Sustainable indicators for designing the wastewater treatment plant

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Abstract. As rapid population and urbanisation in our country have put pressure on our water resources, it is vital to consider sustainable solutions in water and wastewater system, especially to our wastewater treatment plant design. Several studies have shown the importance of having an indicator in both plannings, designing and operating a wastewater treatment plant to help develop a sustainable method in wastewater treatment plants. Therefore, this paper presents a study of crucial sustainable indicators for designing Malaysia's sewage wastewater treatment plant. This paper focused on three (3) aspects: environment, social and economic, followed by significant data to emphasise sustainable indicators. This study was conducted using a quantitative methodology (survey questionnaire online form) and distributed to wastewater engineers or any groups related to the wastewater treatment plant in Malaysia. The survey conducted showed that most crucial sustainable indicators in sewage WWTPs design were (i) nutrient removal, (ii) worker's health and safety, (iii) public health and safety, (iv) operational and maintenance costs, (v) energy consumption and (vi) greenhouse gases emissions.

1. Introduction

Wastewater is defined as used water from various sources such as residential areas and industrial sectors. Wastewater treatment is a process of removing contamination in the water that harmful to the environment and humans [1]. This wastewater treatment aims to produce clean water before releasing it into the environment and used by living organisms, especially human beings. However, wastewater management has become a significant problem due to drastically increased population growth and urbanisation. The high demand on natural resources such as water has put pressure on the environment and threatened the sources of water supplies. According to [2], many rivers in Malaysia suffer from sewage pollution and cause eutrophication. Besides that, human activities such as discharging the untreated wastewater directly into the river or water body also contribute to pollution. Therefore, access to sanitation and drinking water will be quite tricky for the engineers to improve the sanitation system. More than 95% of wastewater in many countries were unproperly discharging the untreated wastewater into the environment [3]. According to [3] there were still many people throughout the world without access to better sanitation. Besides that, focusing on the sanitation target causing the wastewater treatment rise as a critical issue.

Throughout the year, many existing sewages wastewater treatment plants have evolved from basic sanitation facilities to advanced treatment facilities to address sewage pollution. For example, septic tank, imhoff tank, oxidation ponds, aerated lagoons, activated sludge system, package system and mechanical plant [4]. Despite the evolution of the sewage wastewater treatment plant, it remains a major pollutant of inland waterways in Malaysia [4]. Therefore, the development of sewage treatment needs to be more proactive and maintain the sustainability of the treatment system in aspects of the

environment, economic and social to provide a better future towards the environment and economy and community.

One of the targets in promoting this effort is the introduction of Sustainable Development Goals (SDGs), in which the untreated wastewater should halved from 2015 [3]. Sustainable Development Goals defined as the '*development that meets the present generation's needs without compromising the ability of future generations to meet their own needs'*. The meaning of this definition is to show that all human beings in the present or future should have equal rights. One of sustainable development purposes is to promote water protection, conservation, and water efficiency. In SDGs, there are 17 goals, including clean water and sanitation (Goal 6). This goal aims for clean water accessibility and the ability for all people to access drinking water and protect water resources such as rivers. Relation sustainability to wastewater treatment is to urges all people to protect the aquatic organisms and increase public awareness of the impact of pollution on the environment and human safety and health. According to [5] many countries face excessive pollution in water reservoirs and causing severe environmental problems, including disturbing the ecological balance. Thus causing environmental damage and affects the cost operation of the wastewater treatment plant.

Besides that, sustainable indicators in wastewater treatment plants are also important to estimate the sustainability in wastewater treatment, such as environmental impact and energy saving. A sustainable indicator is a statistic used to measure environment protection, social equity and economic growth. Besides that, an indicator can help policy and decision-making and provide quantitative and qualitative information [6]. The selection of good indicator sustainability can alert to a problem that may occur in the system and provide practical actions on how to fix it before it becomes a severe problem.

This study aims to determine crucial indicators for sustainability in wastewater treatment system design. The findings in this study will also determine sustainable indicators that should be considered in wastewater treatment system design and propose relevant qualitative and quantitative data to translate the sustainable indicators.

2. Methodology

This chapter will include the procedure for this study. The methodology for this study is by using quantitative method. The procedures in this work were data collection from a scientific database such as ScienceDirect, Google Scholar, Scopus, Springer and EZproxy from UTM. Besides that, identifying crucial indicators was done through a survey questionnaire. The data from survey questionnaire were analysed using SPSS software.

