Review Article

Assessing Wastewater Management in the Developing Countries of Southeast Asia: Underlining Flexibility in Appropriateness

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Abstract

The majority of the Southeast Asian region is composed of developing countries with urban, peri-urban, and rural areas whose anticipated change in wastewater treatment demand necessitates improvement in wastewater management. The narrative relating to the present scenario has been constructed via a rapid review structure using various literature concerning the state of wastewater management in the Southeast Asian region. Existing wastewater technology systems in the region have been studied in order to identify challenges in improving wastewater management. Several barriers across technology systems have been identified which shows that offering either centralised, decentralised, or cluster technology systems as one solution is not enough to address changing future demands for wastewater treatment. Thus, flexibility has been identified through the discussion as a key concept for proposing technology systems in regions where future demands require solutions in the present. We propose that investments in wastewater management in the developing countries of Southeast Asia require a perspective that focuses not only on what is appropriate for the present demand but also for the future.

Keywords: wastewater management, wastewater technology systems, Southeast Asia

INTRODUCTION

There is an ongoing global effort towards the improvement of sanitation through the improvement of wastewater management. Wastewater management acts as a support towards the sixth and fourteenth Sustainable Development Goals (SDGs) which aim to improve sanitation and marine environment through pollution reduction, respectively. Supporting these goals means addressing the struggle of managing wastewater for safe reuse or environmental discharge. Wastewater management is more readily implemented in regions which rarely experience water scarcity. Hence, identifying the challenges and concerns of affected regions is important in understanding and improving wastewater management.

The Southeast Asian region consists of countries which experience a tropical monsoon climate that brings abundant annual rainfall [1]. The region is dense in terms of population

[2] which calls for the improvement of the current wastewater management practices towards the improvement of sanitation and environmental conservation. The developing countries of the region were identified to need improvement [3]. The region also stands as a marine biodiversity hotspot [4] whose waterbody is vulnerable due to untreated wastewater discharge [5–7]. On a utility level, the urban centres are unable to serve their wastewater treatment demand resulting in poor effluent quality [8]. The present infrastructure is facing an inability to accommodate the rapid increase of population in the urban and peri-urban areas [9]. The coverage of wastewater management in the rural areas remains low [10]. The continuous discharge of untreated wastewater due to poor wastewater management stands to threaten the health, sanitation, and aquatic biodiversity of the region. The current narrative reinforces the need to analyse the situation of wastewater management in the Southeast Asian region.

This paper aims to review the present situation of waste-

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water management in the developing countries of Southeast Asian region, focusing on the barriers encountered towards its improvement. To do so, we present this article in three parts to answer three specific objectives. The first objective is to describe different wastewater technology systems. Thus, the first part focuses on differentiating common wastewater technology systems presenting the strengths, weaknesses, and overlaps of each. The second objective focuses on describing the wastewater management present in the Southeast Asian region. This includes a description of wastewater technology systems in the urban, peri-urban, and rural areas of the region. The narrative of the current wastewater management scenario in the region highlights the different challenges encountered with different technology systems. The capacity of each technology system to treat wastewater is seen to be affected by the interplay of different factors including community, economic, technology, and institutional factors. Finally, the third objective is to summarise the barriers towards the improvement of wastewater management in the Southeast Asian region. A discussion of the economic, community, technical, and institutional factors as barriers is presented. Possible options for improving wastewater management which goes beyond discussing only appropriate technology systems has been identified. We emphasise that wastewater technology systems should maintain local appropriateness and flexibility which accommodates changes in different conditions which are: population, economic capability, social acceptability, and environmental safety.

METHODOLOGY

One of the aims of this review is to identify the current challenges in wastewater management in the Southeast Asian region. A rapid review structure as described by Grant and Booth [11] was used in processing the available literature into a narrative that answers to the objectives presented. The narrative has been established by finding definitions of wastewater technology systems through textbook references. Following this is a review of the development of wastewater management in the Southeast Asian region leading to the current scenario. Peer-reviewed articles, conference proceedings, textbooks, and country reports from wastewater management companies and related organizations were used to define the succeeding narrative relating to the present wastewater management scenario.

DISCUSSIONS ON WASTEWATER TECHNOLOGY SYSTEMS

Centralised, decentralised, and cluster wastewater technology systems

This section describes the basic characteristics of commonly encountered technology systems which are: centralised, decentralised and cluster.

