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On-site wastewater treatment and reuses in Japan

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On-site wastewater treatment poses a challenging problem for engineers. It requires a balance of appropriate levels of technology and the operational complexity necessary to obtain high-quality effluent together with adequate reliability and simplicity to accommodate infrequent maintenance and monitoring. This review covers how these issues have been addressed in on-site wastewater treatment in Japan (termed *johkasou*). On-site systems in Japan range from outmoded designs that discharge grey water directly into the environment to advanced treatment units in high-density areas that produce reclaimed water on-site. Japan is a world leader in membrane technologies that have led to the development of on-site wastewater treatment units capable of water-reclamation quality effluent. Alternative ideas being pursued for on-site technologies also include separate waste stream collection, which would provide for more efficient treatment and reuse. Night soil treatment plants, where sludge from on-site systems is treated, are also distinctive to Japan, serving 37 million people. Japan has governmental regulations in place to ensure routine inspections of on-site units; furthermore, subsidies are available to reduce the cost of on-site systems for building owners. Lessons learned in on-site wastewater treatment in Japan have applications worldwide, from regions where water is scarce, to high-density areas in developing countries that currently lack sewer infrastructures.

1. INTRODUCTION

Johkasou is the Japanese word for on-site wastewater treatment; it is a combination of the words jouka, which means purification, and sou, meaning tank or tub. *Johkasou* are mainly used in two situations: (1) when there is no access to sewers and (2) in high population density areas for on-site wastewater treatment including water reclamation. Up until World War II, Japan was largely a rice-based agricultural society. At that time the most common form of waste treatment was vault toilets (pit latrines), with the night soil collected for use as agricultural fertilizers and soil conditioners. Following World War II, flush toilets were rapidly introduced throughout Japan. As Japan became increasingly industrialised, the population shifted to urban areas and sanitation became a problem due to population density. The transition from vault toilets (pit latrines) to *johkasou* originated to facilitate the introduction of flush toilets. Since then, sewers and *johkasou* have developed side by side.

As of the year 2000, 71% of household wastewater in Japan was receiving some type of treatment and 91% of Japanese residents had flush toilets.[1] A breakdown by population of wastewater treatment methods utilised in Japan is presented in Fig. 1. The *Johkasou* Law mandates *johkasou* for new construction in areas without sewers. *Johkasou* are different from European septic tanks—even the smallest units (5–10 population equivalents (p.e.)) undergo an aerobic process.

1.1. *Tandoku-shori johkasou*

The first type of *johkasou* developed was the *tandoku-shori johkasou* for the treatment of only black water, with grey water being discharged directly into the environment. *Tandoku* means separate or individual and *shori* means disposal or treatment. The only effluent values for *tandoku-shori johkasou* found in the literature were from Wanatabe *et al.*[2] who reported a 65% removal of biological oxygen demand (BOD) from black water, which together with untreated grey water resulted in an effluent value of 31·5 g BOD per capita per day. 30–50 million people in Japan are currently still using *tandoku-shori johkasou.*[3,4] It is obvious that this level of treatment is not adequate to prevent environmental contamination: grey water typically contains higher BOD concentrations than black water.[5] As a result, households with *tandoku-shori* are major contributors to water pollution.[3] The Ministry of the Environment (formerly the Ministry of Welfare and Health) has since realised their mistake in approving *tandoku-shori johkasou* (S. Matsui, pers. comm., 2004) and, as of 2001, only *johkasou* that also treat grey water are allowed for new installations.[6]

1.2. *Gappei-shori johkasou*

The recognition that *tandoku-shori johkasou* were not protecting the environment, coupled with the continually increasing popularity of flush toilets, led to the development of *gappei-shori johkasou* (S. Matsui, pers. comm., 2004). The *gappei-shori johkasou* treat all wastewater from the house (*gappei* means combined or merged). Effluent guidelines put into place by the Ministry of Land, Infrastructure and Transport are dependent on the location and size of installation (size