2.1. Data collection

Data collection for this study includes all secondary sources such as journals, published research articles and review papers conducted in Malaysia and other countries. Relevant information and data were selected to aid in constructing the survey questionnaire before distributing it to targeted participants.

2.2. Questionnaire

The purposes of this questionnaire are to identify the crucial indicator for designing the sewage wastewater treatment plant and to propose the qualitative and quantitative data for emphasised the identified sustainable indicator. The questionnaire is addressed to the wastewater engineer or any groups experienced in the wastewater or water industry. The number of respondents in this questionnaire is 31 respondents.

There were three (3) sections in the questionnaire, namely Demographic (Section A), crucial sustainable indicator in sewage treatment plant design (Section B) and lastly Section C, which is the significant data for emphasised the identified sustainable indicator. Section A consists of the respondents' background section, while section B consists of a crucial sustainable indicator for designing the wastewater treatment plant. Section C consists of the qualitative and quantitative data to emphasise the identified sustainable indicators. Besides that, the survey questionnaire was implemented via Google Form online application.

Four steps have been taken to conduct the questionnaire in this study. The first step is to conduct a library study from the scientific database. The purpose is to identify the sustainable indicators in the

wastewater treatment plant and propose qualitative and quantitative data to emphasise the identified indicators. The information from the literature review was used to form Section B and Section C of the questionnaire. The second step is to validate the questionnaire that has been made. For the validation, three Indah Water Konsortium consultants were selected to validate and comment on the questionnaire before distributing it to the target participants. The third step is to improve the questionnaire based on comments from the consultants. The last step is a pilot test to check the reliability and improve the quality and efficiency of the questionnaire.

2.3. Data analysis

Data from the questionnaires are analysed and interpreted using SPSS software (Statistical Package for the Social Sciences). The data analysis is divided into two (2) parts.

(a) Part one: Descriptive analysis for a demographic section such as frequency distribution and percentage.

(b) Part two: Section B and C data were analysed using one-sample t-test analysis and interpreted into a statistical significant method where the p-value was obtained. Data with a significant level of $p > 0.05$ is specified as not significant, while p-value less or equal to 0.05 were specified as significant. In other words, the smaller the significant level (p-value), the more significant the results.

3. Results and discussion

3.1. Survey participant profile

Two questions were designated to get demographic data from participants, including experience working in the wastewater or water industry and experience on the project design of the wastewater treatment plant.

Table 1. Respondent's demographics analysis results

Question	Distribution	Frequency	Percentage (%)
Experience in working in wastewater or any industry related to wastewater treatment plant	0-5 years	19	61.3
	6-10 years	8	25.8
	11-15 years	2	6.5
	More than 15 years	2	6.5
Experience in wastewater treatment plant design project	1-5 times	14	45.2
	6-10 times	2	6.5
	11-15 times	1	3.2
	More than 15 times	3	9.7
	None	11	35.5

Based on the data obtained from the respondents, most of the respondents have experience working in wastewater for five (5) years and below, with a percentage of 61.3%. In comparison, 25.8% of the respondents have experience for 6 to 10 years, followed by 6.5% for both working experiences of 11 to 15 years and 15 years above, respectively. However, 45.2% of the respondents have experience on working in designing the wastewater treatment plant, followed by 6.5% (6-10 times), 3.2% (11-15 times), 9.7% (more than 15 times) and 35.5% (none experience) as shown in Table 1. Based on these results, although most of the respondents have working experience for five years and below, they have experience in designing the wastewater treatment plant at least one (1) to five (5) times.

3.2. Crucial indicator for designing the sewage wastewater treatment plant

In order to determine the crucial indicators for designing the WWTP, the indicators are divided into three aspects (environmental, social and economic). One sample t-test was used to analyse each

indicator. One sample t-test was used to compare a single sample's mean to a predetermined value to determine if the sample mean is significantly greater or less than the value. In this study, the t-test value used is 3, indicating a neutral response, either important or not important.