The definitions for centralised wastewater technology (CWT), decentralised wastewater technology (DWT), and cluster wastewater technology (CCT) systems vary between researchers. Researchers generally describe a technology system based on its treatment capacity and its proximity to the wastewater source. Ho and Anda [12], Tsagarakis et al. [13], and Boller [14] associated DWT systems with low-rate onsite treatment technologies which have a performance capacity of <5000 person equivalents (p. e.) and Libralato et al. [15] and Tsagarakis et al. [13] described CWT systems to have capacities two magnitudes greater than DWT systems. In terms of community size, Kamal et al. [9] defined DWT systems as able to service 1–100 households while Libralato et al. [15] described CCT systems as able to service 4–12 houses. Cluster wastewater technology systems are also commonly classified under CWT systems by several researchers [16–21]. While these definitions may hold within their context, we have opted to provide our own definition for each technology system to facilitate our discussion. We maintain that DWT systems treat wastewater coming from a single household and CCT and CWT systems collect and treat wastewater from multiple households.

The difference between CCT and CWT is the size of the treatment facility that affects the manner of placement of the treatment facility. The footprint of its treatment facility is smaller compared to a CWT system hence, CCT systems can treat wastewater coming from several households onsite or offsite. Other than the placement of the treatment facility, the differentiation of CCT and CWT in terms of treatment capacity remains difficult to discern. For example, even a small community can have a CWT when the treatment facility is located away from it. On the other hand, when a big communities close with each other have centralized treatment facilities nearby each of them although there is a high chance to merge them into a big treatment facility, they can be recognized as CCTs regardless of the size. We maintain that CWT systems treat wastewater coming from various households in an offsite treatment facility. **Figure 1** shows a graphical representation of DWT, CCT, and CWT systems based on these descriptions.

Fig. 1 Different configurations of wastewater technology systems. (A) Decentralised wastewater technology system, (B) cluster wastewater technology systems, and (C) centralised wastewater technology systems. The yellow broken lines represent the collection system and the yellow diamonds represent the wastewater treatment facility.

Centralised wastewater technology systems are characterised by a vast sewer network used for wastewater collection and a wastewater treatment facility. These systems transport wastewater from a settlement to an end-of-pipe treatment facility where the wastewater is treated for safe discharge into the water environment [16]. The treatment facility for CWT systems are designed to collect and treat wastewater according to environmental discharge limits in a given community [22]. The construction of CWT systems requires the dedication of a majority of the capital cost to the collection system [16,23]. A wide array of technology is also available for the end-of-pipe treatment facility where activated sludge processes are typically employed [24].

Decentralised wastewater technology systems are characterised by their onsite approach to wastewater treatment where wastewater is treated at or near the source. Because wastewater is treated onsite, DWT systems only use a very minimal collection network, often only existing as pipes within the building where they are installed. A majority of the capital cost for DWT systems is dedicated to the treatment facility installation [25] and a wide variety of technology is available for selection [26,27]. In most cases, privately owned septic tanks with pour-flush latrine units are installed where their operation and maintenance are under the responsibility of their respective owners.

Cluster wastewater technology systems collect and treat wastewater from more than one building. Hence, these systems typically have small collection systems that transport wastewater to an end-of-pipe treatment facility [28]. This definition describes CCT systems as small-scale CWT systems. However, the treatment plant location of a CCT system can be onsite or offsite depending on the configuration of the collection system. Cluster wastewater technology systems have collection systems laid out with short, small diameter pipes embedded at shallow depths [16]. Further, CCT systems employ wastewater treatment technologies which need less supervision compared to those used in CWT systems.

Comparisons between CWT, DWT, and CCT systems

Centralised and decentralised wastewater technology systems typically service urban and rural areas respectively. Densely populated urban areas have few areas available to install DWT systems which calls for an offsite wastewater treatment facility. In such cases, introducing CWT systems are preferable. Another difference between the two is the cost for constructing the pipeline needed for the collection system where the cost is high for CWT systems and low for DWT

from DWT systems to the present scenario proceeded as follows: DWT systems were installed in order to improve sanitation especially in areas where only solid waste disposal was practiced. Pit latrines and similar technologies were initially used for human excreta, but the leaching of untreated biosolids to the surrounding soil and groundwater exposed the community to health risks such as gastrointestinal infections and parasites. Foul odors generated from the use of pit latrines also created a feeling of disgust thereby stressing the need to better manage human excreta. These concerns were addressed by the installation of pour-flush latrines which were connected to septic tanks that anaerobically degraded biosolids separated from the wastewater [31,32]. The wastewater from septic tanks are discharged to nearby water sinks (i.e. rivers). The introduction of DWT systems improved human waste removal from the communities but were not effectively treating wastewater. As urban centres developed, the poor quality discharge from these systems worsened the threat to the water environment [6]. Increased water pollution led to government initiatives towards the improvement of wastewater management [37], where the need for installing the collection system connected to an end-of-pipe treatment facility is considered as an effective solution [33,34].