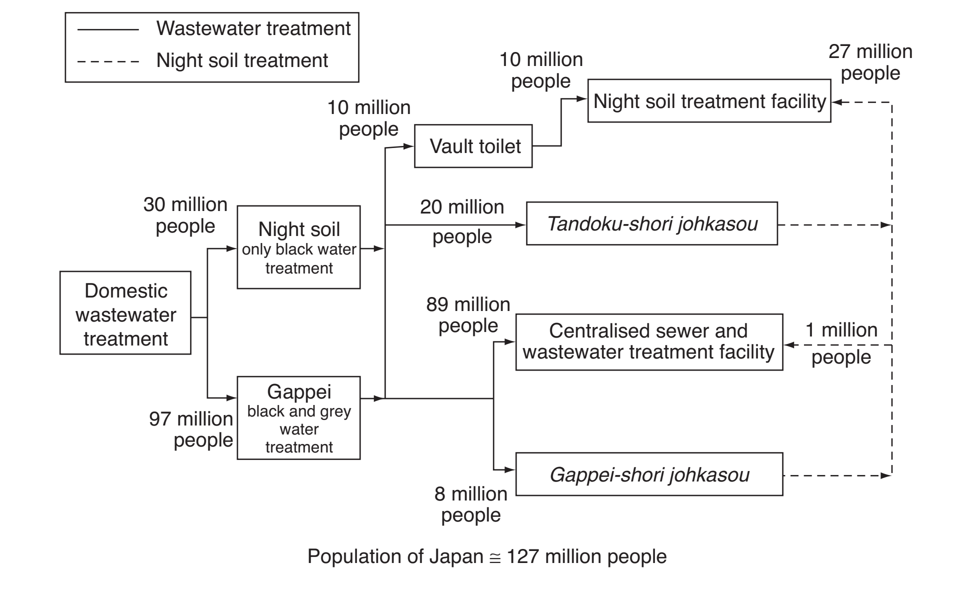

Fig. 1. Current breakdown by population of wastewater treatment methods utilised in Japan (modified from Yang *et al.*,[4] © IWA). These numbers were derived by compiling all of the values in the reviewed literature and using the values that were most commonly presented. A wide range of values was noted in the literature, for example the population served by night soil treatment facilities ranged from 30 to 50 million

classifications range from 5 p.e. to greater than 5000 p.e.). Small-scale (less than 5 p.e.) *johkasou* must meet an effluent BOD of less than 20 mg/l; acceptable effluent values for other scenarios are: 10–60 mg/l BOD, 10–20 mg/l nitrogen (N) and <1 mg/l phosphorus (P)[7] (Y. Okubo, pers. comm., 2004). Two models of commercially available Kubota *johkasou* are presented in Fig. 2.

Gappei-shori removal of BOD is accomplished by either fixed film or suspended growth processes, but is frequently a hybrid of the two.[7] Fig. 3 is a schematic illustration of a typical process flow for *gappei-shori johkasou*. The first stage consists of either filter media in an anaerobic filter tank or sedimentation tank (analogous to a septic tank). The second-stage contact aeration tank also typically contains media for biofilm growth.[8] The medium for biofilm growth is usually plastic and a variety of shapes is used depending on the tank purpose (e.g. settling or activated).[4] *Johkasou* treatment is able to reduce pathogens, but performance is dependent on BOD, temperature and recycle rates, and is not considered sufficiently reliable.[9] Disinfection is typically accomplished with tablets of calcium hypochlorite (S. Matsui, pers. comm., 2004).

BOD values reported in the literature for *gappei-shori* (p.e. < 10) effluent operating without recycle include an average of 14·9 mg/l BOD (489 *gappei-shori* effluent samples)[4] and an average of 21 mg/l BOD (with a range of 2·7–127 mg/l BOD for five small-scale *gappei-shori* sampled once a month over an eight-month period).[8] *Gappei-shori johkasou* are an improvement over *tandoku-shori johkasou* as they treat both black and grey water, but the variable effluent BOD together with the lack of nutrient removal (N and P) indicate that *gappei-shori johkasou* continue to contribute to environmental pollution. Eutrophication of surface waters is a great concern in Japan: surface waters have not seen a decrease in BOD since the 1970s.[10]

