quality parameters obtained from the water quality survey of the Johkasou systems (Fig. 3). Although there are some differences among categories, the environmental load was high and in the order of T-P > NH4-N > T-N, and the impact of COD was extremely small. Because C3 has the advantage of NH4-N and T-P removal, the environmental load of C3 was smaller than that of the other categories. The environmental load of effluent discharge in the operation stage was 44%, on average, and the evaluation of the inventory of effluent discharge using LCA was considered very important. The environmental loads of the total life cycle in all stages are shown in Fig. 4. Comparison among stages demonstrated that the operation stage accounted for a very large proportion of the environmental load of the total life cycle (95% in C3, for example). C3 had the lowest environmental load. In C3, the reduction of phosphorus load via iron electrolysis had impacts on the environmental load. As described thus far, the environmental loads of the phosphorus removal type and very compact type Johkasou systems were calculated, and the superiority of these two types of Johkasou systems was clearly shown.

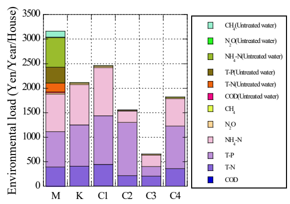



Figure 3 Environmental load of the effluent discharge in the operation stage.

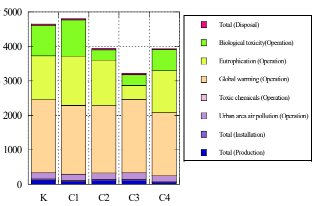
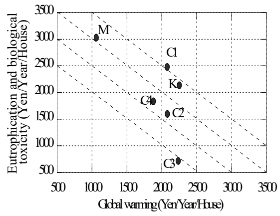



Figure 4 Environmental loads of the total life cycle in all stages.




The relationship between the environmental load for global warming and eutrophication plus biological toxicity is shown in Fig. 5 and the trade-off relation was observed between these parameters. As mentioned above, the feature of each Johkasou system was quantitatively evaluated using the LCA procedure in this study.

Figure 5 Relationship between the environmental load for global warming and eutrophication plus biological toxicity.

## CONCLUSIONS

LCA evaluating the environmental load from various small-scale wastewater treatment systems was performed to quantify the environmental performances of the systems in this study.

- ✓ The model that can evaluate the environmental load from the systems using LCA methods was successfully established and life cycle environmental costs of the classified systems were successfully calculated.
- ✓ The cost of the phosphorus removal was the lowest, as it removed T-P and $NH_4$-N effectively.
- ✓ Trade-off relation was observed between the environmental load for global warming and eutrophication plus biological toxicity.
- ✓ The feature of each system was quantitatively evaluated using the LCA procedure in this study.

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Acknowledgement:
This work was supported by grants-in-Aid for Johkasou research in Japan Education Center of Environmental Sanitation and JSPS KAKENHI Grant Number JP16K16209.