The existence of storm drainages facilitated the improvement of wastewater management for many cases in Southeast Asia. The region experiences abundant rainfall which requires storm drainages for flood control. Thailand, using their version of canals called *klong* and the Philippines with their *estero*, have formed drainage networks which transports stormwater and wastewater away from the living environment [35]. The storm drainages have been turned into combined sewers during the course of directing wastewater to an end-of-pipe wastewater treatment facility. These sets of decisions have introduced CCT and CWT systems while maintaining DWT systems.

Colonial occupation also helped improve wastewater management in Southeast Asia. Malaysia, Indonesia, Philippines, and Vietnam were occupied by the British, Dutch, Americans, and French, respectively. The colonial powers needed to improve health and sanitation in urban centres during their occupation. Hence, these powers focused on projects towards the introduction and improvement of the sewer system in urban centres [36–39]. The collection system fostered during the colonial period of the respective countries helped lay the foundation for CCT and CWT systems. However, the collection system has not been properly maintained and is presently deteriorating in various urban centres in the region. The design capacity upon its installation can no longer meet

the demands of the current population it serves.

The present status of wastewater management

Table 2 summarises the wastewater technology systems used in each country and the subsequent plans for them. The tabulated data came from conference proceedings conducted with Water Environment Partnership in Asia (WEPA) as well as journal articles and wastewater management country reports.

The table shows that wastewater technology systems in Southeast Asia is currently dominated by DWT systems. In urban centres of the region, CCT systems are also observed and few have well-established CWT systems.

The future direction of most countries favours the introduction of CWT systems in urban centres while DWT systems are promoted in rural areas. In the case of Lao PDR and East Timor, DWT systems are preferred for both rural and urban environments citing easier community involvement and lack of funding as the causes of preference. Conversely, countries other than Lao PDR and East Timor have made plans to introduce CWT systems in their urban centres. Indonesia, Malaysia, Thailand, and the Philippines will continue to introduce CWT systems in urban centres while providing DWT systems in the rural areas. Cambodia and Myanmar also prefer CWT systems, but opt to limit its application to urban and tourism centres.

Issues with wastewater management

Literature on the wastewater management in the Southeast Asian region suggest that the improvement of wastewater management is a multifaceted issue. The urban areas of the region have various concerns starting with the existing DWT systems. Wastewater is mostly treated by DWT systems where their predominance stems from their low capital cost. While affordable, these DWT systems are unable to comply with environmental discharge limits [63] making them problematic with the rise of urban population density [64]. Improving the existing DWT system infrastructure is challenging as local solutions are geared towards large-scale wastewater management infrastructure which fail to incorporate existing DWT systems [65]. Some countries have also seen concerns with the introduction of CWT systems. Megacities such as Bangkok [66] and Kuala Lumpur [67] have implemented CWT systems, but hurdles still exist with overcapacity resulting in poor effluent quality. The high population density also demands land for businesses and settlements making physical wastewater management infrastructure presently difficult to introduce. Finally, social per-

Table 2 Wastewater technology systems in the developing countries of the Southeast Asian region.

Country	Present			Future			Remarks	Reference
	DWT	CCT	CWT	DWT	CCT	CWT		
Cambodia	✓	✓				✓	*	40–42
East Timor	✓			✓				43, 44
Indonesia	✓	✓		✓		✓	*, **	45–47
Lao PDR	✓			✓	✓			48, 49
Malaysia	✓		✓	✓		✓	*, **	50, 51
Myanmar	✓	✓				✓	*	32, 52, 53
Philippines	✓	✓		✓		✓	*, **	32, 54–57
Thailand	✓		✓			✓	*	34, 58, 59
Vietnam	✓	✓				✓		32, 60–62

Remarks:

* – CWT will be promoted in urban centres

** – DWT will be promoted in rural areas

ception within crowded districts are also a challenge. When establishment owners in the Philippines were requested by wastewater treatment companies to connect to the collection system, they opted to retain DWT systems citing troublesome construction work as cause for refusal [60].

