LOW-COST SOLUTION FOR URBAN WASTEWATER TREATMENT IN BHUTAN

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Abstract

This paper presents the new technology of urban wastewater treatment of Japanese origin, Dojo-Joka System, which relies on the capacity of the natural soil to decompose the objects and purify the wastewater. This system is applicable, not only to the individual household level, but also to the sewerage at the community level in the name of Niimi System. Their small-scale sewerage system has the advantage over the conventional wastewater treatment technologies as it does not cause any secondary pollution: it uses fewer machines and simpler technologies; it could be operated fully unattended and does not generate large amount of sludge; it could be constructed and maintained at reduced costs; and even so it still assures the cleanliness of the treated water. The pilot plant will soon be constructed in Thimphu to demonstrate its effectiveness in spite of the challenges detected in the preliminary stage of the project implementation.

1. Background

The Development Cooperation Policy of the government of Japan to Bhutan takes up the mitigation of vulnerability as one of its mid-term objectives. In line with this objective, the Policy identifies urban environment as one of the most critical issues, taking into consideration the rapid urbanization and the change of lifestyles, which cause a number of urban environmental problems including solid waste management, wastewater management, traffic congestion, CO_2 emission, to name a few.

In response to the urbanization, there is already a sewerage treatment plant in Babesa, Thimphu, catering to the demand of only a part of the city's population. The existing plant has an obsolete method with three-stage lagoon system and it is treating 1,750 m3/day of sewerage with 54 days detention period. In this treatment method, the facility requires large areas and generates bad odor out to the surrounding areas, thereby affecting the neighbouring environment and causing strong resistance by the neighbours. To cope with such situations, the improvement of the existing plant and installation of additional sewerage facilities have been recommended to meet the demand of the ever increasing population of the capital city. With improvement and construction of such new sewerage facilities, the city

could mitigate unwarranted developmental risks and vitalize tourism. But still the wastewater management in the rapidly urbanized areas has been regarded as a frontier of sustainable development.

Under these circumstances, the Mokan-Joka System Co. Ltd. (MJS) of Japan submitted a pilot project proposal to the Japan International Cooperation Agency (JICA) on the construction of the demonstration site and verification test of a Japanese wastewater management technology, "Niimi Trench Model Sewerage Facility" in Bhutan. The proposal was accepted and, after a series of discussions, the trilateral MOU was signed by the Department of Engineering Services (DoES) of the Ministry of Works and Human Settlement (MoWHS), MJS and JICA, in December 2016. Although the pilot project is still at the preliminary phase and the measurement survey was just conducted in April 2017, we feel that the initiative by the Japanese firm to promote a low-cost sewage technology should be better recognized across the whole construction industry in the country. Once its functional performance is proven effective as well as sustainable, the Niimi System should be scaled up by the local contractors and contribute to the improvement of the sewerage system and urban environment.

This paper aims at bringing to the attention of the seminar participants the new measures to be taken by the MJS on the promotion of an appropriate sewerage system, especially the Niimi System, improved fixed biofilm process.

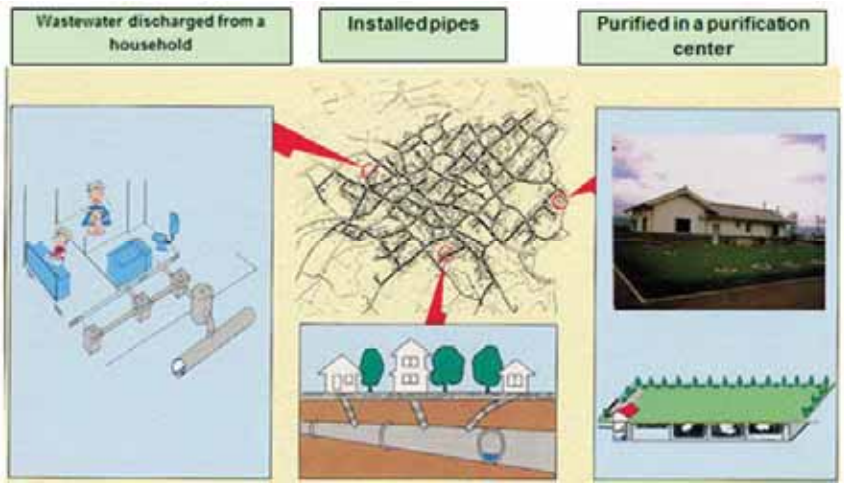
2. What is the Niimi System?