1.3. Nutrient removal in *gappei-shori johkasou*

Investigations into improving *gappei-shori johkasou* have been based on the same methods used in full-scale wastewater treatment plants (WWTPs). Nitrogen removal can be accomplished by recirculation of nitrified sludge to an anoxic bed reactor for de-nitrification[11] or intermittent aeration.[4] Upgrading the *gappei-shori* process flow to incorporate nutrient removal would entail adding a recycle line from the contact aeration zone to the anoxic zone.[4] Such a recycle would also improve effluent by aiding in the prevention of solids washout.[4] Phosphorus removal can be accomplished by physical–chemical methods including absorption or flocculation and sedimentation. These are relatively simple, easy and effective processes, but are somewhat expensive and increase solids.[4,7]

Fig. 2. Two models of commercially available *johkasou* manufactured by Kubota[26] (© Kubota)

Effluent values for nutrient removal *johkasou* reported in the literature include: 14–30 mg/l total N[4]; 12 mg/l BOD with nitrate N (NO_3–N) from 0·07 to 29 mg/l depending on the internal recycle rate.[10] Imura *et al.*,[12] operating a nutrient removal unit with a recycle rate of 3·7 times the influent flow rate, saw consistent effluent values of 7·8, 6·4 and 1·2 mg/l BOD, total N and total P respectively. Increasing recycle and

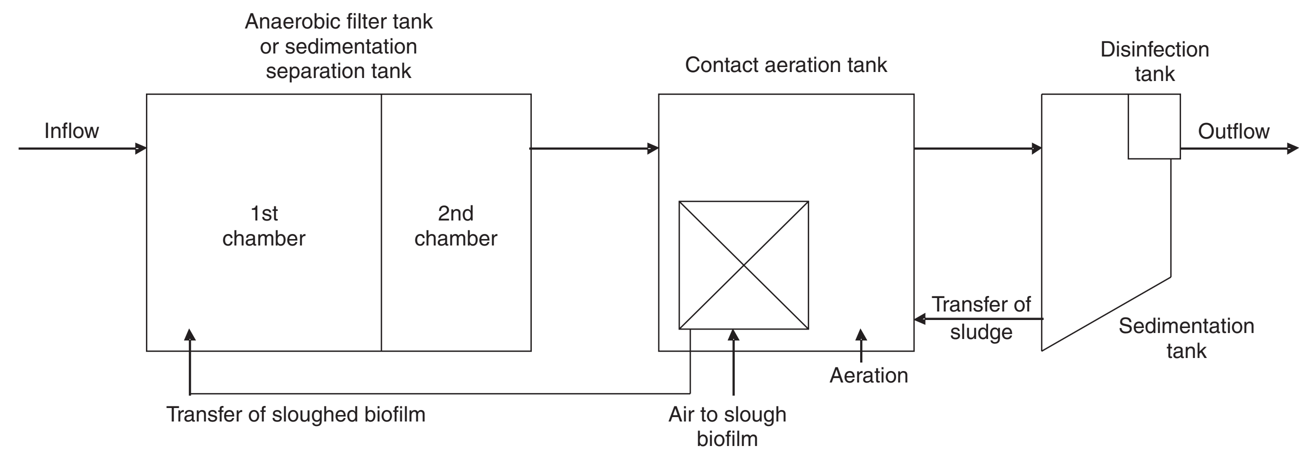

Fig. 3. Schematic of a typical process flow for a household *gappei-shori johkasou* (modified from Nakajima *et al.*[8])

retention times increases the level of treatment, but also costs more and requires more operational complexity; further research in this area should yield more consistent recommendations for recycle rates.

