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Impact of COVID-19 Pandemic on Greenhouse Gas Emissions from Municipal Solid Waste Disposal of Bangkok Metropolitan

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Abstract

The impact of COVID-19 pandemic on greenhouse gas emissions from solid waste disposal in Bangkok was evaluated using statistics of waste quantities disposed by composting, incineration, and landfill methods from the transfer stations during pre-pandemic period (2015-2019) and pandemic period (2020-2022). The potential emissions of greenhouse gases from these activities were evaluated using the 2006 IPCC and 2019 Refinement methodologies. During pre-pandemic period, the emissions was estimated at 1147.98 GgCO_2-eq/year in which waste disposal in landfills contributed majority at 1002.58 GgCO_2-eq/year. The landfill emissions gradually decreased to 861.23, 809.78, and 754.73 GgCO_2-eq in 2020-2022, respectively. Meanwhile, greenhouse gas emissions from composting and incineration of general wastes during the pandemic were maintained at the same levels as the pre-pandemic period. During the pandemic period, greenhouse gas emissions from infectious waste incineration were significantly increasing to 10.79 GgCO_2/year from those during pre-pandemic period (5.42-7.25 GgCO_2/year). Despite of these increases, total GHG emissions from waste disposal in Bangkok in 2022 was reduced by 22% from those in 2018 due to the decreasing amount of general waste produced during the pandemic period.

Keywords : Greenhouse Gas; COVID-19 pandemic; Infectious waste; Bangkok waste

Introduction

Proper handling of municipal solid waste (MSW) is one of the challenges in urban areas especially those situated in developing countries. An increase in the population and the changing lifestyle of the population generally resulted in an increasing quantity of MSW as well as complexation of MSW composition. The change would require more effective waste management and facilities to cope with. In Thailand, the amount of municipal solid waste generated was approximately 27.35 million tons or about 75,000 tons per day in 2020 [1] and it was forecasted to increase to 84,070-95,728 tons per day in 2030 [2]. Within Thailand, the amount of MSW collected and sent to disposal from Bangkok Metropolitan was 9,058 tons per day in 2020 [3]. During MSW management, greenhouse gases (GHGs) can arise from several management activities such as composting, incineration and solid waste disposal on land using either open dumping or landfill methods. They are one of the major anthropogenic activities contributed to the global climate change problem. In Thailand, GHGs generated from waste sector accounted for about 4.3% of the national total in 2019 [4]. From 2019, the occurrence of COVID-19 pandemic has resulted in a drastic change of people lifestyle affecting the generation of waste such as limited social activities and consumption of food at home. On the other hand, the use of single-use personal protection materials and equipment (PPEs) such as face masks and antigen test kits (ATK) has become normal practice for people. A survey on the quantity of used masks and wastes collected at 11 communities in Bangkok has revealed an increase of their weight by almost 100% during October to November 2021 [5]. Additionally, the amount of infectious waste (IW) also increased from increased numbers of patients affected from the pandemic. These changing behavior of the people affects the amount and type of waste generated from their activities thus may lead to the change in GHG emissions and its impact from their disposal [6]. There have been previous studies in other countries in attempt to quantify the generation of the waste arising from single use PPEs and medical waste during COVID-19 pandemic [6-9]. Nevertheless, the extent of impact of COVID-19 pandemic on the amount of waste generated and disposal as well as their associated GHG emissions in Thailand especially Bangkok Metropolitan is still unclear.

Therefore, this study aims to evaluate waste quantity and associated GHG emissions from MSW management in Bangkok Metropolitan during pre-COVID-19 pandemic (2015-2019) and during pandemic period (2020-2022). The waste quantity used in this study was acquired from relevant governmental agencies mainly Bangkok Metropolitan Administration (BMA) for MSW and infectious waste while single-use PPEs was estimated based on estimated number of Bangkok population disposed them when having activities outside their houses. The emissions from MSW, infectious waste and single-used PPEs disposal were estimated by IPCC methodology using actual activity data but default emission factors proposed in IPCC guidelines were assumed. Meanwhile, the study did not cover socio-economical aspect to explain consumption and waste disposing behavior of Bangkok people during the pandemic period.

Materials and Methods

Waste quantity determination

The quantities of general and infectious waste generated during pre-COVID-19 pandemic (2015-2019) and during pandemic period (2020-2022) was obtained from Bangkok Metropolitan Administration (BMA) statistics. All general waste collected from 50 districts in Bangkok Metropolitan was transported to 3 transfer stations, namely On-nut, Nongkhaem, and Saimai stations, with the total weight received being recorded daily. The collected waste is then treated in composting units (~1,600 tons/day maximum capacity) located at On-nut station, an incineration plant (1,500 tons/day capacity) located at Nongkhaem station, while majority of the waste is transported from the transfer stations to their final disposal in landfills. The waste composition at each transfer station was determined and recorded annually.

The infectious waste was collected separately and sent to its disposal in an infectious waste incinerator located at On-nut station. The amount of incinerated waste was recorded daily.

The quantities of PPEs including face masks and antigen test kits (ATK) were estimated assuming the use and disposal of 1 face mask per day and 1-3 ATK every 14 days for Bangkok citizen. This assumption was set following average facemask consumption rate reported in Benson et al [10]. The antigen testing intervals were assumed following the recommendations of international standard for screening of COVID-19 of 1-3 times [11] within the recommended monitoring period of 14 days set by Ministry of Public Health, Thailand. Lyng et al [12] also reported that COVID-19 testing strategies with least frequency of 14 days interval could yield 56.1% and 46.5% reduction in cumulative infections in communities with low and high prevalence, respectively. The waste generation was not considered from whom worked or stayed at home during travel restriction period, estimated at 85% of total population in 2020 as indicated in public transportation records of Ministry of Transport during Dec 2019 (pre-COVID-19 outbreak) - Mar 2020 (after governmental lock-down announcement) [13] but the condition was resumed to normal in 2022. These wastes are generally produced in households and disposed together with general waste excepted those generated in hospitals and clinics which are managed as infectious waste.

Estimation of GHG emissions

The estimation of GHG emissions was performed following guidelines proposed by

Intergovernmental Panel on Climate Change (IPCC). The most updated methodologies include 2006 IPCC Guidelines for National Greenhouse Gas Inventories [14] and 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [15]. According to the IPCC Guidelines, GHGs from following solid waste management activities are considered.

1) Disposal of general waste in landfills

In landfills, methane (CH_4) is generated from anaerobic decomposition of organic waste. To estimate CH_4 emissions from landfills, the activity data used are historical data of waste deposited in landfills, receiving waste amount during the calculation year, degradable waste composition categorized into food waste, paper, textile and yard waste types. The emission factors used in the calculation include degradable organic carbon (DOC), fraction of biodegraded degradable organic carbon (DOC_f), CH_4 generation rate constant (k) for each waste type which are applied specifically to the waste composition of Bangkok. The parameters used in the calculation are shown in Table 1.

For the estimation of GHG arising from disposal of PPE waste in landfills, only paper fraction of those waste was considered to be degradable. The weight of paper in the face masks and ATK materials were estimated based on information provided in their material safety data sheet of a representative commercial product [16].

2) Composting of organic waste mainly food and yard waste. CH_4 and nitrous oxide (N_2O) are considered GHGs in this activity. In the calculation, activity data was the amount of waste (food and yard waste components) treated in compost plant whereas IPCC default CH_4 and N_2O emission factors (4 gCH_4 and 0.3 gN_2O per kg wet waste treated) were used.

3) Incineration of general and infectious waste. containing fossil carbon, mainly plastics, are contributing carbon dioxide (CO_2) emissions. N_2O emissions are also considered in this activity. The estimation of emissions was determined using actual activity data in terms of amount of general and infectious waste incinerated, fossil carbon (plastic) composition (13.33-18.86%) in MSW. The IPCC default emission factors in terms of total (60%) and fossil carbon (40%) content in clinical waste and oxidation factor (100%) for continuous feed stoker type incinerator were applied.

Upon the estimation of GHGs including CO_2, CH_4, and N_2O, overall GHG emissions were determined by converting them into CO_2 equivalent unit (CO_2-eq) using global warming potential of 25 for CH_4 and 298 for N_2O respectively [17].

Results and Discussion

MSW and infectious waste quantity

Table 2 presents the total amount of general waste received at all 3 transfer stations, infectious waste treated in infectious waste incinerator and estimated amount of single-use personal protective materials in Bangkok Metropolitan. The quantities of general waste received were relatively stable between 3.42-3.71 million tons during 2015-2019 (pre-COVID-19 period) while they were reduced to 2.44-2.86 million tons during 2020-2022 (pandemic period) with a decreasing trend observed within this period. On average, the waste amount generated during pandemic period was reduced by 24% from that during pre-COVID19 period. This reduction in waste generation could be mainly due to the effect of pandemic situation on socio-economic activity and the restrictions imposed on society [18]. Moreover, there were relocations of manpower from Bangkok to other provinces due to the shutdown of several commercial activities especially in construction sector in Bangkok. According to statistics from Ministry of Labor, an increase of unemployment rate in April and October 2020 increased by 24% and 181% from the previous year [19]. Fan et al [20] also reported a decrease of waste quantity of 23% in Shanghai, China during the pandemic. Meanwhile, the amount of MSW treated by composting and incineration were varied between 0.25-0.59 and 0.13-0.18 million tons respectively. During COVID-19 pandemic, the amount of waste sent to composting and incineration plants remained relatively constant.