As one of the ecological treatment technologies, the subsurface wastewater infiltration system (SWIS) is the most commonly used system for the treatment and disposal of onsite wastewater and has been used as one of the conventional intensive sewage treatment technologies. SWIS can be an effective process for wastewater treatment utilizing the integrated mechanisms of chemical, physical and biological reactions if the system is carefully designed and managed.
The proposed Niimi System is one of the improved SWISs. It was first developed in 1967 by a Japanese agronomist, Dr. Tadashi Niimi, and since then it has been promoted by the Mokan Joka System (MJS) in Japan. At present, we are able to see so many wastewater treatment plants with the Niimi System all across Japan, and, due to its applicability to each household level, soil absorption septic tanks adopting the same mechanism can be seen in many houses in the rural Japan. It is a kind of integrated technique including the aerobic and anaerobic processes, using intentional anaerobic fixed filtering medium called bio-crystal and periodic aeration of sedimentation tanks.

According to Yang, et al. [2010], the Niimi System adopts an infiltration percolation method backed up by the phenomena of capillary siphoning. This method, even if it's small-scale, could be applied to the single house/building level or to the single facility level. The wastewater discharged from each household is transferred into distribution pipes with numerous small holes in them. Because of the capillary activity, the polluted water is drawn up and distributed uniformly in sand. The pollutants in water are then eliminated by filtration and microbial activity. The treated water is then collected with a collection tube implemented below and pumped out into a reclaimed water tank. To avoid a possible shortcut between distribution tube and collection tube, a water-proof trough is implemented between them. To avoid possible underground water pollution, a water-proof layer is applied. The polluted water body percolates around the circumference through the capillary soakage and soil percolation actions, under the integrated action of soil, microbe and plant together, the organic matter and nitrogen are decompounded, the phosphorus is absorbed by the soil through chemical precipitation, and it can be utilized by the lawn or other plants, even at the single household level.

Building on the original idea of Niimi System, MJS has further developed a variety of sewerage systems in accordance with the amount of wastewater to be treated and with the requirement for the quality of treated water. This system could also apply to the small community level. The Niimi System could be modified and customized to the local specific conditions. In most of the developing countries, for example, where the BOD (Biochemical Oxygen Demand) requirement is lower than that of the developed countries, the treatment may not require such a lengthy process.

Figure 1. Sewerage System



Source: By Author.

Once the wastewater is collected via the pipelines connected with the households in the local community and flown into the treatment plant for purification (See Figure 1), there are basically two processes for digestion at the treatment plant: sedimentation and aeration. For both stages, the tanks are covered with soil (See Figure 2). First, the soil-covered sedimentation tanks are for the removal of sludge. The sewage is then defecated by active microorganisms adhered to the surface of the bio-crystals, approximately 16 centimeters in diameter. In Japan, the third stage tank for settling and contact filtration is installed to purify the water strictly to the quality standard set by the government. But in the case of developing countries, this stage may not be necessary to meet the quality standard of the country.

Figure 2. Niimi System Model Sewerage Facility

Source: By Author.

The Niimi System is not uniform and could be modified in accordance with the local specific conditions including the water quality requirements and the number of beneficiaries. It could cover the population from 51 to 4,000.

3. Relevance of the Niimi System to Bhutan

Bhutan is a small landlocked country, with 52 per cent of national land designated as protected areas for nature conservation. The Constitution of 2008 stipulates that 60 per cent of the national land should be reserved as forests. Therefore, other economic activities such as agriculture, industries, public works, commerce and office buildings as well as residential land development, are battling over the remaining limited land. Available land for urban development is further limited and the central and municipal governments are not able to consider the large-scale facilities that require a huge plot of land for a single purpose.