1.4. *Bunri-johkasou*

An alternative concept for on-site wastewater management, which Matsui (pers. comm., 2004) has termed *bunri-johkasou*, is the separate collection and treatment of waste streams. *Bunri* means separation or isolation. Separate collection and treatment of wastes simplifies the treatment process, while increasing opportunities for beneficial reuses. This concept is increasing in recognition, for example Wilderer[13] identifies five categories of domestic wastewater for separate collection: brown (faeces), yellow (urine), black (faeces + urine), green (kitchen waste) and grey (other wastewater coming from inside the house). Flush toilets contribute the highest volume of water to the waste stream, which could be greatly reduced by using dry or vacuum flush toilets and also allow for the separate collection of undiluted solids. Brown waste could then be fermented for methane and electricity generation (along with other wastes such as animal dung or food waste) or could be used as a soil additive (S. Matsui, pers. comm., 2004). Kitchen waste (green water) contributes the highest amounts of NO_3–N and the second highest loadings of carbonaceous oxygen demand (COD), total suspended solids (TSS) and phosphate (PO_4–P) to the waste stream.[14] Following the installation of separate collection and treatment for brown waste, grey and green water could be collected for treatment in existing *johkasou* (S. Matsui, pers. comm., 2004). Additionally, special *johkasou* have been developed for food waste disposal, which also provide for the reuse of organic matter.[6] Urine diverting toilets allow for the separate collection of urine, which has higher concentrations of N, P and potassium (K) than brown waste.[5] Technology is also available for the conversion of urine to N and P fertilizer (S. Matsui, pers. comm., 2004). This concept has also been successfully employed in Sweden.[15] An illustration of separate collection and treatment of faeces and urine is presented in Fig. 4.

Separate collection should be considered as a viable alternative. Many new ideas seem unfeasible when first proposed, but one should consider the success of separation of municipal solids waste streams for recycling and composting in many countries. In addition, Japan has exported *johkasou* to developing countries where decentralised treatment is an attractive alternative to sewers due to their prohibitive cost. *Johkasou* are expensive (although much less so than sewers), require specialised maintenance and do not fully treat wastewater. The *bunri-johkasou* potentially presents a lower cost solution to the problem, while simultaneously achieving higher levels of treatment (U. Winblad, pers. comm., 2004).

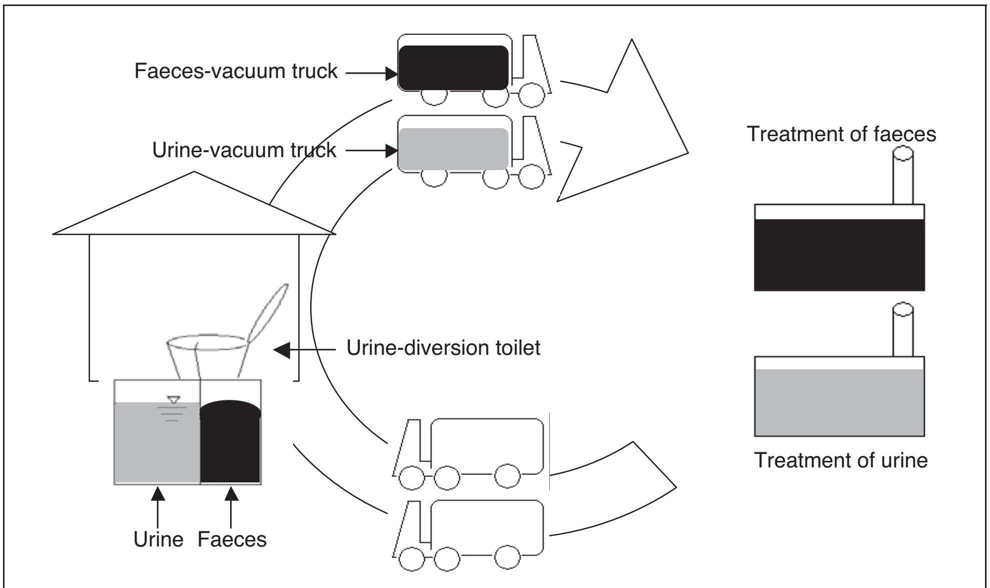

Fig. 4. A vacuum truck collection system with urine–faeces separation (reprinted with permission from Matsui *et al.*[27] © IWA)

1.5. Membrane *gappei-shori johkasou*

Japan is a world leader in the development of membrane technologies. Membranes have been used to upgrade *tandoku-shori johkasou* to *gappei-shori johkasou* for on-site wastewater treatment including reclamation-quality effluent and the treatment of night soil.[4] Water reclamation *johkasou* and night soil are discussed in the following sections. Membranes are currently fairly expensive, but they are becoming more affordable as their use and sophistication increases. Membranes can be submerged in the activated sludge chamber to separate the liquid stream from solids.[7] The small size of the membrane pores prevents the passage of suspended solids. By maintaining a much higher density of microbes, the treatment capacity is greatly increased, resulting in a much smaller footprint compared to gravity settling units.[16]