Table 1 Parameters used for calculation of GHG emission from landfill disposal of Bangkok waste

Parameters	Food waste	Paper	Textile	Yard
Composition in Bangkok waste (%)	43.35-52.96	7.11-11.31	2.33-5.61	4.79-6.13
DOC	0.15	0.4	0.24	0.43
DOC_f	0.7	0.5	0.5	0.1
k (1/year)	0.4	0.07	0.07	0.035
Half-life time ($t_{1/2}$, year)	1.733	9.902	9.902	19.804
Lag time in deposit year (M, months)	7	7	7	7
Methane fraction in landfill gas (F)	0.5	0.5	0.5	0.5
Methane correction factor (MCF)	1.0	1.0	1.0	1.0

Table 2 Amount of waste disposed during 2015-2022

Year	Total MSW (tons)	Composting (tons)	Incineration (tons)	Infectious waste incinerated (tons)	Estimated PPE waste* (tons)
2015	3,710,841	397,310	-	12,369	-
2016	3,347,999	591,665	129,249	13,586	-
2017	3,535,543	584,000	169,717	14,176	-
2018	3,676,533	246,141	176,188	14,917	-
2019	3,422,933	424,022	161,318	15,729	-
2020	2,856,431	559,663	168,730	16,329	496
2021	2,736,299	490.329	164,052	23,509	3,664
2022	2,444,475	553,086	161,454	23,411	6,784

* The face mask/ATK waste was collected and disposed together with general waste

For infectious waste, the waste amount sent to infectious waste incinerator was slightly increasing during 2015-2019 from 12.4-15.7 thousand tons but rising to more than 23 thousand tons in 2021-2022 or 65% increase from those during pre-COVID-19 period. This observation is corresponding to significant numbers of COVID-19 patients hospitalized in Bangkok as reported by Ministry of Public Health at 466,380 in 2021 and 515,987 in 2022 respectively [21]. The disposal of PPE waste started in 2020 at limited quantity due to governmental travel restriction regulation enforced in March. As a results, majority (85%) of Bangkok people stayed at home. Their estimated amount increased to 3.6 tons in 2021 and 6.8 tons in 2022 as the situation resumed back to normal assuming a linear trend. An increase in PPE waste between 2021 and 2022 was also resulted from more frequent uses of ATK from once to 3 times every 14 days. It should be noted that these wastes were generally disposal together with general waste therefore their quantities were already included in total MSW amount presented in Table 2.

GHG emissions from waste management

Table 3 shows estimated GHG emissions from waste disposal of Bangkok during 2015-2022. The GHG emissions of came from 3 distinct methods: landfill, incineration, and composting. The emissions were varied depending on total amount of waste disposed, material composition of waste disposed and percentages of solid waste by each method. During pre-COVID-19 period, there was a gradual increase in GHG emissions during 2015-2018 followed by its slight drop in 2019 due to decrease of waste disposal quantity. Average emission was estimated at 1147.98 $GgCO_2$-eq/year during this pre-COVID19 pandemic period. During 2020-2022, the emissions were gradually decreasing following reducing solid waste amount disposed with an average of 996.68 $GgCO_2$-eq/year or 13% reduction.

Table 3 GHG emissions from waste management in Bangkok during 2015-2022

Year	Composting		Incineration*			Landfill	Total
	CH_4	N_2O	CO_2	CH_4	N_2O	CH_4	$(GgCO_{2eq})$
2015	39.73	35.51	-	-	-	933.68	1068.93
2016	59.16	52.89	67.35	0.00055	1.61	936.79	1117.8
2017	58.40	52.21	65.87	0.00077	2.18	982.56	1161.22
2018	24.61	22.01	74.29	0.00080	2.27	1094.39	1217.57
2019	42.40	37.91	86.40	0.00071	2.14	1005.54	1174.39
2020	55.97	50.03	79.05	0.00073	2.16	861.23	1048.45
2021	49.03	43.84	90.44	0.00076	2.17	809.79	995.27
2022	55.31	49.45	84.66	0.00075	2.16	754.73	946.31

* Incinerator started its operation in March 2016

Among the emissions from different methods, CH_4 emissions from landfills represent the most predominant contributing activities. Generally, it accounted for more than 80% in the total emissions. The CH_4 emissions from landfills averaged at 990.59 $GgCO_2$-eq/year during pre-COVID-19 period and gradually decreased to 861.23, 809.78, and 754.73 $GgCO_2$-eq in 2020-2022, respectively. Meanwhile, GHG emissions from composting and incineration of general wastes were maintained relatively constant between the pre-COVID-19 and pandemic period. Among them, CO_2 emissions from fossil carbon incineration, CH_4 and N_2O emissions from waste composting were the following GHGs contributing activities in that order.

Fig.1 presents estimated GHG emission from infectious waste incineration. During pre-COVID-19 period, the emissions gradually increased from 5.42 $GgCO_2$eq in 2015 to 7.25 $GgCO_2$eq in 2019. The increasing trend continued during COVID-19 pandemic period during which significant increase observed in 2021. The emissions from infectious waste incineration accounted for about 5-7% of the emissions from municipal solid waste disposal during pre-pandemic period and increased to about 10% during pandemic period.

The estimated GHG emissions from land disposal of PPE waste suggested its increase from 0.0003 $GgCO_2$eq in 2020 to 0.043 and 0.0171 $GgCO_2$eq in 2021 and 2022, respectively. At most, the emissions from this waste category accounted for only 0.002% of the total emission from MSW disposal in 2022. The main reason was comparatively very small quantity of PPE wastes were generated comparing to MSW. Moreover, only paper component in face masks and ATK waste was considered biodegradable in landfills. Major fraction of the mass in those wastes was composed of plastic component which is not biodegraded in landfills.

Considering total GHG emissions from MSW and infectious waste disposal in Bangkok Metropolitan, there was an increasing trend of GHG emissions from waste disposal from 1,074.36 $GgCO_2$-eq in 2015 to 1,224.11 $GgCO_2$-eq in 2018 However, the emission was slightly dropped to 1,181.64 $GgCO_2$-eq in 2019. During the pandemic period (2020-2022), there was a continuous decreasing trend in total GHG emissions. In 2022, total emission was 957.12 $GgCO_2$-eq, reduced by 22% from that in 2018.

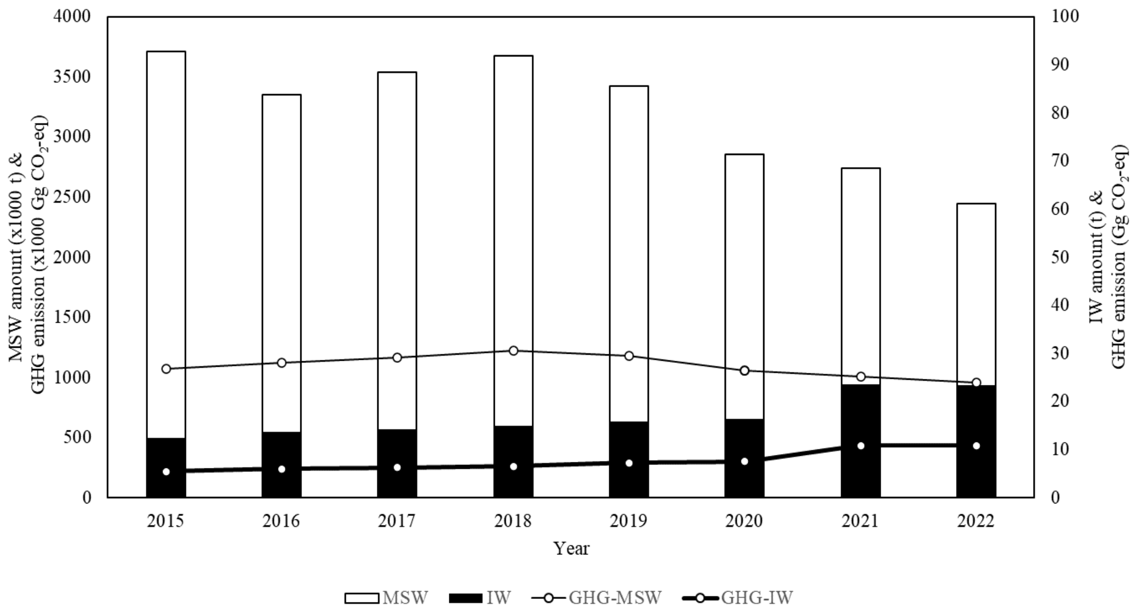

Fig. 1 Variation of amount and GHG from MSW and infectious waste in Bangkok

Conclusions

This study provides a better understanding on the effect of COVID-19 pandemic to waste generation and GHG emissions from waste management in Bangkok Metropolitan. During pre-COVID-19 period (2015-2019), total emissions from general waste management ranged from 1,068.93 to 1,217.57 $GgCO_2$-eq. The emissions gradually declined to 957.12 $GgCO_2$-eq in 2022 mainly due to decreasing amount of waste generated from the effect of changing waste producing behavior of people during the pandemic period. Despite having 35% increase from infectious waste incineration and production of single-use personal protective waste during the pandemic period, total GHG emissions from waste management was reduced up to 22% from the pre-COVID-19 period.

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Evaluation of Green Roof Performance in Slowing Down Stormwater Runoff in Urban Catchment, The Case of Samut Prakan, Thailand

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Abstract

Urbanization implies a reduction of vegetation leading to an increase of bare lands coverage and the expansion of impervious surfaces. Such circumstances are significantly influence the hydrological cycle, reduce evapotranspiration losses, and accumulate surface runoff, raising the risk of floods, particularly in rapidly developing urban areas. Green roofs are considered as one of the most suitable Green Infrastructure (GI) for densely urbanized areas because they can incorporate into new construction or added to existing buildings during renovation or reroofing without further land consumption. This study aims to evaluate the effectiveness of green roofs in helping to slow down water runoff in response to flood risks in Samut Prakan municipal area. The hydrological model EPASWMM 5.1 was created with rain estimated based on historical data and the green roof installation scenarios. 12 green roof scenarios, consisting of 4 main scenarios, are categorized based on the rainfall events (average extreme rainfall, 10-year return period, 20-year return period, 50-year return period). The simulation results show that green roofs significantly reduce surface runoff and peak flow. Specifically, extensive green roofs in Samut Prakan achieved runoff reduction rates of 14.6% to 54.51%, and peak flow reduction rates of 7.43% to 19.6%. Considering the runoff reduction rate, green roof can provide more hydrological benefit than that of traditional storm management system. While the performance of green roofs in tropical climates may be less effective compared to those in arid and temperate zones, the results of this study are consistent with previous research and provide valuable insights for optimizing green roof design and implementation in tropical country as Thailand.