The proposed Niimi System model sewerage facility relies on the capacity of the soil organisms, and all the wastewater treatment tanks installed under the top soil. This enables the land use of the same sewerage facility for the other purposes, such as the development of public spaces as green parks or athletic fields.

This indicates that the Niimi System has a potential to greatly contribute to the country's achievement efforts on the Sustainable Development Goals (SDGs). The promotion of the Niimi System may address a few different SDG targets locally at one shot, such as: 6.2 (access to adequate and equitable sanitation and hygiene for all); 11.1 (access for all to adequate, safe and affordable housing and basic services); 11.3 (inclusive and sustainable urbanization); and 11.7 (universal access to safe, inclusive and accessible, green and public spaces). Of course the land use of the ground is up to the further planning of the municipality and the community.

Figure 3. Conventional Plant vs. Soil-Covered Plant

Source: By Author.

Second, soil-covered treatment plants can easily prevent secondary solution. As is already mentioned in Section 1 above, the existing sewage treatment plant in Babesa, Thimphu, has been facing the public complaints against the bad odor that the three waste stabilization ponds spread out. This is the pathway that Japan has also taken in the past. The large-scale plants had to install new mechanisms attached to the existing sewerage system. But they caused extra cost on the existing system and the incremental costs have been borne by the users or taxpayers in general. Compared to the conventional sewerage systems, the Niimi System could avoid secondary pollution by covering the treatment plant with soil. It could help reducing the foul odor beneath the surface, thus preventing air contamination. Soil-covered treatment plant could be located in the areas adjacent to the residential area in the urban sector (See Figure 3).

Third, in addition to its contribution to environmental and social sustainability, the Niimi System will enhance the financial sustainability of the treatment plant. It doesn't require a large plot of land for acquisition. It still requires blower units for aeration for the secondary digester tanks. The soil-covered contact oxidation process is a biofilm process in which air is constantly supplied by a blower to purify wastewater in an aerobic state. Besides the blower units, however, the Niimi System uses very few mechanical equipment. Therefore, overall construction cost of the plant is relatively low.

The blower units are an indispensable component for contact oxygen tanks, and sludge management issue still remains for sedimentation tanks. These cause expenses for operations and maintenance (O&M). However, it is not necessary to replace the core filter medium, bio-crystals, for more than 50 years, which is assumed to be the life span of conventional sewerage facilities.

Financial sustainability has long been a focus of the controversy over the rationale for large-scale treatment plants in Japan. The large-scale sewerage development projects faced strong resistance from the local residents and environmental activists in many parts of the country in the 1980s. While the local residents wanted just flush toilets installed in their own houses, politicians and local contractors used to interpret it as a collective need of the whole community for a large-scale wastewater treatment plant and mobilize public finance for very expensive big projects. They used to benefit from the construction as politicians were re-elected and local contractors could make profits from public works. Now that many projects were completed and local users have been benefiting from the sewerage services.

But what came next was the heavy burden of the running cost of the large-scale plants and the repayment of huge public debt for the construction. The shrinking population and long recession have exacerbated the situation and the local governments have been suffering from budget deficits. In addition to the cut-back in public spending, they have also resorted to the measures to levy heavier burdens on the residents, by raising tariffs for sewerage services. Now the people are paying for their own earlier decision to let the government build a large-scale plant, instead of low-cost and quick-impact small-scale solution.

The Niimi System was first certified in 1967 and it has gained popularity especially in the rural areas in Japan, where they had limited fiscal space to bear the cost for a large-scale wastewater treatment plant. The Japan's experience in the selection of sewerage systems gives us a lot of lessons to learn. The Niimi System is extremely relevant to Bhutan, which also has only limited fiscal space but has been much more conscious of the virtue of environmental sustainability.

4. Past Experience of the Mokan-Joka System in Bhutan

In the previous sections we have highlighted the Niimi System (Dojo-Joka System) to brief in the next section on the proposed construction of the demonstration site and verification test under the JICA funding. However, in the definition of the Mokan-Joka System (MJS) of Japan, the Dojo-Joka System, which means the soil-based wastewater disposal system with capillary siphon trench, consists of the following three technologies, and the Niimi System in the narrow sense is a part of the whole Dojo-Joka System. All three technologies have been invented by Dr. Tadashi Niimi and dependent on the natural forces of the soil. In the actual implementation of the Dojo-Joka System in the sewerage development, the MJS combines the three technologies in accordance with the local specific conditions and needs of the beneficiaries. The Dojo-Joka System can apply not only to an individual house but also to the whole sewerage system development in the target community.

