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Decentralised Wastewater Management Systems in Developing Countries: Key Barriers and Potential Resource Recovery Applications

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Centralised wastewater systems are considered as conventional means for wastewater treatment, however, the implementation of large-scale systems and expansion of sewerage networks in developing countries prove to be challenging due to political, social, financial, technical, and environmental factors. Several studies identified decentralised wastewater management (DWM) systems as a promising solution due to its benefits including resource recovery for energy and agricultural applications. The successful implementation of DWM systems in developing countries contributes to the main objective of Sustainable Development Goal (SDG) No. 6 which is to provide basic sanitation access to all. A low carbon society can also be promoted through energy recovery from wastes and reducing energy requirement in the transport and handling of wastewater and sludge. The paper provides an overview of the barriers and potential resource recovery and reuse applications to implement decentralised wastewater management systems in developing countries. The initial review showed that there are existing technologies already used for resource recovery such as anaerobic systems for biogas production, nature-based systems for crop cultivation and water reuse, and mechanised systems like moving bed bioreactors for wastewater treatment and reuse. However, developing countries are faced with several barriers in the planning and implementation of sustainable wastewater management systems. The information from the literature review is used as a guide to determine interventions for key barriers and to draft a policy guidance manual on technology selection for decision-makers in the Philippines.

1. Introduction

Basic access to sanitation to all is one of the Sustainable Development Goals (SDG) specifically SDG No. 6. World Health Organization (WHO, 2019) reported that two billion people are still deprived of basic sanitation services. Poor sanitation practices can result in the pollution of water resources leading to waterborne illnesses to the affected communities. The WHO established a framework for the monitoring of access to drinking water, sanitation, and hygiene (WASH) services. However, this seems to be challenging due to limited studies and data in low and middle-income countries (Odagiri et al. 2018).

Centralised wastewater management (CWM) is established as the conventional way of treating wastewater. It is commonly implemented in urban and highly populated areas where the economy of scale is feasible (Sotelo et al., 2019), and this is due to the decrease in the cost for sewer connection with increasing number of connected households (Xu et al., 2019). For peri-urban and rural areas where households are scattered,

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decentralised wastewater management (DWM) is recommended wherein wastewater is treated near the source of generation. The scale of DWM differs among several studies. Reymonds et al. (2020) stated DWM can serve 10 – 1,000 households, while Singh et al. (2019) mentioned that DWM can treat up to 1,000 m^3/d wastewater. Advantages of DWM include, but not limited to, resiliency to shock loads, low energy requirement, simple operation and maintenance requirements, and recovery of valuable resources for various reuse applications (Singh et al., 2019).
The paper aims to provide an overview of the potential technologies, resource recovery pathways, and barriers and drivers in the implementation of decentralised wastewater management systems in the developing countries. The review could provide insights on developments on wastewater treatment and management and determine interventions from the critical barriers observed in the Philippines and other developing countries. Literature search was carried out using Scopus database for articles related to decentralised wastewater management worldwide.

2. Systematic Review

A literature search was carried out last March 14, 2022 using Scopus database with the following keywords in the title and abstract: "sanitation" AND "wastewater" AND "decentrali*" OR "centrali*". The initial search generated 351 published documents from 1988 until present. The inclusion of old literatures is to check the changes on the advancements or trends on DWM. Initial screening checked for duplicates, and excluded articles published in foreign language and categorised as "Erratum" and "Note" (n = 15). Further screening removed all irrelevant and inaccessible articles based on abstract and titles (n = 3) and content (n = 40). Articles with topics on pharmaceuticals, emerging contaminants, water treatment, disinfection, and remote control were considered irrelevant. A total number of 246 articles are considered in the systematic review, including 26 relevant articles from other search engines (Google Scholar and Google) and from references.

3. Sustainable wastewater management systems

Conventional wastewater treatment plants (WWTPs) contribute to greenhouse gas (GHG) emissions since high amount of energy is required to treat large volumes of diluted water. With source separation and decentralised wastewater treatment, the energy and nutrient recovery are fully maximised (Garrido-Baserba et al., 2018). The potential amount of nutrients recovered from different wastewater constituents are presented in Table 1 below. Furthermore, the demand for commercial fertilisers and energy-intensive technologies for treatment and transport can be reduced (Garrido-Baserba et al., 2018).