Keywords : green roof; stormwater; urban flooding; SWMM

Introduction

Severe consequences and threats that cities are now facing as a result of climate change, posing a great risk to human life and entire urban systems. Rising global average temperature is associated with widespread changes in weather patterns. Extreme weather events such as sea level rise, heat wave and large storms are likely to become more frequent or more intense. In conjunction with urbanization, population increase, centralization, and high-density development, floods continue to be a biggest concern. Urbanization implies a reduction of vegetation leading to an increase of bare lands coverage and the expansion of impervious surfaces. Such circumstances are significantly influence the hydrological cycle, reduce evapotranspiration losses, and accumulate surface runoff, raising the risk of floods, particularly in rapidly developing urban areas [1, 2]. To alleviate damage and disruption, most cities must, therefore, manage surface water runoff in urban areas to minimize a population's exposure to flooding hazards. Traditionally, stormwater management approaches towards flood risk management have focused on capturing and conveying runoff within piped systems [3, 4]. However, in most cases such strategies have been constrained by the expense and complexities of expanding subterranean infrastructure, the high cost of infrastructure maintenance and the pressure to adopt sustainable stormwater management practices.

This situation has resulted in increasing interest in the use of alternate interventions, such as green infrastructure (GI), a generic term for drainage interventions by mimicking natural hydrologic processes through different techniques depending on urban context (4).

Although the maintenance of green areas and recovery or restoration of degraded vegetation areas is one of the best options to manage storm water runoff in an environmentally sound, these types of GI are limited by urban space availability. In this way, the adoption of green roofs is postulated as an alternative to deal with this problem [5, 6]. Green roofs (GR) are considered as one of the most suitable GI for densely urbanized areas because they can incorporate into new construction or added to existing buildings during renovation or reroofing without further land consumption. Previous studies have revealed that adoption of GR can be effective at reducing stormwater runoff and flooding in urban area [7-9]. According to its performance, the adoption of green roofs is increasing in popularity and has attracted the attention of many researchers. However, the majority of the research on green roofs has been concentrated in two main climatic groups, the temperate and continental, only a few studies were found to be conducted for tropical climatic zones [10, 11]. While there is an urgent need for the prioritization of urban flood risk management particularly in tropical regions, such as Thailand, there remain many potential barriers for the adoption of GR and other low impact development technologies (LIDs). Some of the most important factors that prevent the widespread adoption of GR in Thailand are the lack of scientific data and design guidelines to support the implementation. Summarizing the studies GR applications for managing urban stormwater in different climatic zones, Akther, M. et. al., (2018) concluded that the means and medians of the stormwater retention rate are between 56.04% - 78.10%. The medians of the stormwater retention rate among the climatic groups, tropical, dry arid and semi-arid, temperate, continental, and polar were statistically significantly different [12]. With a different climatic condition from those on the temperate zone, adaptation of GR in tropical regions requires relevant and reliable research to measure the application of GR in local conditions as well as how to adapt the design to the climatic features [13, 14].

In this regard, this study aims to evaluate the effectiveness of green roofs in helping to slow down water runoff in response to flood risks in Samut Prakan municipal area. The hydrological model EPASWMM 5.1 was created with rain estimated based on historical data and the green roof installation scenarios. The outputs from this research identify reasonable GR strategies that could be implemented within the study area. Indeed, the research explore how green roof intervention can be implemented to manage flooding across a range of rainfall events.

Methodology

Study area

Samut Prakan City Municipality located in a low-lying area of Pak Nam Subdistrict, of Samut Prakan Province. The study area is approximately 7.33 square kilometer with average annual rainfall of 1,100 - 1,500 mm. Located at the mouth of the Chao Phraya river, the municipality surrounds by many streams and canals, and has been recognized as a flood prone area due to its annual flooding and geography. Being the administrative, economic and transportation centers of the Samut Prakan, Pak Nam Subdistrict has experienced rapid urbanization, which has led to considerable increases in both population and building density. The high proportion of impervious surfaces, combing with extreme rainfall and its geographic factors significantly increases the risk of floods in the municipal area.

The land use density in Samut Prakan Municipality is concentrated along the Chao Phraya River and main roads. The increase in buildings is mostly for residential and commercial purposes. As illustrated in Table 1, land uses are classified into four categories: roofs, other impervious surfaces, roads and streams. The analysis of land use data reveals that 86.53% of Samut Prakan municipality is covered with impervious surfaces which are 28.19% roofs and 58.33% other impervious surfaces. For pervious surfaces, the total area was 13.48% divided into green area (5.85%) and streams (7.64%).

Table 1 Land use characteristics of study area

Land use	Area	
	sqkm.	%
Roofs	2.07	28.19
Other impervious surfaces	4.28	58.33
Total impervious surfaces	**6.35**	**86.52**
Green area	0.43	5.85
Streams	0.56	7.64
Total pervious surfaces	**0.99**	**13.48**
Total areas	7.33	100

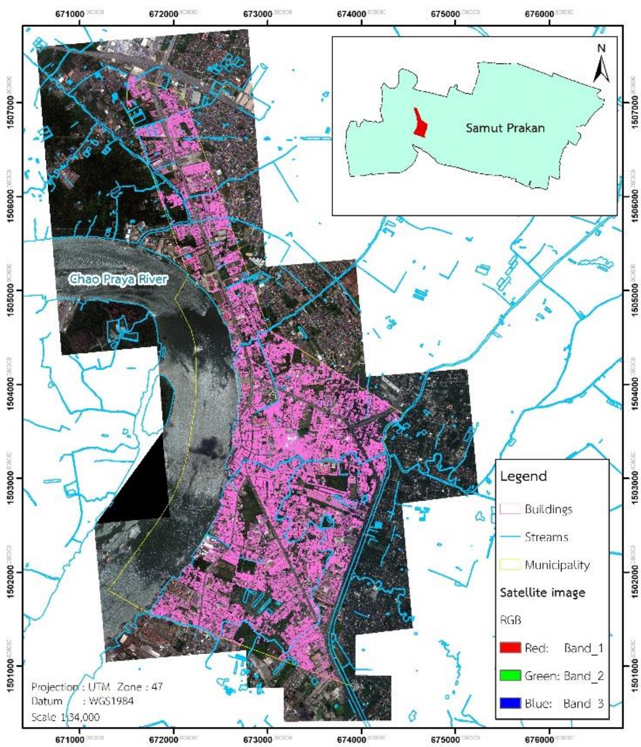

Figure 1 Map showing digital image, buildings and streams of Samut Prakan municipality.

Data uses

In order to achieve the research objectives, the study area was divided into 48 sub-catchments (Fig.2) according to Digital Elevation Model (DEM), the rainwater pipe network and land use. Geographic information system (GIS) was applied to analyze water flow direction and slope. The flow direction was verified by Samut Prakan municipality and fields measurements. Rainfall data from the Meteorological Department and the Bangkok Drainage Department were used to analyze the 10-year, 20-year and 50-year cycles of rainfall recurrence using Gumbel's method. Rooftop attributes were collected from Samut Prakan Office of Public Works and Town & Country Planning, and categorized by observed aerial photos and field study. Conduit data, such as length, diameter, and type of conduits, were suggested by Samut Prakan municipality. Parameters in SWMM's LID control (Table 2), consisting of surface layers, soil layers, and drainage mat, were estimated from SWMM user manuals [16] and Ekmekcioğlu, et. al.,

(2021) [3]. The Green-Ampt method is used to estimate infiltration losses. The dynamic wave theory is used for flow routing computation and Manning's equation is applied to calculate runoff [17]. The capacity of a sub-catchment and its flow coefficient were determined by the land cover of each sub-catchment. Overland flow will pass through the outlet, and the model's validation was simulated by comparing it to observed data obtained from the floodgate within the study area.

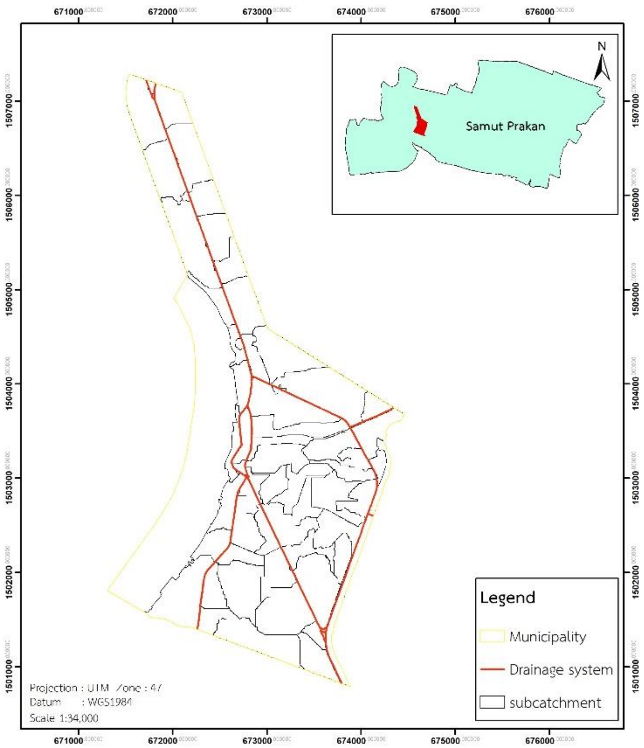

Figure 2 Subcatchment of study area generated by DEM, rain water pipe network and land use

Table 2 Parameters of LID control

Layer	Data	Value
Surface	Berm Height (mm)	300
	Vegetation Volume Fraction	0.1
	Surface Roughness (Manning's n)	0.24
	Surface Slope (%)	2
Soil	Thickness (mm)	150
	Porosity	0.463
	Field Capacity	0.232
	Wilting Point	0.116
	Conductivity (mm/hr)	3.302
	Conductivity Slope	60
	Suction Head (mm)	134.62
Drainage Mat	Thickness (mm)	75
	Void Fraction	0.5
	Roughness (Manning's n)	0.1

Data source: Rossman, L.A. (2015); Ekmekcioğlu, et. al. (2021); Liu, et. al. (2020).