The concerns of wastewater management in peri-urban and rural areas are different from those in urban centres. Although some peri-urban areas may be capable to introduce DWT systems, the presence of unplanned settlements are problematic. Rural areas have problems with sparse population making the construction of CWT systems financially unsound [65]. In both peri-urban and rural areas, addressing the lower population means that some form of DWT system may be installed. However, DWT systems fail to improve effluent quality due to the lack of desludging and poor effluent monitoring [68]. Even when present, the services needed are often not easily accessible to remote areas (i.e. small island communities, agricultural communities). A lack of awareness towards improved sanitation is also problematic in the rural areas making the introduction of wastewater management difficult [43]. All of these issues raise the demand for a case-to-case evaluation of the wastewater management needs of a given locality.

CONSIDERATIONS FOR IMPROVEMENT

Defining barriers for improvement

Challenges in introducing wastewater technology systems were addressed in the previous sections. Here, the challenges are further discussed under four kinds of barriers. The section on economic barriers is presented because wastewater

technology systems cannot be installed or improved without the financial means to do so. Following this section is a discussion on community barriers which include the issues encountered with the perception and willingness of a local community to improve wastewater management. Here, a local community refers to a village, a neighbourhood of an urban area, or a subset of a region connected by economic or hydrological ties. Wastewater treatment technology systems cannot be successfully introduced and maintained without establishing local needs for sanitation and water environment protection. Institutional barriers are also presented because the implementation of wastewater technology systems require institutional backbone. Finally, technical barriers relate the availability of technical expertise with infrastructure including the technology which support the technology system. These barriers often overlap with each other where the existence of one barrier may affect the next.

Economic barriers

In the context of developing countries, the initial cost of a technology system dictates whether or not it would be chosen for introduction [69]. It has been previously described that wastewater treatment in the Southeast Asian region is dominated by DWT systems mainly comprised of septic tanks. The initial preference for choosing these low-tech, low-cost DWT systems generally stems from the lack of funding available to a locality. Measures have been taken to secure funding to improve the existing wastewater management infrastructure. In the cases of Cambodia and Thailand, the government allocated funding for the development of CWT systems in their urban areas [34,36]. In the Philippines and Malaysia,

funding has been provided through the privatization of wastewater treatment facilities which improve the physical and management infrastructure for wastewater management [70]. External funding from development organizations has facilitated the introduction of treatment technologies in rural areas. Such cases are observed in Lao PDR, Cambodia, and Indonesia where DWT systems have been constructed using private loans or grants [43].

The costs for maintaining the collection and treatment facilities, including sludge treatment, also pose challenges. Money would have to be secured for continuous operation. Problems for the repair of damaged infrastructure due to a lack of funding lessened the effectiveness of treatment from DWT systems in Indonesia [43]. Palanca-Tan [71] reported that the willingness to pay for desludging by the end-user is a hurdle for Metro Manila, where the government is expected to subsidise the costs. The Indonesian and Malaysian governments have introduced the *polluters pay principle* to cover the cost of operation and maintenance of treatment facilities [72,73]. This principle subscribes to the polluter or end-user the responsibility of paying for wastewater treatment. Even under this principle, Kuala Lumpur still has problems due to a lack of funding needed to expand the treatment coverage and address maintenance costs [70].

Community barriers

The introduction of wastewater management whether in urban, rural, or peri-urban areas relies on the community's need for sanitation. The local community must be engaged into the idea of sanitation in order for any wastewater technology system to be effective. The community-approved standard will determine the technology system to be applied. An example of this would be the case of introducing *ecosan* (ecological sanitation) toilets in rural Vietnamese communities which were successfully introduced, but only after sufficient participatory community introduction [74].

The need for wastewater management is recognised in the urban area but issues still persist in building physical infrastructures related to it. The social stress accompanying construction work impedes the introduction of technology systems whether DWT, CCT, or CWT. Attempts at establishing CWT systems in the Philippines failed due to local opposition known as Not in My BackYard (NIMBY) [60]. NIMBY describes that communities will object to infrastructure development if it is done in close proximity to them due to the negative perception of the infrastructure quality. Thus, wastewater infrastructure development would experience continuous delay detrimental to wastewater man-

agement.