Zhang and Yamamoto[16] in a comparison of *johkasou* membrane bioreactors (MBRs) and conventional activated sludge (CAS) systems found MBRs to have a more consistent and better quality effluent. Ohmori *et al.*[17] and Yang *et al.*[4] also found MBR *johkasou* performed well (total N 8 mg/l, BOD 2·3 mg/l, TSS < 5 mg/l and total coliform <100 cells/ml), but needed maintenance every three months and sludge withdrawal and membrane cleaning with sodium hypochlorite every six months to prevent fouling of the membrane. Ebie *et al.*[18] operated a MBR *johkasou* with a recycle of three times the influent flow rate and consistently saw effluent ammonia N (NH_3–N) < 1 mg/l, except when temperatures fell below 10°C and nitrification was inhibited. Membranes can greatly increase the treatment capacity of *johkasou*, but they also add yet another dimension to the complexity of *johkasou*. It is essential to find the 'right' operating conditions to prevent membrane fouling.[7] Overall, MBR *johkasou* appear to be very promising for effective on-site treatment; the increased cost and maintenance of MBRs can be justified for installations in high-density areas where space is a limiting factor. Hopefully knowledge gained from research and implementations will reduce maintenance demands and reliability will continue to increase.

2. *JOHKASOU* WATER RECLAMATION

70% of Japan is mountainous with short, steep rivers that drain rapidly to the ocean. This topography, combined with rainfall concentrated as typhoons and monsoons (mean annual average 1714 mm), puts a strain on the water supply.[19] In addition, Japan has the fourth highest population density in the world, placing a high demand on water resources in urban areas.[1] In response to water shortages, on-site *johkasou* treatment including water reclamation is promoted by the government in urban locations, even if they are currently entirely served by sewers.[20] In Fukuoka City new construction with floor space greater than 3000–5000 m^2 and in Tokyo greater than 30 000 m^2 is required to incorporate on-site water recycling facilities (H. Yamagata, pers. comm., 2004).[21] In Tokyo, if a building has floor space greater than 10 000 m^2, or a building footprint greater than 3000 m^2, it is also required to have facilities for rainwater collection.[21] As of 1997, there were 1475 individual building and block-wide *johkasou* nationally capable of producing reclaimed water.[19] On average, 130 additional *johkasou* capable of producing reclaimed water are installed annually.[21] In Japan, the most common uses of reclaimed water are urban non-potable (e.g. toilet flushing), in contrast to many other countries where reclaimed water is primarily used for agriculture.[19] In Tokyo 61% of non-potable water use is met by reclaimed sources.[21] No serious human health incidents have been reported from the use of reclaimed water and odour issues have only been reported in a handful of buildings.[21] If on-site wastewater treatment includes grey, black and rainwater for reuse then non-potable water demand can potentially be fully met through on-site recycling.[21] Table 1 presents water quality criteria for non-potable reuse in Japan.[19]

Capital expenditure per unit of reclaimed water decreases with increasing flow rate, but operations and maintenance (O&M) increases with increasing flow rate.[21] On-site water reclamation in Japan has been shown to be more economical than the use of public sewers with water supply from municipal water reclamation (i.e. dual-pipe water delivery system) for flows greater than 100 m^3/d.[21]

3. NIGHT SOIL TREATMENT

Johkasou need to have sludge removed at least once a year to prevent the washout of solids.[4] A vacuum truck that typically has a 2–4 tonne sludge storage capacity is used for this purpose,[4] but *johkasou* desludging vendors are also starting to use sludge concentration and dehydration trucks for increased efficiency.[22] A mobile sludge removal truck is shown in Fig. 5. There are 1185 night soil treatment plants in Japan for the treatment of sludge, servicing 37 million people. Disposal of night soil is regulated by the Waste Management and Public Cleansing Law, enacted in 1970 to preserve the environment and protect public health.[23] Prior to this law, 90% of *johkasou* sludge was treated in night soil treatment facilities, 5% was