SWMM model

In this study, the effectiveness of the green roof was evaluated through mathematical model EPASWMM 5.1. The EPA Storm Water Management model (SWMM) is a dynamic rainfall-runoff-routing simulation used to simulate both single-event and continuous rainfall-runoff quantities and quality from primarily urban areas [16]. The water component of the SWMM works by calculating the amount of rainfall in the sub-catchment and then transforming it into runoff. The Low Impact Development (LID) is a stormwater management approach that uses plants, soil, and natural processes to manage runoff. This approach involves creating areas that absorb, slow down, or store rainwater to alleviate the problems of flash flooding or standing water in urban areas with impervious surfaces.

There are 12 scenarios, consisting of 4 main scenarios that are categorized based on the rainfall events (average extreme rainfall, 10-year return period, 20-year return period, 50-year return period). Each scenario was further divides into three cases based on the percentage of green roof area: (1) 0% green roof and (2) 50% green roof and (3) 100% green roof. The reference scenario assumed no green roof. Green roof can be assigned in LID control modules within selected sub-catchment by defining the corresponding area coverage. The conversion green roof response is analyzed by runoff volume reduction and peak flow reduction which is calculated with the relative percentage different between outflow and the conversion in green roof and rainfall event.

Results and Discussions

The runoff reduction of green roof was simulated under three difference green roof coverages (0% GR 50%GR, 100%GR) and four different return period of rainfall (average extreme rainfall, 10-year, 20-year, 50-year rainfall events). The results indicated that green roofs significantly reduce surface runoff and peak flow. Table 3 shows the runoff reduction rate of different green roof coverages in various rainfall events. In extreme rainfall, a 50% GR can reduce rainfall runoff 14.6% and 21.71% for a 100% GR. For different rainfall return period, runoff reduction increased with an increasing rainfall period and green roof coverage. The runoff reduction rate increased from 18.40% to 27.01% in 10-year rainfall event, compared to a 50-year rainfall event after replacing 50% green roof coverage. For replacing with a 100% green roof coverage, runoff reduction rate is 37.18%, 44.22%, and 54.51% in 10-year, 20-year, and 50-year of rainfall events, respectively.

The results demonstrate that extensive green roofs in Samut Prakan achieved runoff reduction rates ranging from 14.6% to 54.51%. This finding suggests that green roofs in urban settings can reduce peak discharge. However, compared to other studies conducted in tropical climates, the extensive green roof system in this study seems to be less effective at reducing peak flow. For example, Sim., et. al. (2016) found a significant difference in the average runoff retention between extensive green roofs in semi-arid climates (75.2%) and maritime climates (43.4%) [18]. Mentens., et al. (2006) found that green roofs can provide a peak reduction of almost 50% [19]. Kasmin., et. al. (2014) reported that a similarly configured green roof in a Malaysian climate could reduce runoff by 84% [20]. Liu and Chui (2019) reported that, in the case of Sydney, green roofs can reduce peak runoff by 45-55% for different return periods [21]. Overall, the results of this study are consistent with previous researches in that the performance of green roofs in tropical climates is less effectively compared to those in arid and temperate zones.

In addition, there appears to be only a slight change in the runoff coefficient of the green roof as the rainfall intensity increases. As the rainfall return period increases from 10 to 50 years, the runoff coefficient of a 50% green roof increases from 82.55% to 83.98%, and from 67.11% to 68.47% for a 100% green roof. This change is consistent with previous research findings. Liu., et. al. (2020) found that the green roof retention capacity decreased as the precipitation intensity increased. Specifically, the runoff coefficient increasing from 57.41% to 72.19% when the precipitation intensity changed from a 2-year storm to a 100-year storm [22]. However, the slight change observed in this study, compared to Liu., et.al.(2020), could be due to the differences in characteristics of the simulation parameters that are partly influence by local conditions such as slope, green roof ratio, and rainfall intensity.

Table 3 Runoff reduction rate (%)

Green roof coverage	Runoff reduction rate (%)			
	Extreme Rainfall	Return period (Year)		
		10	20	50
Green roof 0%	-	-	-	-
Green roofs 50%	14.60	18.40	21.91	27.01
Green roofs 100%	31.71	37.18	44.22	54.51

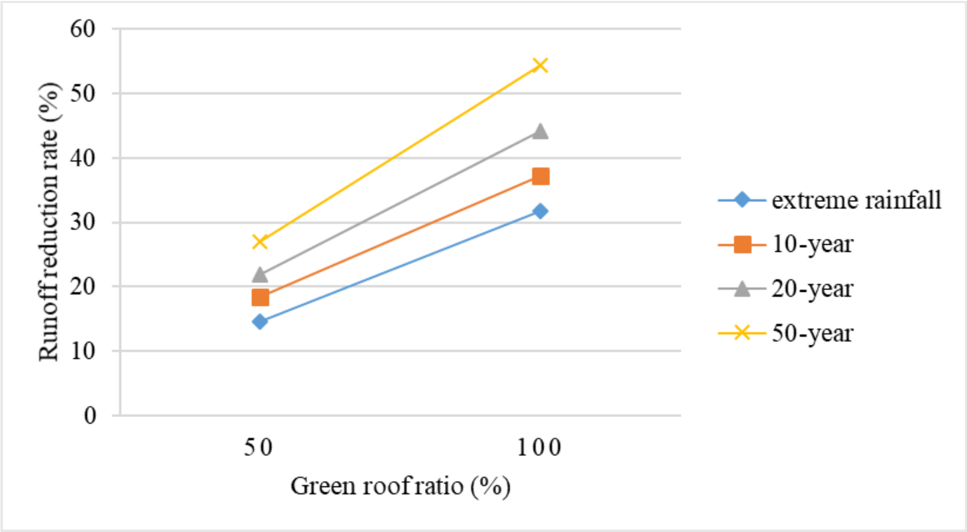

Figure 3 The impact of rainfall return period and green roof ratio on runoff reduction rate

Figure 4 shows the specific changes in runoff depth and runoff volume reduction. Under the same rainfall event, runoff depth decreased when green roof coverage area increased while runoff volume reduction increased when green roof increased. For the same green roof ratio, runoff depth and runoff volume reduction increased when rainfall increased. The correlation between runoff reduction and green roof ratio tends to be linear. The more green roof coverage ratio, the more reduction rate.

The results indicate that as rainfall return periods increased, the average runoff and runoff reduction also increased. However, the rate of average runoff reduction for the same green roof ratio decreased at different rainfall return periods. Though some previous research suggests that runoff reduction decreases with increasing rainfall return periods, this is not always the case. For instance, Liu and Chui (2019) found that the amount of annual average runoff dramatically increased through the increasing rainfall recurrence interval for a certain period of time [20]. This can be attributed to the fact that in this case, green roofs have sufficient capacity to hold rainwater even during peak precipitation, particularly for small return period [21]. Indeed, runoff reduction is site-specific and greatly influenced by several factors particularly, rainfall characteristics and soil storage [3].

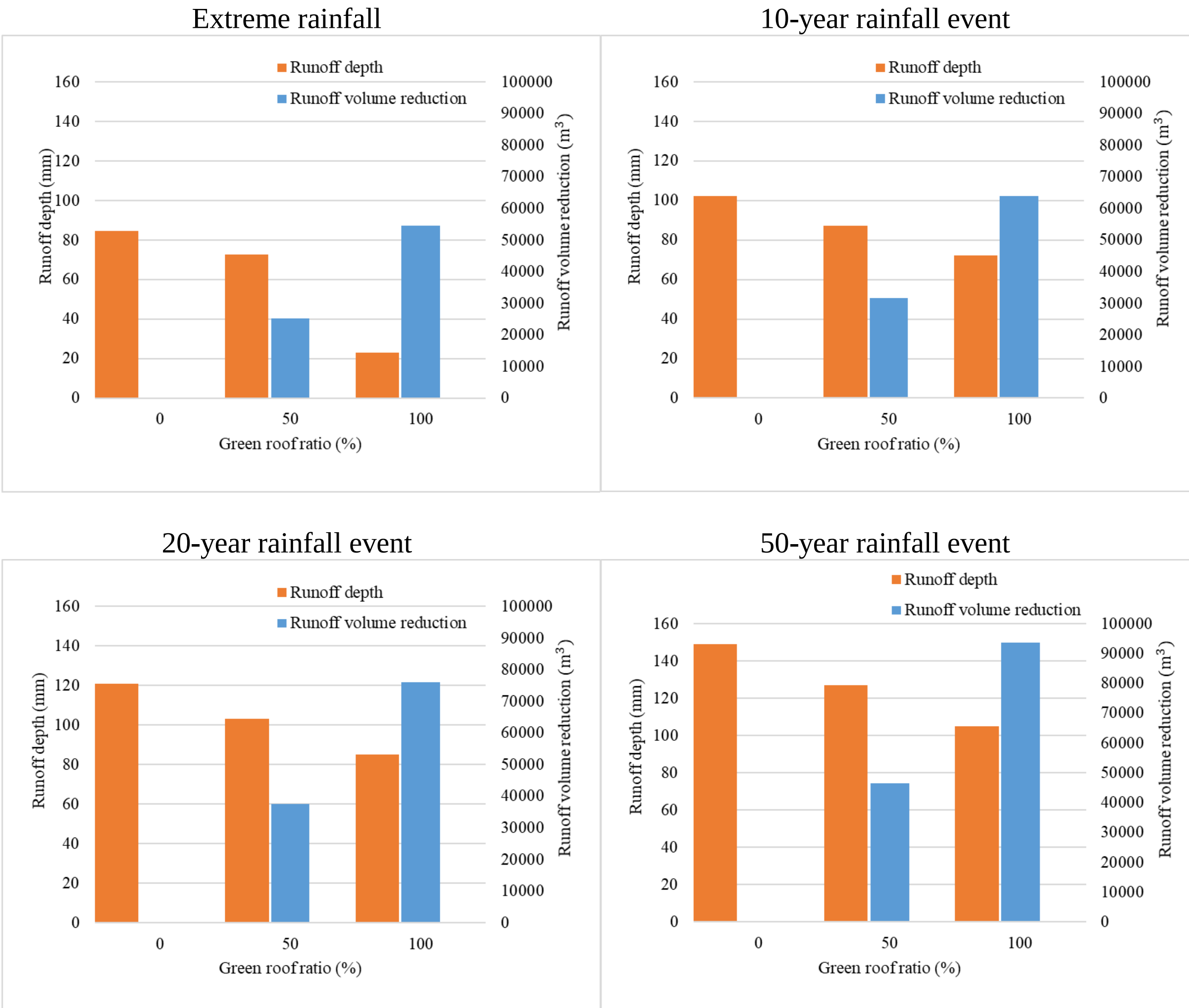

Figure 4 Variation of runoff depth and runoff volume reduction

Figure 5 and 6 shows the changes in peak flow and peak flow reduction rate during the different rainfall event and green roof ratio. Under the same rainfall scenario, peak flow decreased with increasing green roof while peak flow reduction rate increased with increasing green roof. It can be demonstrated that the increasing in area of green roof can reduce more peak flow. For the different rainfall, the peak flow increased with increasing of rainfall and the peak flow reduction decreased with increasing of rainfall. The peak flow of a 20-year rainfall event is 11.08 cms, which is an increase from 10.02 cms for a 10-year rainfall event. The peak flow of a 50-year rainfall event increased further to 16.28 cms. Notably, the increase in peak flow between the 10-year and 20-year rainfall events was smaller than the increase observed during the 50-year rainfall event. This may suggest that the green roof is approaching its capacity, although this can depend on the specific design and capacity of the green roof.