1) *Niimi Trench*: Combination of soil-covered sedimentation tanks and capillary infiltration trench. Works without power;
2) *Niimi System:* Combination of soil-covered sedimentation tanks and soil-covered contact oxygen tanks. Needs power supply; and
3) *Deodorizing Soil-Cover:* Addition of soil-cover over to the existing septic tanks. Soil deodorizes the septic tanks without power.

With the grant from the Japanese Ministry of Foreign Affairs, MJS conducted the first technical feasibility study in Bhutan in 2012. They collected the test data on the soil capacity to decompose organic matters and infiltrate water, collected data on the water quality at different points of a few river basins, and undertook the fact-finding on the existing wastewater treatment plants and the living environment in Thimphu and Paro. In addition to the survey, MJS constructed small demonstration facilities in two locations:

- ✔ Toilet facility for teachers at the Motithang Higher Secondary School (Thimphu): Septic tank and leaching pit were replaced by soil-covered sedimentation tank and capillary infiltration trench[1].
- ✔ Individual residential house (Paro): Deodorizing soil-cover replaced a fume stack structure and covered the septic tank for toilet.

[1]Due to the reconstruction of the school building, the *Niimi Trench* installed at the Motithang Higher Secondary School has been closed and not being used any more.

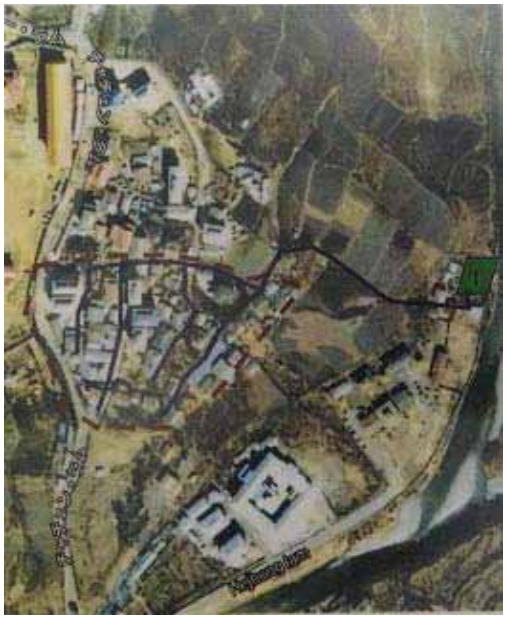
The past intervention on the demonstration site construction was about the *Niimi Trench*, sometimes combined with the installation of deodorizing soil-cover. According to the Japanese standards, BOD removal ratio is around 55 per cent for septic tanks. But the ratio was expected to improve to 97 per cent with the *Niimi Trench*. In addition to the on-site wastewater treatment, it had deodorizing effect.

The new proposed pilot project is therefore aiming at demonstrating the effectiveness of the *Niimi System* for the BOD removal of the whole residential area.

5. Outline of the Pilot Project for the Niimi System Demonstration

MJS has identified the southern half of the Hejo area in Thimphu as a model area of constructing a small-scale sewerage system adopting the Niimi System with fixed biofilm (See Figure 4). Once it is installed, it is expected to improve water quality of small stream and environment for upgrading livelihood and health condition of local residents. The project also verifies the applicability of fixed biofilm process type technology to the local specific conditions of Bhutan and develops the proposal for the effective dissemination system.

Figure 4. Aerial Photo of the Pilot Area



Source: By Author.