Another concern is the perception of where wastewater is generated. Urban centres of Southeast Asia are a mix of commercial, industrial, and residential districts which make a variety of wastewater sources. In Manila, resistance to invest in sewerage infrastructure by the residential sector is partly being caused by the misconception that the majority of the pollutant load came from industrial sources [71].

The need for sanitation in rural areas can be achieved through the awareness of disgust. Community-Led Total Sanitation (CLTS) has been established as a method of inducing disgust and shame in rural communities. The ultimate goal of CLTS is for a community to recognise that sanitation is worth investing in [75]. Its effectiveness has been established throughout most of the developing countries in the Southeast Asian region, but national and regional institutional policy has been a deterrent in successful implementation of sanitation technology [43].

Finally, the willingness of a community to practice routine maintenance in cases where technology systems are installed is also a key issue. Commonly used septic tanks are often not deslugged due to end-user decisions [68,76]. As such, the impaired treatment capacity has led to deteriorated water environment quality.

Institutional barriers

Effective wastewater management is also dependent upon institutional engagement. Wastewater management policies in Southeast Asia are often formulated on a national level such as: national environment protection law (Vietnam), national plan (Thailand), national strategy (Philippines), national program (Indonesia) [77]. These policies form a national level or top-down approach to wastewater management. These have improved wastewater management in most countries in Southeast Asia. The success is in part, due to the implementation of good practices on a national level and in part, the continuous activity of private institutions as in the cases of Malaysia and Philippines [70].

In some cases, national level policies are unfavourable to the improvement of wastewater management. Water environment protection policies with stringent specifications for nitrogen in receiving water bodies have been implemented in the Philippines [78] and Vietnam [79]. Technologies that can provide the necessary treatment are costly which may oblige wastewater management companies to reallocate investments intended for the expansion of their current technology systems. Additionally, the top-down approach is typically designed towards the wastewater management of city centres

which can make it unsuitable for application outside the urban context. The installation of DWT systems in Vietnam have been met with such challenges that although a nation-level standard for urban infrastructure development existed, the skill needed to install them were not translated to peri-urban communities [65]. National government involvement in the improvement of wastewater management in Indonesia has seen a lack of movement on the local government level which negatively influences peri-urban areas [80]. These examples illustrate that the top-down intervention is crippled without institutions to implement and support its advocacies [81].

A highly decentralised management regime can lead to local organizations losing interest in maintenance on their own. Indonesian attempts at establishing community-managed DWT systems failed due to the community's failure to regularly perform sludge removal [82]. This failure has necessitated a municipal management scheme where local stakeholder organizations must be paired with a centralised management to ensure successful implementation. These have been observed in Indonesia and Lao PDR where the engagement of rural communities to sanitation were done through a national level community-based implementation program [49,78]. The institutions involved have been tasked to address local community engagement to sanitation projects, capacity-building, and capacity management activities. Creating a participatory environment to strengthen local stakeholder involvement with effective government actors ensures that the installation and management processes maintain balance between government, private sector, and local community actors. Constructing and maintaining decentralised wastewater systems necessitates "a clear distinction [...] regarding where private households' responsibility stops and public responsibilities start." [80] Each stakeholder group engaged in a local wastewater management project must not become overwhelmed by top-heavy or bottom-heavy governance.

Technical barriers

Technical barriers for DWT, CCT and CWT systems are seen in urban centres. Effluent that is unable to meet environmental discharge specifications is caused by poor desludging practices of DWT [45,51,77]. In CCT and CWT systems, effluent quality is affected by collection system coverage [8] and treatment plant overcapacity [67]. Although desludging services are often present in urban centres, septic tanks are rarely serviced not only because of social barriers such as owner neglect, but also because of limited maintenance capacity of wastewater treatment companies

[32]. Private solids waste management companies that offer desludging services may also be limited in terms of capacity to receive and execute needed services [84,85]. Countering the need for maintenance requires either the installation of low-maintenance technologies or the connection to a CWT system. Examples of low-maintenance technologies introduced are CCT systems in the Philippines where lagoons, wetlands, and package plants are used [60]. Aside from desludging treatment facilities, collection systems also require maintenance. Although interconnected storm drainages and combined sewer networks are present [71,86], they have deteriorated and do not function properly in Vietnam [83], Lao PDR [87], and Myanmar [51].