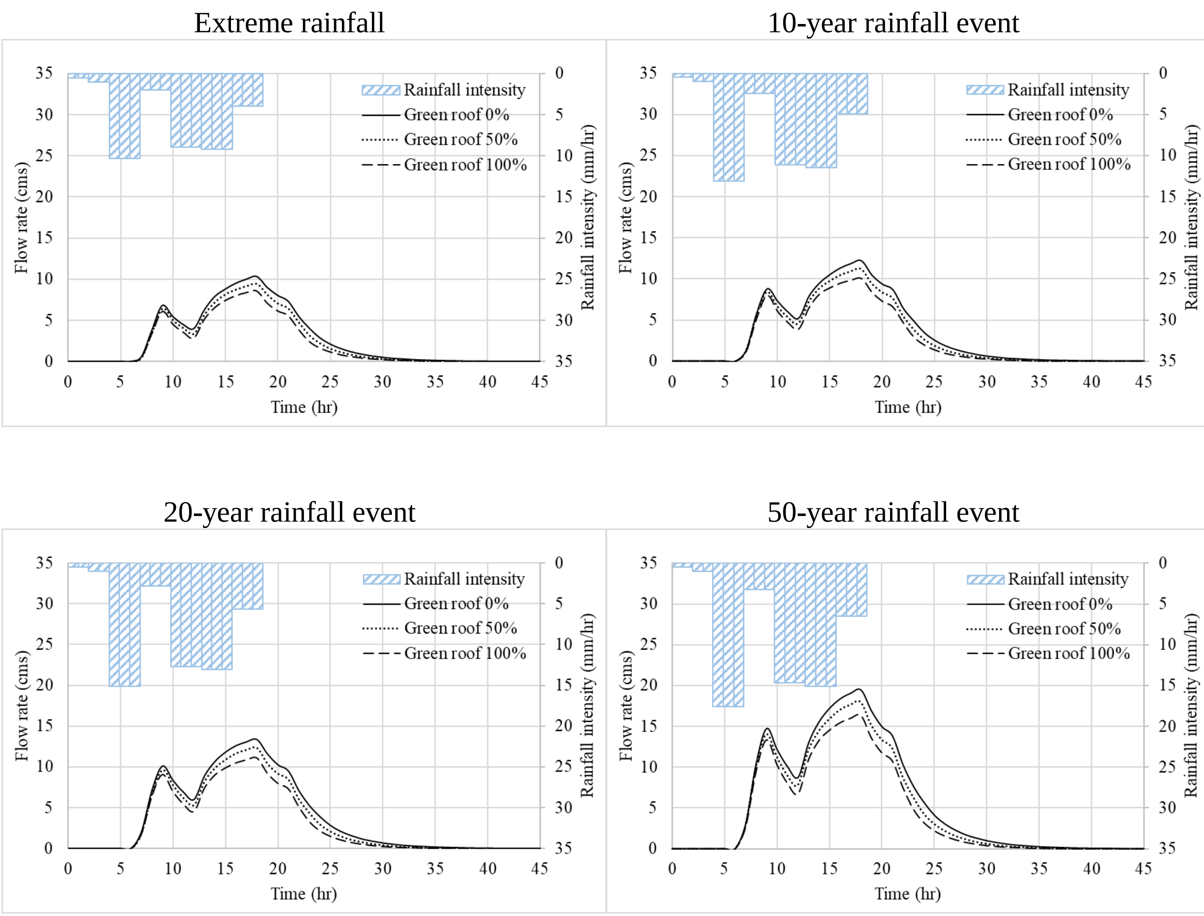

Figure 5 The hydrographs simulated based on the percentage of green roof area at assigned rainfall event return period (Extreme rainfall, 10-year, 20-year, and 50-year return period)

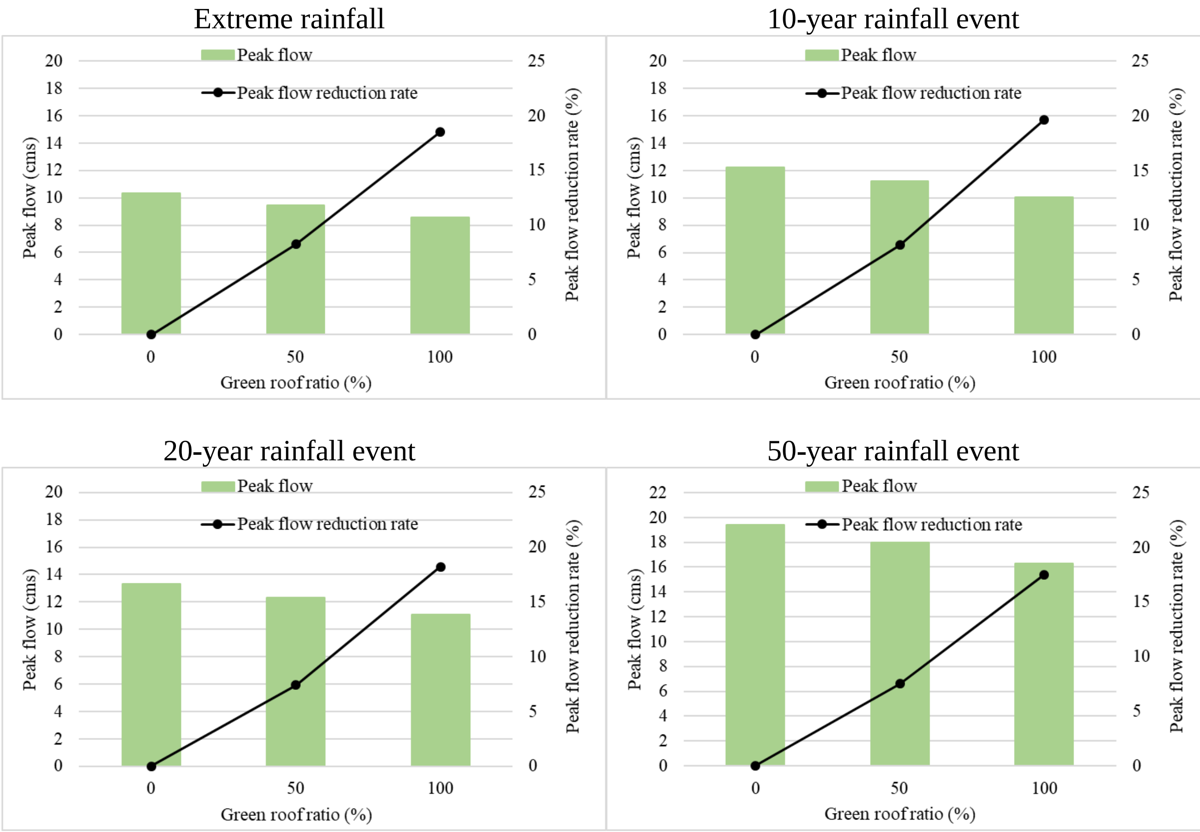

Figure 6 Variation of peak flow and peak flow reduction rate

Conclusion

This study aims to evaluate the effectiveness of green roofs in helping to slow down water runoff in response to flood risks in Samut Prakan municipal area. SWMM were used to investigate the efficiency of green roof. The study area was divided into 48 sub-catchments based on GIS data and analyzed using rainfall event data and changes in green roof area. The rainfall event used average extreme rainfall, 10-year, 20-year, and 50-year return period. The green roof coverage area ratio was varied from 0% to 50% to 100%. The impact of green roof on the runoff reduction shows that the runoff volume reduction was increased while the runoff depth decreased under different condition. For the peak flow and peak flow reduction, the peak flow was decreased and the peak flow reduction rate was increased when increasing the green roof coverage. In addition, the runoff coefficient slightly changes when rainfall intensity increases. The results suggest that an increase in green roof coverage is associated with a reduction in runoff and peak flow. This widens the range of available solutions for managing floods and mitigates the constraints of traditional structural stormwater management systems. It provides important knowledge for considering flood management policies and implementing measures for building construction and land development in the future.

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Microbial Contamination of Groundwater in Rural Area of Sittwe District, Rakhine State, Myanmar

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Abstract

Rakhine state has high rates of open defecation compared to other parts of Myanmar. In the rural area of the Sittwe district, pit latrines were constructed near water sources such as boreholes, wells, lakes, creeks, and rivers. The discharge of chemical and microbial contaminants from pit latrines to groundwater may have a negative impact on human health and drainage and solid waste disposal are major challenges in both urban and rural areas. Open defecation, lack of waste management disposal, and construction of pit latrines near water sources lead to fecal contamination or pollution of the groundwater table. Groundwater samples in rural areas of Sittwe district, Rakhine State, Myanmar were characterized microbiological properties of groundwater. For microbiological analysis, water samples were analyzed for qualitative analysis of total coliform and quantitative analysis of fecal coliform (*Escherichia coli*; *E. coli.*) by membrane filtration technique (MFT) to determine the safety aspect of the utilization of groundwater as a source of drinking purpose. Almost all the indicator organisms' counts in collected samples were above WHO guidelines for drinking water quality and Myanmar national drinking water quality standard (MNDWQS). The presence of fecal coliform bacteria indicates that the water is contaminated with fecal waste from human or warm-blooded animals and the presence of total coliform indicates that the groundwater is contaminated with both fecal waste and other coliform species from the environment. Safe drinking water, adequate sanitation, and hygiene are crucial to prevent microbiological contamination of drinking water which can produce diseases such as diarrhea. Reduction of open defecation, construction of systematic latrines, proper waste disposal, and management can protect the groundwater pollution and increase the quality of drinking water.