5-1. Expected Outcomes

According to the trilateral MOU between DoES, JICA and MJS, the pilot project has the following four expected outcomes:

1. Serviceability of sewerage treatment technology of the Dojo-Joka System (soil-based wastewater disposal system) shall be proven effective through model facility to be constructed at the Hejo area in Thimphu;
2. Technical know-how of the System shall be imparted to the Bhutanese counterparts, so that they could operate and manage the model facility independently;
3. A comprehensive business development plan shall be developed for the O&M of the sewerage facility and for the development of the future business advancement plans; and
4. With utilization of the new sewerage facility, mind of public residing in the pilot project area shall be changed for better environmental sustainability.

5-2. Outline of the Pilot Facility

In the pilot area, there are 86 houses/buildings with the population of 704. Presuming that the per-capita water consumption is 140 l./day, the total water consumption in the area is expected to be around 100m3/day. All the households are equipped with flushing toilets and septic tanks are already installed.

Under these circumstances, MJS has been planning the construction of a pilot plant with one unit of the *Niimi System*, one control building and access road in the area of approximately 1,000 m2. It must have an intake capacity of 100m3/day, and input BOD is expected to be 200mg/l. After the treatment, the target BOD for discharged water is expected to be 20mg/l.

5-3. Activities

According to the contract agreement between JICA and MJS, MJS is supposed to undertake the following activities, which should be completed and reported by the end of March 2018.

5-3-1 Construction of Model Facility

With regards to the Output 1) in Section 5-1 above, MJS has been undertaking basic data collection, such as water supply and sewerage plans, future demand of water and drainage, as well as relevant laws, permits and approval

procedures. It also analyses the household wastewater quality with reference to the record of water intake and total discharge, and forecast the future demands and location of the treatment facilities.

Then MJS will design the sewerage network from objective houses to the planned treatment facility, and seek necessary approvals from the relevant authorities on the construction of the facility, including the pipeline network. In parallel to these works, they will procure the materials and equipment, confirm the certificate of completion and transfer related technical know-how.

They also start the preparation of organization chart and manuals relating to the O&M of the facility; select the water quality inspection agency and propose relevant inspection system; develop a proposal on proper management and treatment of sludge; study on the financial requirement for O&M of the facility; and develop a proposal for environmental monitoring and its administrative framework.

5-3-2 Transfers of Technical Knowledge and Skills

With regards to the Output 2) in Section 5-1 above, MJS will work on the transfer of knowledge and skills related to the *Niimi System* sewage treatment facility to the counterparts and the advancement of appropriate O&M capacity of the facility.

First MJS selects the candidates for the technical transfer out of the staff of MoWHS, and request for their company at the construction supervision and trial operations. The counterparts are requested to actively participate in the joint preparation of the O&M manual and on-site training programs for other operators.

MJS also conducts the training program in Japan to help them acquire the knowledge on O&M. This also includes the observation visit to the similar facilities in Japan, which were constructed with the *Dojo-Joka System.*

5-3-3 Comprehensive Business Development Plan

With regards to the Output 3) in Section 5-1 above, MJS is supposed to draw up a business development plan to operate and maintain the sewerage facility and future sewerage development. First, they will collect and analyse the data on the national sewerage development plan that includes the basic approach, construction standards and guidance, budgeting procedures, etc. Further, they work on the data collection and analysis on the skill level and business track records of contractors on sewerage facility construction and operations.

MJS must also study on the procurement system, sources of materials and equipment related to construction of the sewage treatment facilities, including prices and suppliers. The study includes the identification of challenges and assessment of risks concerning procurement of materials and equipment, and construction of sewerage facility, and listing of the risk mitigation measures.

Based on the actions taken as listed above, MJS will make a mid-term projection of the sewerage demand growth and reflect it on the preparation for the comprehensive business development plan in the sewerage sector in Bhutan.

5-3-4 Sensitization of Residents on Environmental Sustainability

As the pilot project clearly defines the beneficiaries, it is essential to create a strong sense of ownership on the environmental sustainability of the locality and proper use of the sewerage facility, among the residents in the target community. And this is crucial for the success of decentralized small-scale sewerage system.

Under this heading, MJS will organize seminars and workshops to impart know-how of the constructed facility to the counterparts, relevant institutions and firms. But also they will disseminate information to the local residents on the value of facility constructed and improvement of environment through operations of the facility.