	Parameter	Toilet flushing	Landscape irrigation	Environmental water (e.g. water features)
Criteria	Total coliform bacteria (CFU/ml)	$\leqslant 10^*$	Not detected	Not detected
	Residual chlorine: mg/l	Trace amount	$\geqslant 1·4$	NA
Guidelines	Appearance	Not unpleasant	Not unpleasant	Not unpleasant
	Turbidity units	NA	NA	$\leqslant 10$
	BOD: mg/l	NA	NA	$\leqslant 10$
	Odour	Not unpleasant	Not unpleasant	Not unpleasant
	pH	5·8–8·6	5·8–8·6	5·8–8·6

*This is equivalent to 1000 CFU/ml. Note that Californias Wastewater Reclamation Criteria[19] is 2·2/100 ml total coliforms.

Table 1. Water quality criteria for non-potable reuse in Japan (reprinted with permission from Ogoshi *et al.*[19] © IWA)

Fig. 5. Mobile sludge removal vehicle (reprinted with permission from Matsui *et al.*[27] © IWA)

dumped in the ocean and 5% was treated in WWTPs;[22] the dumping of sludge into the ocean was banned in the year 2000.[6]

Night soil treatment plants commonly employ advanced treatment. Treatment processes typically include activated sludge, biological denitrification, chemical P removal, separation of solids and colour removal by partial ozonation and activated carbon. Night soil treatment plants frequently employ membranes for solid–liquid separation and effluent BOD, N and P concentrations are comparable to those obtained in WWTPs (S. Matsui, pers. comm., 2004).[24] The push for upgrading from tandoku- to *gappei-shori johkasou* is overwhelming night soil treatment facilities because combined black and grey water has three times the BOD load than black water alone, resulting in greater solids production.[11] However, when *gappei-shori johkasou* are operated for biological nutrient removal, higher circulation rates result in less solids production in addition to increased nutrient removal.[11]

Following night soil treatment, biosolids are recycled in a variety of ways. Reuses include production of biogas for energy, compost, agriculture and cement manufacturing.[4,10] Japan has