Keywords : Groundwater Pollution; *Escherichia coli*; Drinking Water; Risk Assessment

Introduction

According to a WHO report, more than two billion people are living with water stress. Around two billion people worldwide are drinking water sources polluted with fecal matter. Microbial contamination of drinking water as a result of contamination with feces poses the greatest risk to drinking water safety [1]. *Escherichia coli* (*E. coli.*) are commonly found in the large intestine of humans and warm-blooded animals [2]. Most strains of *E. coli.* are harmless and can cause severe foodborne illness due to the production of Shiga toxin produced by *E. coli.* (STEC). Human transmission of *E. coli.* O157:H7 occurs by contaminated foods, water, and direct contact with the infected person or animal [3]. Abdominal cramps and diarrhea are the symptoms of the diseases caused by STEC that may in some cases progress to bloody diarrhea (hemorrhagic colitis). It may also cause fever and vomiting [4].

Diarrhea, cholera, dysentery, typhoid, and polio can be transmitted through microbiologically contaminated drinking water and are estimated to cause 485,000 diarrheal deaths each year [1]. Diarrheal disease is the second leading cause of death in children under five years old, and around 525,000 children are killed by diarrheal diseases every year. Safe drinking water, appropriate hygiene, and sanitation can significantly reduce the incidence of diarrheal disease. Globally, there are approximately 1.7 billion cases of childhood diarrheal disease every year [5]. In 2020, over 1.7 billion people still do not have basic sanitation services, such as private toilets or latrines. The remaining 494 million are still flushing in open areas such as street gutters or surface water bodies [6]. In 2020, WHO estimated that 74% of the world's population, 5.8 billion people, would use a safe and reliable water supply free from contamination. However, diarrhea remains a major killer but is largely preventable. Each year, 297,000 children aged less than five years could be prevented from dying through improved water, sanitation, and hygiene [1]. The first large-scale review of the safety of drinking water through fecal contamination testing will be carried out in the 2019 intercensal survey. Rakhine and Ayeyarwady are particularly vulnerable and in need of help due to their high dependency on surface water, as well as the impact of climate change [7]. Almost 18% of deaths among children under five in Myanmar are due to diarrhea each year [8].

Since the turn of the 20th century, when there was a long period of stagnant development in Rakhine state, it has been plagued by communal problems which have left its inhabitants desperately short of basic needs. This regrettable situation was compounded from 2012 to 2014 when violent communal riots between members of the Muslim and Rakhine communities erupted in various parts of the state [9]. The tensions that flared in June and October of 2012 resulted in widespread displacement and camp settlement; the loss of housing, and psycho-social trauma that impacted both community and family-level traditional support mechanisms as well as individual mental health [10]. In Rakhine State, the coverage for water and sanitation facilities stands at 75 percent and 58 percent respectively, while 99 percent of the camps are administered by WASH focal agencies [11].

Sittwe is one of the 17 townships of the Rakhine state, which is the most western of Myanmar's States and Regions. It is the second most populous state with around 3.2 million [12]. According to the Myanmar Census, there are approximately 83% of the rural population and 17% of the urban population in Rakhine State [13]. World Bank stated that Rakhine State has the highest level of poverty in all States and Regions [9]. The main challenges faced by the state of Rakhine in its social development are poor infrastructure, particularly road infrastructure, insufficient connectivity with other parts of Myanmar, energy shortages, and lack of communication facilities [12].

Rakhine state is high levels of open defecation due to a combination of factors. Households have very limited spare funds for the construction of latrines in households. Furthermore, low-lying paddy fields divided by a maze of streams and channels make up a large part of the populated area. This leads to a great many opportunities for open defecation without consequence on bodies of water [14]. The use of unprotected groundwater aquifers, which do not contain any water purification or disinfection measures for drinking purposes, is a major public health concern [15]. A variety of pathogenic microbes, such as bacteria and viruses, may be present in solid waste contamination with human and liquid excreta, which is usually disposed of in landfills, open dumping sites, and near unlined disposal sites. In the groundwater aquifer, harmful chemicals, nutrients, and pathogenic bacteria are being released as well as polluting an ecosystem of water [16]. Discharges from sewage works and runoff from informal settlements are major factors affecting the microbiological quality of groundwater [17]. In low-income countries, contamination of drinking water is a significant burden on their health caused by waterborne diseases such as diarrhea. The presence of fecal indicator bacteria, Escherichia coli, or thermotolerant coliform, is recommended for the WHO to assess fecal contamination [18].

In the area of Rakhine State, drainage, and solid waste disposal are major challenges in both urban and rural areas [19]. A high risk for diarrheal and other infectious disease outbreaks due to insufficient WASH facilities, which are exacerbated by rains and waterlogging. According to WHO reports, Rakhine state has regularly reported cases of severe acute watery diarrhea for the past 5 years [20]. In Rakhine state, five severe cases of diarrhea were reported; 3,345 mild cases and 795 cases in 2014, by the Inter-Cluster Coordination Group for Humanitarian Country Teams [12]. Since 25 April 2021 at Sittwe and Pauktaw camps for internally displaced persons, there has been an increase in cases of acute vomital diarrhea as reported by the early warning alert and response system. More than 2,000 cases have been reported [21]. UNOCHA reported an acute watery diarrhea outbreak in Rakhine State, acute watery diarrhea has been outbroken in conflict areas and IDP camps across Kyauktaw, Pauktaw, and Sittwe Townships. A total of 686 cases have been detected across these three townships, of which 385 cases were in Sittwe camps and most of the reported cases are among children under five years [22].

The purpose of this study was to determine the microbiological properties of groundwater from rural areas of Sittwe district, Rakhine State, Myanmar, and to determine the safety aspects of utilization of groundwater as a source of drinking purpose.

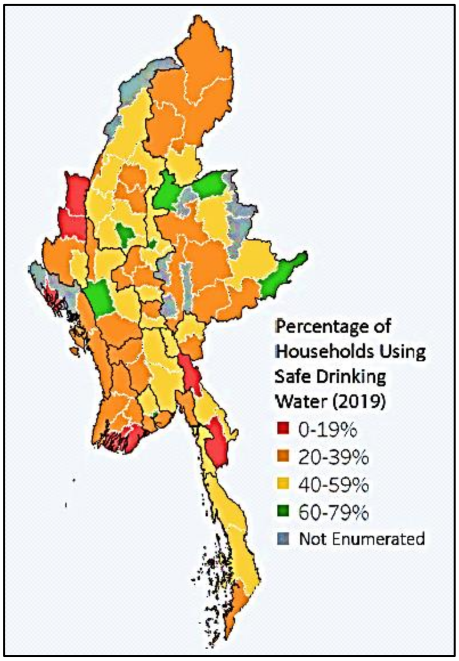

Figure 1 Percentage of Household using Safe Drinking in Myanmar [7]

Materials and Methods

1. Study Area and Collection

Two hundred and three samples of groundwater samples were collected using polyethylene terephthalate (PET) bottles from tube wells located in Ma Gyi Myaing (MGM), Ywar Gyi South (YGS), Ywar Gyi North (YGN), Aung Mingalar (AMGL), Nga Pon Gyi (NPG) and Aung Taing (AT) villages, Sittwe district, Rakhine State, Myanmar. Collected groundwater samples were transported in a cool box to the laboratory and groundwater samples were analyzed within 24 hours.

2. Laboratory Analysis

Total coliform and fecal coliform (*E. coli.*) were determined by Palintest PTW10005 Potates+ Repaid Respond Water Quality Laboratory instrument (Membrane Filtration Technique; MFT) and was approved by USEPA for measuring coliforms. The water sample was filtered through the membrane filter (0.45 µm, 47 mm) using a vacuum to pull the water through a membrane. The membrane filter was placed onto an absorbent pad rich with lauryl sulfate nutrient broth in a petri dish and incubated at 37°C; total coliform (qualitative) and 44°C; fecal coliform (*E. coli.*) for 24 hours. Yellow colonies were enumerated. The measurement was conducted in duplicate and reported the average number. The interpreted results were compared with the WHO Guidelines for Drinking Water Quality [5] and Myanmar National Drinking Water Quality Standard (MNDWQS) [23].

Figure 2 Map of Sittwe District, Rakhine State, Myanmar [24]

Table 1 Composition of Membrane Lauryl Sulfate Broth

Nutrients	Composition (g/L)
Peptic Digest of Animal Tissue	39
Yeast Extract	6
Lactose	30
Sodium Lauryl Sulfate	1
Phenol Red	0.2

*Final pH: 7.4±0.2 at 25°C

Table 2 WHO and Myanmar National Drinking Water Quality Standard

Standard	Total Coliform	*E. coli.*
WHO	Absent	Absent
Myanmar	Absent or 0 MPN/100ml	Absent or 0 MPN/100ml
Emergency Situation*	10 MPN/100ml	3 MPN/100ml

*MNDWQS

Results and Discussion

Large numbers of people use pit latrines, which must be filled rapidly every 3 months without sewage and proper waste disposal in Rakhine state. The relocation of latrines to a number of sites is not feasible due to space constraints, expensive transport costs, and complex logistical arrangements. Around 35% of the population are practicing open defecation in 2012. Rakhine State has high rates of open defecation compared to other parts of Myanmar [19]. According to the survey conducted on 203 households located in the rural area of Sittwe district, the depths of the tube wells were a minimum of 25 ft. to a maximum depth of 40 ft., and pit latrines were constructed near the water sources such as boreholes, wells, lakes, creeks, and river. In low-income countries, pit latrines are one the most common systems for the disposal of human excreta, and the discharge of chemical and microbial contaminants from pit latrines to groundwater may have a negative impact on human health [25]. The distances of boreholes were minutest 5 ft. to a maximum of 100 ft. from latrines. Open defecation, lack of waste management disposal, and construction of pit latrines near water sources lead to fecal contamination or pollution of the groundwater table.