Other than the aforementioned problems, the need for specialised parts needed for maintenance is also a concern. Answering this issue means the introduction of a technology that uses local materials such as the case of Muntinlupa City in the Philippines where *cocopeat* was used for the treatment of municipal wastewater [60].

The issues in rural areas begin with the absence of a technology system. Even when DWT systems are present, professional desludging services may not be readily available to rural communities [69]. A report presented to USAID cited that rural septic tanks are rarely emptied [68]. In this case, the desludging would have to be addressed by untrained personnel which may damage the technology system.

Finally, in Southeast Asia where DWT systems have been and still are being introduced, infrastructure development and maintenance is done on a piecemeal approach. The construction of DWT systems, as opposed to having CWT systems, require that the technologies introduced over time is different for system to system and locality to locality. Thus, piecemeal introduction of technology systems makes maintenance difficult because services would have to be as diverse as the technologies in place [88].

Table 3 summarises the challenges within each barrier to briefly highlight the key points that need to be addressed to improve wastewater management in the developing countries of Southeast Asia. The table also summarises some of the offered solutions to the challenges.

From the table, it can be seen that similar challenges for wastewater management exist regardless of area and technology system. Challenges in the introduction and maintenance of the physical infrastructure are described in every barrier. Solutions have been offered to address some of the identified challenges.

Table 3 Summary of barriers to the improvement of wastewater management in the developing countries of Southeast Asia.

Barriers	Challenges to wastewater management	Present solutions offered
Economic	<ul style="list-style-type: none"> ▪ Capital cost of investment in wastewater management infrastructure ▪ Additional maintenance cost of installed infrastructure 	<ul style="list-style-type: none"> ▪ Government or private funding to provide initial capital investment
Community	<ul style="list-style-type: none"> ▪ Establishment of need for wastewater management through establishing the need for sanitation infrastructure ▪ Lack of knowledge of water pollution source ▪ Resistance to practice routine maintenance of infrastructure 	<ul style="list-style-type: none"> ▪ Community-Led Total Sanitation (CLTS) used to create need for sanitation
Institutional	<ul style="list-style-type: none"> ▪ Mistranslation of national level policies to different localities and implementing institutions ▪ Decentralised maintenance management of treatment facilities ▪ Lack of discussion of needs and wants between institutions and localities 	<ul style="list-style-type: none"> ▪ Creation of national-level policies for environmental protection ▪ Participatory engagement of stakeholders with local wastewater management institutions
Technical	<ul style="list-style-type: none"> ▪ Poor maintenance for existing infrastructure ▪ Absence of wastewater management infrastructure ▪ Piecemeal introduction of infrastructure 	<ul style="list-style-type: none"> ▪ Desludging by wastewater management institutions ▪ Introduction of low-maintenance CCT systems ▪ Introduction of CWT systems

REFOCUSING THE DISCUSSION PERSPECTIVE

Limitations to the discussion of wastewater technology systems

Various discussions have been made about which kind of wastewater technology system can improve wastewater management in developing countries. Several arguments against CWT systems have emphasised that developing countries have limited financial and technical capacities to introduce these systems [9,16,17,20,27,69,89]. An alternative option would be to introduce a combination of DWT and CCT systems which are hereafter called as decentralised cluster technology (DCT) systems. In their discussions, DCT systems can address financial constraints because they are flexible to economy and treatment [9,16,27]. However, a DCT system should have comparable performance with a CWT system in order for it to be the better alternative [89]. Further, DCT systems would generally be the better option if they are managed in a centralised manner [16,89,90]. Monitoring, maintenance, and sludge management should be under an institution that has professionals in wastewater management [16,19]. The arguments thus far have shown that both CWT and DCT systems have their own strengths and weaknesses and suggesting one over the other would not be enough to improve wastewater management.

The discussions in the above-mentioned articles often pres-

ent appropriateness as the key towards improving sanitation. According to Massoud et al. [16], the physical conditions, economic capability, and social acceptability of a locality should be addressed in order for a technology system to be appropriate. Nelson and Murray [69] added management and energy requirements and Ho [17] raised environmental protection as other dimensions to be considered. Isunju et al. [83] summarised these ideas by likening appropriateness with sustainability where dimensions of economy, environment, and culture are considered. Ujang et al. [20] cited that an appropriate technology system should be both suitable and reliable to a given community but offered no solutions to address the changes that come with the flow of time. All of these definitions cover significant requirements for a technology system to be able to improve sanitation. However, the change of a community structure, and thus demand for treatment, over time was not emphasised within their presented solutions.