Table 2. The significant indicators

Aspects	Indicator	Mean	*p*
Environment	Nutrient removal (BOD, COD, TSS, Nitrate, etc)	4.23	0.00
	Energy consumption	3.61	0.01
	GHG emissions	3.74	0.00
Social	Worker's health and safety	4.16	0.00
	Public health and safety	4.03	0.00
Economic	Operational and maintenance costs	3.81	0.00

Table 2 shows three crucial indicators in the environmental aspects: nutrient removal indicator, energy consumption and GHG emissions. The majority of wastewater treatment systems used in Malaysia for nutrient removal is activated sludge. However, the operating costs are high and contribute to the sludge disposal problem at the end. Therefore, one of the approaches to address this issue is by using an environmentally friendly method such as phytoremediation. Phytoremediation is a method of removing, stabilising, transferring, or reducing contaminants in soil or water media using green plants, making it an attractive biological treatment method [7]. Besides that, it is found that phytoremediation agents can remove organic and inorganic contaminants, and it requires low cost, low energy consumption and minimal environmental disturbance [8]. According to [9] reported that the phytoremediation agents such as Eichhornia crassipes (Water hyacinth) could remove 83%-92% of COD and TSS. Hence, nutrient removal technologies or methods used in wastewater treatment plants should be chosen wisely to achieve sustainability in the wastewater treatment plant. This is especially for supporting SDG 6, which is clean water and sanitation, and SDG 14 to sustainably manage and protect marine and coastal ecosystems from pollution and comply with Environment Quality (Sewage) Regulation 2009.

The second indicator in the environmental aspect is the energy consumption indicator. The energy used in the WWTP continuously increased as clean water demand increased and eventually affected the total cost operational expenditure (OPEX) [10]. Besides that, [11] stated that most WWTP found low energy efficiency performance levels due to high water demand and higher discharge parameters in the treated effluent. In addition, the energy used from fossil fuels contributes to environmental issues such as the greenhouse effect and acid rain. Thus, reducing the dependency on fossil fuels must be considered to achieve SDGs and support Green Technology Masterplan Malaysia (2016-2020). The goal of GTMP is to promote sustainable development and strengthen the green technology and economy focusing on energy, manufacturing, waste, building, water and transportation. Besides, to support the GTMP in terms of energy, WWTP must reduce their dependency on fossil fuels by utilising renewable energy like biogas. For example, biogas produced from IWK's sewage wastewater treatment with an anaerobic digester system was reported to be capability to generate 20 MW hour per day [12]. Hence, it synchronised with SDG 7 (Affordable and Clean energy) and SDG 13 (Climate action) and supported the National Green Technology.

The operation of WWTP causes direct emissions of GHG such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), where carbon dioxide is emitted from the energy consumption during plant operation [13]. Well-managed WWTP operation protects the environment and supports SDG 7 (Renewable Energy) and SDG 8 (Climate Action) and compliance with the National Policy of Climate Change. Besides, [3] stated that energy use influences GHG emissions in the wastewater treatment plant. The more WWTP depends on fossil fuels as energy source, the more they contribute to GHG emission. Therefore, the need to use renewable energy and well-managed wastewater treatment plant operation in terms of energy use is needed. In addition, the Malaysian government is considering climate change in

the infrastructure system engineering design for water to ensure sustainable management and encourage the private sector to include net-zero GHG in their sustainable operation agenda [14].

In the social aspect, public health and safety indicators and worker health and safety indicator are selected as crucial indicators in WWTP. Various activities in WWTP such as toxic air contaminants, detection of chemicals and control of pollutants present in wastewater impact human health [15]. In fact, producing clean water, proper wastewater treatment, and disposal are essential for community health. The treated wastewater in urban areas should meet with Environment Quality Act 1974 and its regulations Environmental Quality (Sewage) Regulation 2009 before being discharged to surface water. According to [16] stated that an analysis made by the International Occupational Safety and Health Information Centre (CIS) found many accident hazards in the sewage wastewater treatment industry, such as water-born disease, hearing loss as well as slip and fall. The awareness of safety and health in the WWTP is important to reduce occupational accidents in the workplace. Besides that, in Malaysia, there are laws enforced by the Department of Occupational Safety and Health, such as the Occupational Safety and Health Act (OSHA) 1994. Thus, provide safety and healthy work environment for the wastewater operators or other workers by implementing safety guidelines, provide personal protective equipment and training are needed. Besides that, compliance to OSHA Act 1994 and Environmental Quality Act 1974 reduce the accidence level, avoid disease, and support SDG 3 (Good health and well-being) by ensuring healthy lives for all workers and the public. SDG 14 (Life below water) and SDG 11 (Sustainable Cities & Communities) also are supported by preventing any disease and pollution that may harm the public and environment.

Lastly, operational and maintenance cost indicators are selected as crucial indicators for the economic aspect. The investment spends on the sewage wastewater treatment plant for its operation and maintenance is high. The electricity cost of the WWTP contributes the highest expenses, followed by contractor costs and office rental and premises. According to Malaysia's Indah Water Konsortium (IWK), the electricity cost in 2010 was around RM 152.50 million and has been increased since 2007 [10]. This shows that the operating cost is influenced by electricity usage in the WWTP. Therefore, while planning a new WWTP in the future, it is important to consider using equipment with energy-saving, implementing periodical maintenance of equipment, and using alternative energy sources.