Table 1: Composition of different wastewater constituents expressed in g/capita-d (Larsen and Maurer, 2011)

Composition	Greywater	Urine	Faeces	Combined
Organic matter	54	10	60	120
Nitrogen	1.4	11	1.5	14
Phosphorous	0.5	1	0.5	2.0
Potassium	-	2.7	0.9	-

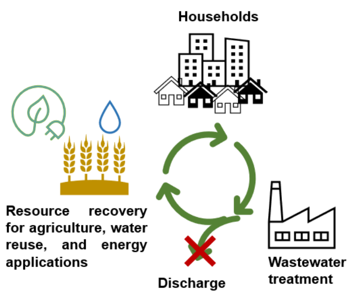

Figure 1: Sustainable wastewater management system

Some technologies for decentralised wastewater treatment with resource recovery mechanisms are discussed: Anaerobic treatment technologies such as upflow anaerobic sludge blanket (UASB), anaerobic baffled reactor (ABR), and anaerobic digestion (AD), among others, have high removal of organic matter and have the capability to produce biogas for energy or fuel source. In the study of Kulak et al. (2017), AD of feces (brown water) and food waste exhibited higher nutrient recovery and lower global warming potential. The AD in the study of Lansing et al. (2016) produced a biogas of 0.108 m^3/d, while the pilot-scale AD by Dinh and Le (2020) achieved a maximum of 304.8 L biogas per kg of volatile solids (VS). The drawback with anaerobic treatment technologies is the poor nutrient removal performance as observed in the studies of Yulistyorini et al. (2019) and Dinh and Le (2020) in Table 2. Effluent of anaerobic treatment technologies should be treated prior to discharge.

Constructed wetlands are examples of nature-based technologies with multiple resource recovery pathways. Treated wastewater can be reused for crop cultivation and non-potable applications (e.g. irrigation, cooling water in heat exchanger, toilet flushing, etc.), while the biomass can be used as animal feed (Oliveira et al., 2021) or feedstock for energy production (Masi et al., 2018). Other examples of nature-based technologies are wastewater ponds for crop cultivation and fish farming (Jana et al., 2018), and photobioreactors (PBR) for microalgae cultivation (Slompo et al., 2020). The technology performances of selected studies on nature-based technologies are shown in Table 2.

Recent literatures have cited the following technologies with resource recovery capabilities: moving bed bioreactors (MBBRs) where treated wastewater is used for plant watering (Ali et al., 2021), NEWgenerator™ system proposed by Shyu et al. (2021) where the captured nutrients are used as fertiliser, and struvite reactor for the recovery of struvite fertilisers from septic tank liquor (Goel and Kansal, 2020).

Table 2: Biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorous (TP), and total suspended solids (TSS) removal efficiencies of different technologies

Technology	% Removal efficiencies					References
	BOD	COD	TN	TP	TSS	
ABR	74	-	-	21	66	Yulistyorini et al., 2019
AD	-	50 - 51	38	12.5	-	Dinh and Le (2020)
Constructed wetlands	81 - 95	65 – 99.1	38 – 99	39.1 – 97	79.3 - 98	Moreira and Dias (2020)
	87.9 – 89.9	72.7 – 78.1	43 – 44.3	47 – 51.2	89.5 – 89.8	Pillai and Nair (2021)
Microalgae-PBR	-	-	66	74	-	Slompo et al. (2020)
NEWgenerator™		94.5	82.1	43	97.6	Shyu et al. (2021)

4. Barriers and drivers in implementing wastewater management systems

Table 3 provides the barriers in developing countries and are categorised using the Political, Economic, Social, and Technological (PEST) framework.

Table 3: Barriers in implementing DWM systems in the Philippines and other developing countries.

Barrier	Political	Economic	Social	Technological
Lack of government involvement	X			
Lack of coordination in policy dissemination and urban planning	X			
Lack of available funding to construct, operate, and maintain wastewater treatment facilities		X		
Unwillingness of end-users to pay due to limited financial capacity or unawareness on improved sanitation services		X		
Negative preconceived notions on wastewater treatment and reuse			X	
Absence of community involvement during planning and maintenance of treatment facilities			X	
Limited land available for construction				X
Inadequate management of technologies				X

The involvement of the government is significant to the success of a sanitation or wastewater treatment project. The local government oversees the planning and provide resources during construction and maintenance. Failed cases of sanitation systems resulted from the disinterest and unwillingness of the local government to commit in the proposed sanitation projects (Davis et al., 2019). Reymonds et al. (2020) reported that lack of support from the government agencies on small-scale wastewater treatment and reuse systems in India due to absence of unified database. Lack of coordination among agencies is another political barrier as evidenced by weak dissemination of policies and coordination in urban planning (Reymonds et al., 2020). These issues can be addressed by creating a unified database for monitoring and creating a centralised agency for the implementation and monitoring of sanitation systems (Reymonds et al., 2020).

Wastewater treatment plants have high short-term capital costs with slow returns (Liu et al., 2021). Continuous funding is required for the maintenance and operation of wastewater treatment systems (Sotelo et al. 2019). Furthermore, there are reports on the consumers' unwillingness to pay for the improved services due to limited financial capability. The interview conducted by Brunner et al. (2018) showed that participants with low annual household income only agreed to pay to invest on decentralised wastewater treatment \ when the cost-sharing scheme was mentioned. The results from randomised controlled trials (RCT) in evaluating CLTS programme recommended providing funding for the community to invest in toilets (Cameron et al. (2019).