Overall, 44% of collected groundwater samples (90 of 203) were negative and 56% of groundwater samples (113 of 203) were positive for total coliform and *E. coli.* Aung Taing village was found the highest microbial contamination (85%), Ma Gyi Myaing was ranked as the second contaminated area (70%), Nga Pon Gyi, Ywar Gyi South, Ywar Gyi North were third contaminated areas, 66%, 53%, and 40%, respectively. Aung Mingalar was the lowest contaminated area (7%) in Sittwe compared to others and the results were shown in Table 3. The distribution of *E. coli.* concentrations in groundwater samples, according to WHO risk categories [26], were shown in Table 4 and Fig. 3. Of the total number of groundwater samples (203) in MGM (n=30), YGS (n=30), YGN (n=30), AMGL (n=30), NPG (n=44) and AT (n=39); 30%, 47%, 60%, 93%, 34%, and 15% were in compliance with WHO standard (<1 cfu/100ml), 13% 23%, 6%, 7%, 27% and 36% were in low risk level (1-10 cfu/100ml), 47% 13%, 6%, 0%, 32% and 23% were in intermediate level (11-100 cfu/100ml) and 10%, 17% 28%, 0% and 7% were in high-risk level (101-1000 cfu/100ml), respectively. Overall microbiology quality of groundwater samples in the rural area of Sittwe (n=203) were 44% (n=90) in compliance, 20% (n=41) at the low-risk level, 22% (n=43) in the intermediate level, 26% (n=10) in high-risk level, respectively.

Table 3 Total coliform and *E. coli.* contamination of groundwater in rural area of Sittwe

Village	Number of Sample (n)	Total Coliform		*E. coli.*	
		Negative (n, %)	Positive (n, %)	Negative (n, %)	Positive (n, %)
MGM	30	9 (30)	21 (70)	9 (30)	21 (70)
YGS	30	14 (47)	16 (53)	14 (47)	16 (53)
YGN	30	18 (60)	12 (40)	18 (60)	12 (40)
AMGL	30	28 (93)	2 (7)	28 (93)	2 (7)
NPG	44	15 (34)	29 (66)	15 (34)	29 (66)
AT	39	6 (15)	33 (85)	6 (15)	33 (85)
Overall	203	90 (44)	113 (56)	90 (44)	113 (56)

Table 4 Water quality results of groundwater based on WHO classification of health-risk

	Number of *E. coli.* (CFU/100 ml)				
	<1 (Compliance)	1-10 (Low Risk)	11-100 (Intermediate)	101-1000 (High-Risk)	>1000 (Very High-Risk)
	n (%)	n (%)	n (%)	n (%)	n (%)
MGM	9 (30)	4 (13)	14 (47)	3 (10)	0 (0)
YGS	14 (47)	7 (23)	4 (13)	5 (17)	0 (0)
YGN	18 (60)	2 (6)	2 (6)	8 (28)	0 (0)
AMGL	28 (93)	2 (7)	0 (0)	0 (0)	0 (0)
NPG	15 (34)	12 (27)	14 (32)	3 (7)	0 (0)
AT	6 (15)	14 (36)	9 (23)	10 (26)	0 (0)
Overall	90 (44)	41 (20)	43 (22)	29 (14)	0 (0)

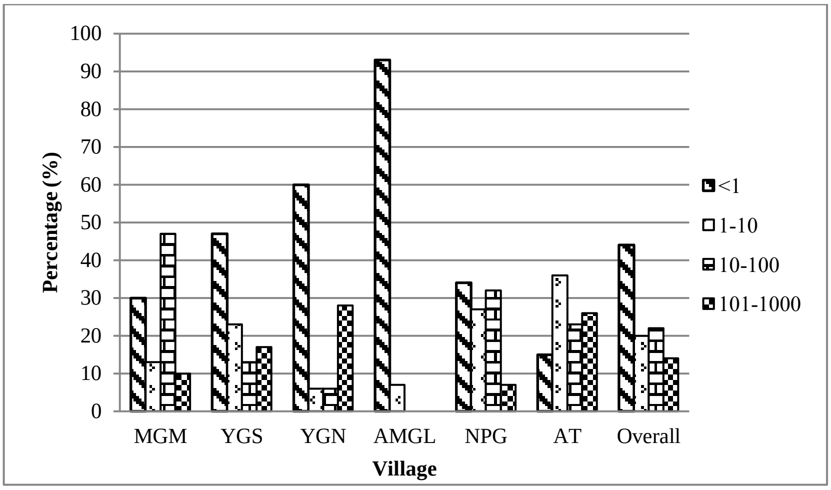

Figure 3 Water quality graph of groundwater samples based on WHO health-risk classification

Pit latrines in Sittwe are typically built near tube wells or boreholes for reasons of space, hygiene, and convenience. Pit latrines are a major source of groundwater contamination due to their widespread use in rural and suburban regions. When the safe distance between a water point and a pit latrine is not sufficiently maintained, groundwater sources are frequently affected. In many underdeveloped nations, including Myanmar, inadequate sanitation systems promote microbial contamination and water-borne diseases [27-28]. Pit latrines exacerbated microbial contamination of adjacent shallow tube well water where hydrogeological conditions (i.e. thickness and hydraulic properties such as hydraulic conductivity of surface clay aquitard, depth of groundwater table, and groundwater flow direction) played a significant role in bacterial transport [29]. Fecal waste contains a variety of pathogens, including viruses, bacteria, protozoa, and helminths (parasitic worms). This waste eventually percolates to the groundwater table. Pit latrines, it is often assumed, should not be utilized in locations where groundwater is used for residential water consumption. The groundwater protocol in Southeast Asia does not prohibit pit latrines in such places, but it does advise prudence and suggests that pit latrines be positioned at least 75 meters from water sources [30]

The results of the water quality analysis showed that groundwater from the rural area of Sittwe has risks associated with pathogenic infections due to microbial contamination of groundwater. The bacteria contaminate the water and can cause illnesses and illness among the local people In comparison to others, *E. coli.* had higher ingested dosages, infection risks, and illness per year. This implies a significant prevalence of E. coli-related illnesses in the studied area [31]. It is crucial to highlight that during the research period; a lot of observations were taken about the environmental conditions in the district, which provides insight into the pollution of the water sources. First, we discovered that their groundwater sources shared similar characteristics, namely the lack of effective physical barriers such as concrete seals, well linings, hygienic covers, and secured aseptic lids, among others, capable of avoiding terrestrial runoff containing anthropogenic and animal waste, which will undoubtedly pollute the sources. This could be related to the current study's discovery of E. coli counts in groundwater sources. Building strategically planned pit latrines is an important step in preventing microbial contamination of groundwater, which serves as a primary supply of drinking water for many communities. These pit latrines are designed to hold and decompose human waste properly, reducing the possibility of harmful germs penetrating the surrounding soil and seeping into groundwater. These systems contribute to the overall well-being of communities by decreasing the transmission of waterborne diseases by adhering to correct construction and maintenance regulations. Implementing such measures is critical to guaranteeing access to safe and clean drinking water, particularly in locations where sanitation infrastructure is inadequate or non-existent.

Second, a domestic water treatment system developed to address E. coli contamination in groundwater sources is an important lifeline for safe and clean drinking water. Typically, these systems use a combination of filtration and disinfection approaches. Water is first filtered to eliminate suspended particles and silt. The bacteria are then successfully killed or inactivated using ultraviolet (UV) or chlorine-based disinfection procedures. These systems ensure that residents in areas with contaminated groundwater have access to a consistent source of drinkable water, protecting public health and reducing waterborne infections. Finally, raising water and sanitation (WASH) knowledge is critical for reducing waterborne infections. Communities can dramatically lower the risk of diseases like cholera and dysentery by instructing safe water practices and good sanitation. Individuals can be empowered to make informed decisions that protect their health and the well-being of their families by learning about the importance of clean water sources, good hygiene, and waste disposal. Such public awareness initiatives are critical in guaranteeing access to clean, safe water and improved sanitation, eventually protecting public health and fostering a higher quality of life for all.

Conclusion

Over 50 percent of collected groundwater samples were contaminated with total coliform, and fecal coliform (*E. coli.*) and exceeded WHO guidelines for drinking-water standards and Myanmar's national drinking-water standards. Overall, the groundwater in the village is not suitable for human consumption without prior treatment such as chlorination. Diarrhea is still outbreak in Rakhine State and the diarrhea outbreak has only affected children under the age of 5, with the fatalities being toddlers. The quality of water and sanitation facilities has been found to be unsatisfactory in a large number of cases of diarrhea. To prevent the outbreak of diarrhea and to increase water and sanitation facilities, government, non-government, and community organizations should support the WASH campaign, environmental awareness sessions, and first-aid training. In recent years, most of the organizations supported in construction of pit latrines to reduce the open defecation system, while this provides a desirable alternative to open defecation, widespread use of unlined pit latrines may result in hazardous side-effects. Therefore, government and non-government organizations should develop the design of pit latrines, septic tank systems, and sewage management systems. In addition, the rural area of the Sittwe is far from the mainland, and difficult to access high technology for the treatment of the drinking water system. Despite this constraint, addressing the issue requires a comprehensive approach that combines preventive measures, various water treatment techniques (such as boiling, chlorination, SODIS, filtration, UV treatment, and biological treatment), and community education on hygiene practices. Given the limited access to high-tech solutions, reliance on simpler, cost-effective methods such as boiling and community-based interventions becomes essential. Community involvement, ongoing education, and regular water quality monitoring remain critical for achieving and sustaining success in mitigating E. coli contamination in the region. Physical, chemical, and microbiological qualities of water should be carried out on all the water sources in the State at least two times per year to monitor the contaminants.