3.3. Identifying the significant data for emphasised the identified crucial indicators

Table 3. Significant data for identified sustainable indicators

Environment	Qualitative and quantitative data	Respondents Acceptance/Recommendation	Mean	SD	*p*
Energy consumption	Energy usage in WWTP (Quantitative)	Accepted	3.84	1.15	0.00
	Usage of fuels and electricity from renewable sources (Qualitative)	Rejected	3.35	1.25	0.12
	Legal standard to meet	New monitoring data is proposed			
Nutrient removal	Contaminant removal efficiency to mitigate environment risks (Qualitative)	Accepted	4.32	0.74	0.00

Table 3. Significant data for identified sustainable indicators (continued)

Environment	Qualitative and quantitative data	Respondents Acceptance/Recommendation	Mean	SD	*p*
Nutrient removal	Quality level of discharge water compliance with DOE (Qualitative)	Accepted	4.48	0.76	0.00
	Profiling of incoming waste	New monitoring data is proposed			
	Compliance to local regulatory	New monitoring data is proposed			
GHG emissions	Carbon dioxide emission intensities (Quantitative)	Accepted	3.74	1.06	0.00
	Index of greenhouse gas emissions (Quantitative)	Accepted	3.74	1.06	0.00

Based on Table 3, the proposed quantitative and qualitative data for energy consumption is energy usage in WWTP per volume of treated wastewater and usage of fuels and electricity from renewable energy. The data analysis showed that the qualitative data is significant where the p-value is less than 0.05. However, for quantitative data, the p-value is greater than 0.05, which indicates not statistically significant. This means the proposed qualitative data for energy consumption indicator is not chosen as important by most respondents. For the energy usage in WWTP, other than renewable energy as an energy source, the size of plant, design, and technologies used should also be considered [17]. This is because some of the technology used in the WWTP required high energy consumption, such as aerators and blowers in the aeration tank. The need to improve energy efficiency in WWTP is essential to reduce the cost of energy consumption and minimise the operation cost. Even though increasing energy efficiency in the plant requires a high cost, it has been proven that the cost of energy consumption is reduced [18]. Therefore, to emphasise the energy consumption in WWTP, renewable energy, types of technology used and energy efficiency need to be considered. However, another suggestion by respondents to emphasise energy consumption is a legal standard to meet.

Next is nutrient removal (BOD, COD, TSS and Nitrate) indicator. Contaminant removal efficiency to mitigate environmental risks and quality level of discharge water compliance with the Department of Environment (DOE) is qualitative data to emphasise the nutrient removal indicator. The p-value for these qualitative data was statistically significant, with a p-value of less than 0.05. The efficiency of the technology used in the wastewater treatment plant to remove the contaminant in the wastewater before being discharged into the water bodies are important to prevent pollution and avoid spreading disease to public and aquatic organisms. The wastewater discharge should also comply with Environmental Quality (Sewage) Regulation 2009 under Environment Quality Act 1974 regulated by DOE to ensure sustainable growth among the community and protect the environment. The neglect of the Environment Quality Act 1974 caused damage to the country's environmental, social, and economic sectors. Malaysia faced various issues due to the discharge of undesirable effluents and waste products into the environment, leading to natural resources degradation, pollution, and human health risks for many years. Therefore, considering the efficiency of nutrient removal in WWTP and compliance to DOE is crucial to achieving sustainability in WWTP. However, the respondents also suggested that profiling incoming waste and compliance with local regulations should be considered to emphasise the nutrient removal indicators for sustainable WWTP.

The proposed quantitative data for the GHG emissions indicator is carbon dioxide emission intensities and the index of GHG emissions. Table 4 shows that both quantitative data for GHG emissions are statistically significant. One of the concerns of the Malaysian government to achieve sustainable development is climate change due to GHG emissions in many sectors, including wastewater

treatment. Excessive greenhouse gases emission into the atmosphere has led to climate warming. The CO_2 emission is produced by the emission of carbon dioxide directly and indirectly. The combustion of CH_4 and the organic matter oxidation occur in biological reactors emitted CO_2 directly while indirectly in energy consumption in the WWTP [13]. High carbon dioxide intensities and GHG index will increase GHG emissions. Therefore, reducing CO_2 and other greenhouse gas emissions in the WWTP will reduce the GHG emission into the atmosphere.