Unawareness or negative preconceived notions on wastewater treatment and reuse can inhibit the development of wastewater management. Oppositions to the construction of wastewater treatment plants are reported because of potential odour and nuisance problems (Sotelo et al., 2019). In other countries, there are challenges in the social acceptance of treated wastewater reuse (Brunner et al., 2018). Another social barrier is the lack of community involvement during planning and/or maintenance due to the inability of the sanitation project to address the community's sanitation priorities or to induce behavioural change in the community (ex. use of toilets) (Davis et al., 2019). Education and capacity-building are significant ways to increase awareness on sanitation and acceptance on DWM systems. The implementation of education programmes such as the CLTS show the importance of sanitation in rural communities by inducing disgust and shame (Sotelo et al., 2019). The RCT in Indonesia showed that the CLTS programme evidently increased the awareness within the community (Cameron et al., 2019). The five-year programme conducted by Indonesia government and UNICEF focused on capacity building and strengthening of advocacy implementation. Improved sanitation is observed based on the increasing use of toilets among the poorest households and decreasing number of villages practicing open defecation (Odagiri et al., 2020).

Technological barriers include technology performance, maintenance, land area availability, among others. For example, households in Southeast Asian developing countries rely on septic tanks that are poorly maintained and rarely desludged (Sotelo et al., 2019). Furthermore, the septic tanks and other on-site technologies have poor nutrient removal performance as discussed. Its overflows can contribute to the pollution of water bodies. Another example is the large land requirement for the construction of constructed wetlands and other nature-based technologies. Moreira and Dias (2020) recommended installing pre-treatment technologies to reduce the land area requirement and clogging issues.

5. Wastewater management situation in the Philippines

The Metropolitan Waterworks and Sewerage System (MWSS) is a public-private partnership that provides water and sanitary operations in Metro Manila, and the provinces of Rizal and Cavite. The Manila Water Company Inc. (MWCI) and Maynilad Water Services Inc. (MWSI) are two water concessionaires that provide water and wastewater services in the east and west zone of Metro Manila, respectively (MWSS, 2020) Despite the continuous efforts to provide improved services, only 10% of the population in Metro Manila as of 2015 have access to piped drainage channels while the rest had integrated drainage systems for effluent collection. Furthermore, septic systems serve as primary treatment for communities lacking recourse to a sewage network in both city and countryside regions. As of 2015, about 7 million Filipinos apparently used open defecation, whereas 19 million continue to rely on inadequate sanitary services. Such negligence causes annual financial damage of more than 78 billion pesos, 55 deaths per day, and ecological harm (WHO, 2017).

The barriers identified in the Philippines have similarities with the barriers in Table 3 such as lack of available funding, unwillingness of consumers to pay, discharge of effluent to receiving water bodies due to lack of wastewater infrastructures (ARCOWA, 2018). There are currently no national initiatives in place to conduct and evaluate effluent sediment gathering and processing for water quality management. There is also an inadequacy of thorough and inclusive governance at the local level, as well as effective public participation. Despite these challenges, the LGUs and government agencies strive to improve sanitation access in the country. The following references below provided some initiatives and/or programs related to wastewater management:

- Philippine Approach to Total Sanitation (PhATs), which aims to reduce the open defecation practices in several rural communities (Robinson and Gnilo, 2016)
- Expansion of sewerage and septage management services in Metro Manila and Bulacan (Cabral, 2016).
- Amendments on the cost-sharing scheme of the National Sewerage and Septage Management Program (NSSMP) (Cabral, 2015).
- Implementation of decentralised wastewater management (DWM) systems in Zamboanga City (Cabral, 2016) and San Fernando City (UN-ESCAP, UN-Habitat, and ATI, 2015)
- Rehabilitation of Boracay Island to improve wastewater treatment and disposal (ARCOWA, 2018)

6. Conclusion

Sustainable wastewater management systems promote the recovery of high valued resources (energy, fertiliser and water) by integrating resource recovery technologies in wastewater treatment plants. This can be achieved with decentralised wastewater treatment systems where wastewater is treated near the source of generation. The recovered resources are maximised and are readily available for various reuse applications. The common resource recovery technologies in the developing countries are anaerobic treatment systems and nature-based systems. Other mechanised systems have also been mentioned, but not often implemented. To implement an effective decentralised wastewater management system, the political, social, economic, and technological barriers must be addressed. Some of these barriers are evident in the Philippine setting. Nonetheless, the developing countries are making efforts to address these challenges by providing education on sanitation, exploring different financial mechanisms and partnerships, involving the community during the planning process, among others. The NSSMP manual provided an initial toolkit for LGUs in the planning of their sewage treatment facilities. The information gathered from the literature review could be used as to update and improve the NSSMP manual or draft a policy guidance manual for decentralised wastewater management in the Philippines. The literature review is complemented with policy review and stakeholder interviews to determine the critical barriers and to provide interventions. Furthermore, the authors plan to create a toolkit or improve an existing toolkit to be utilised by the decision makers for planning wastewater treatment projects.

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