6. Challenges Identified at the Initial Stage

Since the signing of the trilateral MOU in December 2016, MJS has initiated some of the activities as described in the Section 5-3 above, and the project team has come to Bhutan for on-site measurement survey and stakeholder consultations. Although the pilot project is still in the initial stage, we have identified the following issues that may affect the successful implementation of the new wastewater treatment plant.

First, we should have taken into consideration the risk that there is a lack of coordination between the MoWHS and the municipality. According to the MOU, the Ministry was supposed to "ensure sufficient land or space with all auxiliary facilities to the site, including motorable access for the installation of the Product throughout the implementation period." However, it turned out that the Thimphu Thromde was not included in the information loop on the site selection and the MJS team has received a new request from the mayor when they visited him in April. It is our understanding that the DoES gives technical advice on the design and specification

of the urban sewerage networks on-call basis, and it is the municipalities that actually design, order the civil works for construction and procure the materials and equipment. However, the lack of coordination frequently occur between the two public entities.

Second, there seems to be a perception gap over the definition of the pilot project. While MJS/JICA have been looking at it as an experiment to demonstrate and verify the effectiveness of the technology of Japanese origin, most of the Bhutanese stakeholders, Royal Government of Bhutan, municipality, media and citizens, seem to be looking at it as a full-fledged ODA project. This was already recognized in the request by the mayor of the Thimphu Thromde, who said that the project should cover the whole Hejo area. The mayor's request sounded quite natural as the one from a politician, but it was also true that this pilot scheme has an upper limit on the budget to be granted to each Japanese small and medium enterprise (SME). Now the MJS team has been revising the original plan reflecting on the interest of the municipality and on the JICA budget ceiling. The mayor stated that the municipality is ready to fill the financial gap with the municipal budget and support the comprehensive sewerage network development in the whole Hejo area. This is a welcome signal, but still MJS/JICA have been facing the risk that the delay of the disbursement from the municipality may cause the delay of the completion of the whole system.

Third, the proposed Niimi System is still not maintenance-free. Compared to the other systems, it may not cause huge expenses for O&M. But it still needs some budget allocation for constant aeration even though the control system is more simplified than those of the conventional treatment plants. Sludge also must be removed from time to time. If the O&M is not undertaken in an appropriate manner, the effectiveness and sustainability of the whole system may easily be affected.
Fourth, once they started on-site measurement survey, they came across the issues such as limited space for installing pipes in the town, and narrow access roads to bring construction equipment and materials into the target area. Hejo is a typical township. Whenever we consider the installation of such decentralized small-scale facilities in the small residential/business areas, we may face the similar difficulty to the ones we have already faced in Hejo.

7. Concluding Remarks

Large-scale infrastructure is highly visible and draws much attention from the politicians and bureaucrats as well as contractors. However, we should bear in mind that it requires a huge capital investment and a high running cost. At the end of the day, the beneficiaries or general taxpayers have to bear the costs for large-scale

infrastructure. To make the matters worse, wastewater treatment is regarded as a public service that even the direct beneficiaries are not able to feel the benefit and therefore not ready to pay the high sewerage bills.

In order for the beneficiaries to feel the benefits and be ready to bear the costs, the public services need to come as close as possible to the beneficiaries. We believe that this is the idea behind the strategic direction to decentralization emphasized in the 12th Five Year Plan. We have been proposing this idea of decentralized small-scale wastewater treatment plants in line with the policy direction.

They have the advantage over the conventional wastewater treatment technologies as they do not cause any secondary pollution: they use fewer machines and simpler technologies; they could be operated fully unattended and do not generate large amount of sludge; they could be constructed and maintained at reduced costs; and even so they still assure the cleanliness of the treated water.

Once the construction of the pilot plant in Hejo is completed, you can only see the huge open space over the sedimentation tanks and aeration tanks beneath the surface soil. That makes it difficult for many civil engineers to imagine what kind of construction process was taken and what kind of difficulties that the stakeholders have faced during the project implementation period. And this is the reason we repeatedly emphasize that the process should be more highlighted and that engineers and contractors should come and see the construction and interact with the project staff on-site.