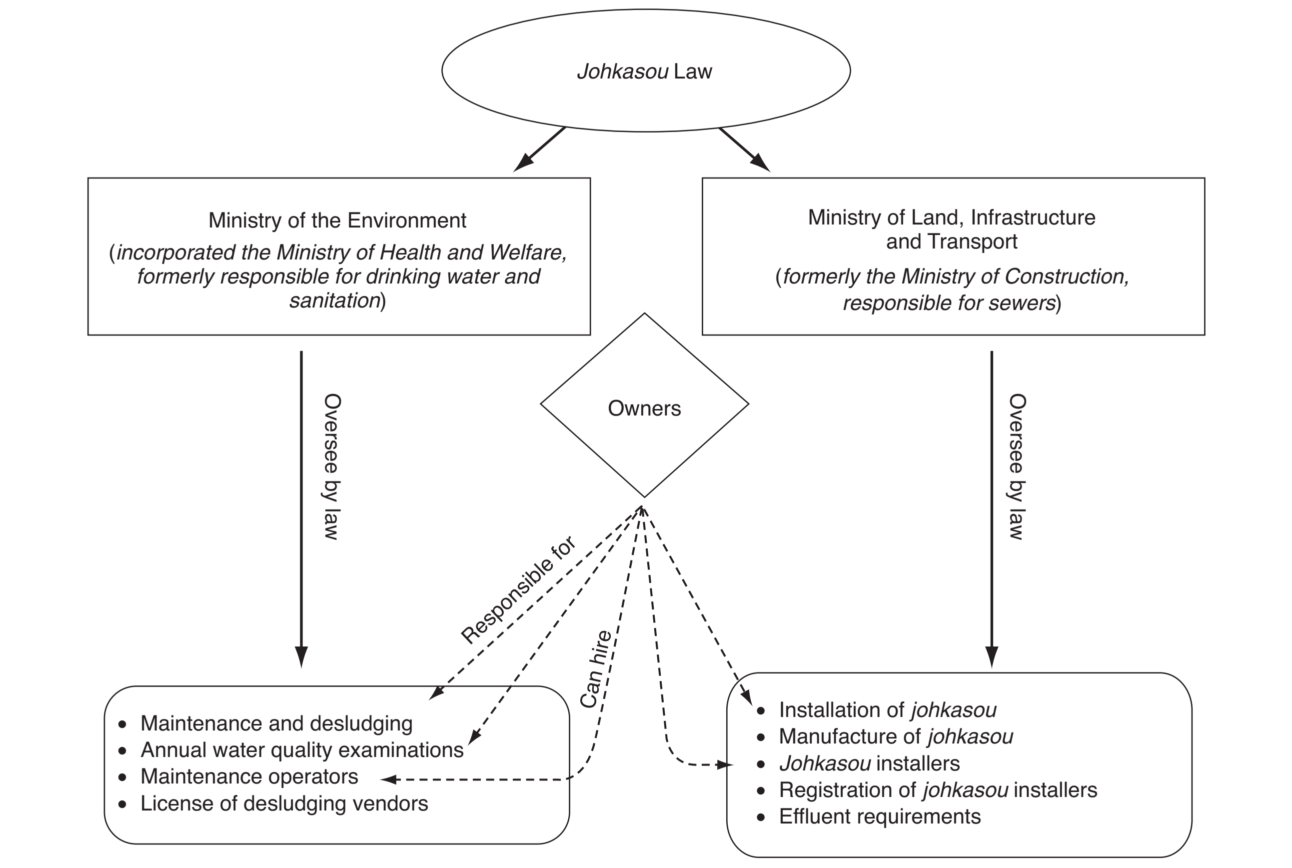

Fig. 6. Organisation of the government structure responsible for implementing and enforcing the *Johkasou* Law (S. Matsui, pers. comm., 2004, Y. Okubo, pers. comm., 2004)

one of the highest biosolids recycling rates in the world, comparable to those of Norway and Denmark.[1]

4. *JOHKASOU* REGULATIONS AND SUBSIDIES

The 1983 *Johkasou* Law is responsible for the regulation of manufacture, installation, maintenance and desludging of *johkasou*, in addition to the registration of *johkasou* installers and maintenance operators and the license of *johkasou* desludging vendors.[3] Fig. 6 outlines the organisation of the government structure that is responsible for enforcing the *Johkasou* Law.

A lack of maintenance by homeowners has been a downfall of aerobic treatment units in other countries. To account for this, *johkasou* owners in Japan are subject to annual water quality examination by an inspecting agency. Inspection includes an overall visual inspection of the unit, water quality testing (pH, dissolved oxygen, transparency, residual chlorine, BOD and N if designed for N removal) and inspection of maintenance and desludging records.[4] *Johkasou* are typically monitored a few times a year by maintenance operatives.[22] Maintenance is typically contracted out to separate operatives for both *johkasou* maintenance and desludging.[4]

The *Johkasou* Law also established a national subsidy to reduce costs to homeowners[3] (subsidising *johkasou* is also more cost effective for the government than building sewers). The Ministry of Health has also promoted and subsidised the installation of *gappei-shori* instead of *tandoku-shori johkasou*. The amount subsidised by government agencies varies by situation. Reported values for the subsidy are 60% of the total capital cost covered by the household, 27% by the local municipalities and 13% by the federal government (an unsubsidised *gappei-shori johkasou* costs around 540 000 Yen).[25] Total annual subsidies increased from 100 million Yen in 1987 to 21 billion Yen in 2000.[6]

5. CONCLUSION

Satisfying wastewater treatment needs through on-site treatment requires a multifaceted approach, incorporating technologies ranging from separate waste collection to membrane bioreactors. The feasibility and appropriate implementation of treatment varies greatly depending on location. In Japan it is apparent that many *johkasou* treatment methods need to be upgraded to ensure adequate protection of the environment. However, Japan is also a world leader in membrane technologies that allow for very high-quality effluent to be used as reclaimed water. The unique history of on-site wastewater treatment in Japan illustrates the many factors that must be taken into consideration when determining suitable technologies. In any location, assurance that a maintenance plan will be implemented is critical to the long-term success of all technologies. Other important factors include cost, footprint, desired level of treatment, availability of water and opportunities for beneficial reuse. Advances need to continue being made in on-site treatment processes to provide more reliable systems, allowing for high-quality effluent and biosolids that can be considered safe for reuse applications, while at the same time being affordable and simple to maintain.

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