Table 4. Statistical survey results on significant data for Social and Economic aspects indicator

Social	Qualitative and quantitative data	Respondent Acceptance/Recommendation	Mean	SD	*p*
Worker's health and safety	Awareness of safety in the workplace (Qualitative)	Accepted	4.65	0.66	0.00
	Implementation of SOP and guidelines (Quantitative)	Accepted	4.52	0.72	0.00
	Work safety training provided (Qualitative)	Accepted	4.55	0.72	0.00
	Awareness of health in the workplace (Qualitative)	Accepted	4.58	0.72	0.00
Public health and safety	Potential impacts of the plant design on public (Quantitative)	Accepted	4.16	0.86	0.00
	Awareness of health issues (Qualitative)	Accepted	4.29	0.82	0.00
	Awareness on the safety (Qualitative)	Accepted	4.29	0.82	0.00
Economic	Qualitative and quantitative data	Respondent Acceptance/Recommendation	Mean	SD	*p*
Operational and maintenance costs	Operating costs per volume unit of wastewater treated (Quantitative)	Accepted	4.29	0.97	0.00
	Maintenance cost of facility per year (Quantitative)	Accepted	4.23	0.88	0.00

Table 4 shows the statistical survey for proposed qualitative and quantitative data for the social and economic sectors. The proposed qualitative and quantitative data for worker health and safety indicators are awareness of safety in the workplace, awareness of health in the workplace, implementation of SOP and guidelines and work training provided. All these qualitative and quantitative data emphasise the work health and safety indicator for sustainable WWTP. The awareness of safety and health in the workplace should be taken as a serious matter in WWTP as the workers have been involved in various activities in wastewater treatment plants and exposure to chemical and toxic air contaminants. According to [15], safety, such as providing PPE to workers and good work training, should be implemented to

avoid any hazardous situations and accidents. Besides, [19] also added that conducting awareness programs about safety and possible risk in the workplace will decrease accidents. Besides that, implementing SOP and guidelines in the workplace aids in preventing any accidents or hazards in the workplace. Besides, the SOP and guidelines in the workplace should be updated if have changes in operation in the workplace. Therefore, these qualitative and quantitative data emphasise the importance of worker health and safety for sustainable WWTP.

Meanwhile, the proposed qualitative and quantitative data for emphasised public health and safety indicator is the potential impact of WWTP plant on public, awareness of safety and awareness of health issue. A wastewater treatment plant is one of the sources of toxic compounds and gases contaminant, which can lead to environmental pollution to its surrounding. Therefore, when designing the wastewater treatment plant, it is crucial to consider its effects, especially local health and safety. According to [20], one of the potential impacts of WWTP on the public environment is microbial air pollution and can spread for 800 meters from its source. Therefore, it is important to identify potential impacts to prevent or control any issue. Besides that, public concern on clean water quality for their safety is needed to be evaluated. According to [21] a better understanding of the public concern of drinking water contributes to water management, such as the use of treatment processes and customer services. Besides that, the awareness of health issues also needs to be evaluated, especially for maintaining public life quality. For example, well facilities management such as proper treatment and disposal of wastewater is crucial to protect the environment and public health. Besides that, risk assessment related to the WWTP needs to be implemented to obtain the risk that may happen during the operation of WWTP, which may affect human health [22].

For the economic aspect, the proposed quantitative data for emphasised operational and maintenance cost is the operational cost per volume unit of treated wastewater and facility maintenance cost per year. Operations are any activities conducted in the WWTP, while maintenance involves activities or actions to ensure the equipment used in the WWTP is efficient to reach their objectives [23]. Usually, the operation cost is affected by the equipment used and the characteristic of the wastewater. Therefore, to achieve sustainability in the wastewater treatment plant, it is very important to choose the high performance of equipment used during the operation, such as can treat wastewater at a lower cost [24]. Lower operation costs will reduce the expenditure facility, thus producing more profit and can help to improve or maintain the facility. Besides, if the maintenance cost increases due to the lack of preventive maintenance, this will decrease the profit and asset cost of the facility.

4. Conclusion

This study significantly gives a new perspective in the decision-making, planning and operation of wastewater management services, especially in developing sustainable wastewater treatment plants. In conclusion, the survey questionnaire has shown that these five indicators for designing the sewage wastewater treatment plant are crucial and should be considered. The identification of crucial indicators is to embrace the impact of the development and operation towards achieving environmental, social and economic sustainability, which can significantly be a green baseline for designing a future wastewater treatment plant.

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