The developing countries of Southeast Asia have fast-growing urban centres which lead to increased economic activity, physical infrastructure, and population [30]. Technology systems should be constructed with flexibility enough to address dramatic fluctuations in treatment demand caused by rapid population change. Peri-urban areas are expected to increase in population and in area to accommodate settlements for people working within urban centres. The present rural areas may be affected in two ways: the population

could decrease because of migration to urban and peri-urban areas, or the population could increase because of rural area transformation into peri-urban. Population change in all localities can also be affected by population slump where birth rate is below mortality rate. A population slump is already being observed in Thailand [2]. Availability of opportunity or occurrences of calamity can also cause demographic fluctuations emphasizing the need for technology systems to accommodate population over time.

Defining flexibility

An appropriate wastewater technology system should also be able to accommodate changing demands. To this, Jeffrey et al. [91] proposed that robustness, flexibility, and adaptivity are key concepts to water technology systems that can respond to change over time. Thus, the concept of robustness, flexibility, and adaptivity of a technology system should be discussed to complement the provided characteristics of appropriateness. Spiller et al. [92] provided a definition for each concept acquired from engineering and design literature. They described robustness as a way for a technology system to perform as intended while accommodating performance fluctuations derived from external sources. Robust systems are designed and installed with an anticipated treatment capacity over its lifetime. Hence, the limitation of a robust technology system occurs when the defined capacity is breached. Flexible and adaptive technology systems change to accommodate external variations. The difference between the two is that the system change must come from external initiative for it to be flexible and internal to be adaptive. In this case, a flexible wastewater technology system allows for the installation of assets to accommodate for external changes in demand while an adaptive one does not require installations or removals because it is built to change on its own. Based on the given definitions, robust systems are flexible as they still allow external changes within a provided limit. Thus, flexibility of a technology system is the concept that should be emphasised alongside appropriateness in order to propose solutions towards the improvement of wastewater management. In the future, an appropriate technology system should also be flexible such that it addresses changes in demand, time, culture, economy, and environment.

Incorporating flexibility in appropriateness

Wastewater management in urban and peri-urban areas call for solutions which can answer to future demand uncertainty [93]. Incorporating flexibility in designing technology systems is beneficial for the improvement of wastewater

management [94]. Spiller et al. [92] and Roefs et al. [94] suggested that flexible design can be achieved through phased expansion or step-by-step infrastructure construction where the current demand is satisfied first by a technology system and adjusts said system in the future should the demand change. Although phased expansion has a projected higher capital cost compared to building robust technology systems [95], investing in flexible systems merit long-term cost-effectiveness and elimination of idle capacities [96,97]. Here, idle capacity is exhibited in robust systems through unused allowances integrated in their design. In terms of wastewater technology systems, phased expansion in developing countries could start with the introduction of DCT systems to satisfy the current demand then provide an allowance for future changes [92,94]. Maurer et al. [97] advised that introducing small systems, similar to DCT systems described in this manuscript, would be better for a locality with a high growth of demand which necessitates flexible solutions.

Incorporating flexibility in appropriateness means building a wastewater management system that can withstand changing treatment capacities. In the advent of population increase, a community that incorporates flexible design can treat the additional load and in the case of decline, the flexible system can ideally downsize treatment capacity. An interplay between various technologies within technology systems should be considered in a flexible wastewater management system. While yet to exist, a flexible and appropriate system is expected to lessen the threat to the water environment in the Southeast Asian region.

CONCLUDING REMARKS

The improvement of wastewater management in the developing countries of Southeast Asia necessitates solutions designed for the region. We have found through the discussion that a wide variety of technology systems are in place which include DWT, CWT, and CCT systems. Wastewater in urban areas is still largely treated by DWT systems while future development largely leans towards the implementation of CWT systems. Various literature suggests the appropriateness of a technology system to be the key towards the improvement of wastewater management. However, the literature definition of appropriateness fails to address the uncertainty of wastewater treatment demand. In regions where future demands require sound investments in the present, flexibility should be emphasised in the proposed design of wastewater technology systems. Further research on both technology and management systems should incorporate the flexible and ap-

proprate design concept for the improvement of wastewater technology systems.

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