Sewerage still remains as a frontier of civil engineering in Bhutan. Due to the lack of past experience in sewerage development, the country has been facing a severe shortage of human resources in spite of the rising demand for wastewater treatment in the era of rapid urbanization. The knowledge gap between the government engineers, contractors and college students is still small in the case of sewerage sector, and there is a chance that the college students can soon emerge as knowledgeable human resources if they target sewerage and start learning it at college.

MJS/JICA would welcome the students' observation visit to the pilot project site in Thimphu in the coming few months.

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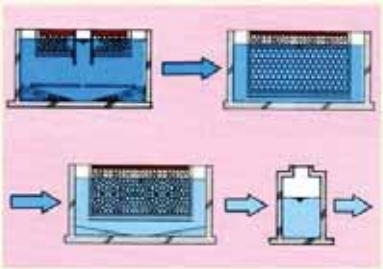
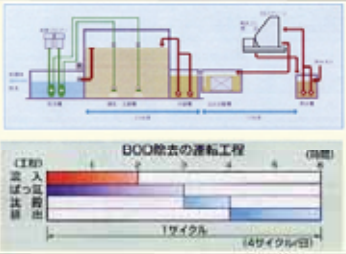
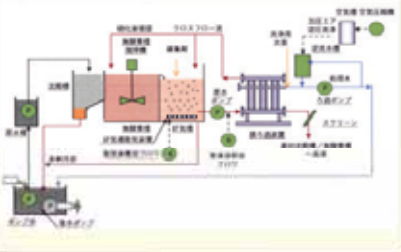
Annex

Summary of the Niimi System and Comparison to Other Conventional Systems

Contents	Niimi System (Dojo Joka System)	
Invention	Invented in Japan and certified as a treatment method in 1967	**Method of treatment**
secondary pollution measures	Prevents pollution and odors easily with the soil covering method	Soil coated sedimentation tank or via fixed biological membrane method
Life span	50 years or more for the concrete structures	**Flow sheet** 
Land area required	Small area as per the design criteria for developing countries	
Optimum conditions	Low construction cost and running cost. Best suited for developing countries	
Distinctive features	The Niimi System makes sewage treatment easy and avoids secondary pollution. The Plant could be developed into parks and areas for recreational purposes. This System makes full use of the natural forces of the soil.	

Contents	Sequencing Batch Reactor	Membrane Bio Reactor
Method of treatment	All phases of the treatment process occur sequentially within the same tank	Activated sludge treatment method
Flow sheet		
Merit	By combining the primary settling, aerobic, anoxic clarification operations in a single tank, the land area required for the treatment plant is lesser	Suitable for class A quality palatable discharge. The process involves higher degree filtration.
Demerit	Requires various flow control equipment, thereby, increasing the chances of break down, often requiring replacement. Care for secondary pollution and a separate sludge treatment facility will become necessary.	Since the whole treatment process involves bio membrane filtration, regular replacement of the membrane will become necessary. The System will also require due care for secondary pollution and a separate facility for the treatment of sludge.

Source: By Author.

Authors' Profile

Koji YAMADA is Chief Representative of the Japan International Cooperation Agency (JICA) Bhutan Office since April 2016. Before his appointment in Bhutan, he used to serve as Senior Advisor to Director General at the Operations Strategy Department, JICA HQs, and was a strong advocate for mainstreaming SDGs in JICA's development cooperation operations. Joining in JICA in 1993, he has served for various ODA operations mainly for South Asia and research projects at the JICA Research Institute. He has also worked as co-financing officer at the World Bank in 2000-2003. He is Visiting Professor on development studies at the Nihon Fukushi University, Japan.

Hiroko KIMURA was born as a daughter of Dr. Tadashi Niimi, who developed the soil-covered sewerage system, Dojo-Joka System. Since her graduation for the Japan Women's University, she spent the first few years as a pre-primary school teacher. Then she joined forces with her father as his PA in 1973, and she founded a new consulting firm specializing in the construction of sewerage plants with Dojo-Joka System. Her company, Mokan-Joka System (MJS), has facilitated the installation of more than 300 units of Dojo-Joka System in the urban sewerage and rural drainage works as well as installation of combination septic tanks.