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Assessment on Health Impacts and Costs of Fine Particulate Matter from Passenger Transport in Bangkok Metropolitan Region

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Abstract

The world has faced fine particulate matter ($PM_{2.5}$) problems affecting human health. Globally, $PM_{2.5}$ has caused 4.14 million pre-mature deaths, which is the fourth leading cause of death in the world. According to the annual report of the Pollution Control Department, the $PM_{2.5}$ value in Bangkok exceeded the national standards for 89 days in 2022. Transport was the dominant source of fine particulate matter in Bangkok. This research aims to develop an emission inventory and assess the health impacts and health costs of fine particulate matter from passenger transport in the Bangkok Metropolitan Region. The emission inventory was divided into two parts : fuel use and fuel production. Health impacts and health costs were quantified in the units of disability-adjusted life years (DALY) and Baht, respectively. According to research results in 2022 and 2027, the scenario that shifts 30% of private passenger transport to electric trains can reduce health impacts to 15,202 DALY/year and 9,011 million Baht (in 2022) and to 17,178 DALY/year and 10,883 million Baht (in 2027). Future policies should promote electric public transport and minimize the use of private vehicles.

Keywords : Air pollution; Fine particulate matter; Life cycle assessment; Vehicle emission

Introduction

Currently, $PM_{2.5}$ pollution is a major issue across all regions of Thailand, including the Bangkok Metropolitan Region. According to the STATE OF GLOBAL report for 2020, air pollution was the primary factor causing premature deaths, ranking fourth globally with 4.14 million fatalities. Moreover, air pollution has been linked to chronic obstructive pulmonary disease (COPD), resulting in 28% of deaths, diabetes with 21%, and a further 19% of deaths due to ischemic heart disease in the high-risk group aged 70 and above. Additionally, 9% of deaths in this age group were attributed to air pollution, while air pollution is also responsible for 5% of deaths in children under the age of 5 [1].

The $PM_{2.5}$ concentration was reported to exceed the permissible limit in all areas. Bangkok exceeded the standard limits of 89 days in 2021 [2].

Statistical analysis of passenger transport data in 2019 revealed that roads, trains, and water accounted for 38%, 33% and 14% of the total transport in Bangkok. Emissions data from inland water transport in 2019 showed that the total annual emission of NO_x, NH_3, SO_2 and $PM_{2.5}$ was 317.5, 0.03, 0.6 and 12.1, respectively. In 2019, the main source of 44.7% of the $PM_{2.5}$ emissions from inland water transport was the Chao Phraya boats, followed by Saen Saep boats which were responsible for 33.8% of $PM_{2.5}$ emissions [3]. In addition, it was also calculated that the vehicles travelling in the Bangkok Metropolitan Region between 2024 and 2029 are expected to emit 8,965 and 7,234 tonnes of pollutants, respectively. These emissions will cause a loss of 47,513 and 41,731 DALY [4].

The current study investigated the health impacts and health costs of passenger's transport modes such as road, water and railways in the Bangkok Metropolitan Region. This study aims to (1) develop and analyze an emission inventory of pollutant emissions that contribute to the formation of $PM_{2.5}$ from passenger transport modes of road, water, and rail; (2) assess the health impacts and health costs resulting from the release of $PM_{2.5}$ emissions from passenger transport by road, water, and railways; and (3) assess the significance of reducing the health impacts and health costs of fine particulate matter emissions caused by changes in travel patterns.

Methodology

1) Sampling and study area description

A study was conducted to examine the health impacts and health costs of road, water, and rail transport in Bangkok, Pathum Thani, Nonthaburi, Samut Prakan, Nakhon Pathom, and Samut Sakhon provinces of Thailand. The study was divided into two parts. In part 1, the type of vehicles used and the pollutants emitted via exhaust pipes by fuel burning were discussed. Part 2 focused on the contribution of oil and electricity generation to pollution levels. The pollutants investigated were $PM_{2.5}$ and its precursors which are NO_x, NH_3, and SO_2. The study focused on the three modes of transport to determine the travel modes of the population. Transportation options include road transport such as cars with passenger cars < 7 seats, passenger cars > 7 seats, private motorcycles, public motorcycles, buses, public water transport including; cross river ferries, Chao Phraya boats and Saen Saep boats, and rail transport such as electric trains and trains.

The research unit studied road, water, and rail passenger transport in the Bangkok Metropolitan Region in 2022 and made predictions for the year 2027 using data from 2022.

2) Study scenarios

Table 1 depicts the scenario assessed using the transport development strategy of Thailand.

3) Emission inventory

Road transport

Pollution from road transport was calculated using the European Monitoring and Evaluation Program (EMEP)/European Environment Agency (EEA) Air Pollution Emission Inventory Guidebook 2019. Equation 1 is used to estimate the emission of $PM_{2.5}$, NO_x and NH_3, while equation 2 is used for SO_2. The emission factors of exhaust emissions from road transport are shown in Table 2.

Table 1 Study Scenarios

Scenarios	Description
BAU (2022)	Business as Usual (BAU) in 2022
2 (2022)	In 2022, the number of passenger's car was decreased by 30%, and shifted to bus mode.
3 (2022)	In 2022, the number of passenger car was decreased by 30%, and shifted to water transport option.
4 (2022)	In 2022, the number of passenger's car was decreased by 30% and shifts to electric trains.
1 (2027)	the number of passengers is predicted in 2027.
2 (2027)	In 2027, the number of passenger's car was decreased by 30%, and shifted travel by to bus. shifted to bus mode.
3 (2027)	In 2027, the number of passenger car was decreased by 30%, and shifted to water transport option.
4 (2027)	In 2027, the number of passenger's car was decreased by 30% and shifts to electric trains.

Table 2 Emission factors of exhaust emissions from road transport

Type	Age(year)	Technology	Fuel	$PM_{2.5}$ (kg $_{PM2.5}$/pkm)	NO_x (kg $_{NOx}$/pkm)	NH_3 (kg $_{NH3}$/pkm)	SO_2(kg $_{SO2}$/pkm)
Passenger Car < 7	1< to 5	Euro 4	Gasoline	9.57E-07	5.30E-05	2.97E-05	6.09E-06
			B7	2.51E-05	5.06E-04	8.07E-07	5.22E-06
			B20	2.18E-06	5.09E-04	8.70E-07	5.22E-06
			LPG	9.57E-07	4.87E-05	2.94E-05	1.46E-05
			CNG	9.57E-07	4.87E-05	2.94E-05	5.22E-06
Passenger Car < 7	6 to 10	Euro 4	Gasoline	9.57E-07	5.30E-05	2.97E-05	6.09E-06
			B7	2.51E-05	5.06E-04	8.07E-07	5.22E-06
			B20	0.00E+00	0.00E+00	0.00E+00	5.22E-06
			LPG	9.57E-07	4.87E-05	2.94E-05	1.46E-05
		Euro 4	CNG	9.57E-07	4.87E-05	2.94E-05	5.22E-06
Passenger Car < 7	11 to 15	Euro 3	Gasoline	9.57E-07	8.43E-05	2.97E-05	6.09E-06
			B7	3.13E-05	6.74E-04	8.70E-07	5.22E-06
			B20	0.00E+00	0.00E+00	0.00E+00	5.22E-06
			LPG	9.57E-07	7.83E-05	2.94E-05	1.46E-05
		Euro 4	CNG	9.57E-07	4.87E-05	2.94E-05	5.22E-06
Passenger Car < 7	16 to 20	Euro 3 + 2	Gasoline	1.53E-06	1.67E-04	6.63E-05	6.09E-06
			B7	3.88E-05	6.44E-04	8.70E-07	5.22E-06
			B20	0.00E+00	0.00E+00	0.00E+00	5.22E-06
			LPG	1.53E-06	1.25E-04	6.43E-05	1.46E-05
		Euro 4	CNG	9.57E-07	4.87E-05	2.94E-05	5.22E-06
Passenger Car < 7	>20	Euro 2+1	Gasoline	1.91E-06	3.55E-04	8.37E-05	6.09E-06
			B7	5.95E-05	6.09E-04	8.70E-07	5.22E-06
			B20	0.00E+00	0.00E+00	0.00E+00	5.22E-06
			LPG	1.91E-06	2.92E-04	8.02E-05	1.46E-05
		Euro 4	CNG	9.57E-07	4.87E-05	2.94E-05	5.22E-06
Passenger Car > 7	1< to 5	EURO 4	Gasoline	9.17E-07	5.33E-05	2.52E-05	8.33E-06
			B7	3.11E-05	6.99E-04	1.00E-06	6.67E-06
			B20	2.73E-06	7.06E-05	1.00E-06	6.67E-06
			LPG	9.17E-07	4.67E-05	2.82E-05	1.40E-05
			CNG	9.17E-07	4.67E-05	2.82E-05	5.00E-06
Passenger Car > 7	6 to 10	Euro 4	Gasoline	9.17E-07	5.33E-05	2.52E-05	8.33E-06
			B7	3.11E-05	6.99E-04	1.00E-06	6.67E-06
			B20	0.00E+00	0.00E+00	0.00E+00	6.67E-06
			LPG	9.17E-07	4.67E-05	2.82E-05	1.40E-05
		Euro 4	CNG	9.17E-07	4.67E-05	2.82E-05	5.00E-06
Passenger Car > 7	11 to 15	Euro 3	Gasoline	9.17E-07	1.08E-04	2.52E-05	8.33E-06
			B7	5.96E-05	8.66E-04	1.00E-06	6.67E-06
			B20	0.00E+00	0.00E+00	0.00E+00	6.67E-06
			LPG	9.17E-07	7.50E-05	2.82E-05	1.40E-05
		Euro 4	CNG	9.17E-07	4.67E-05	2.82E-05	5.00E-06
Passenger Car > 7	16 to 20	Euro 3 + 2	Gasoline	1.52E-06	1.58E-04	5.56E-05	8.33E-06
			B7	7.73E-05	9.62E-04	1.00E-06	6.67E-06
			B20	0.00E+00	0.00E+00	0.00E+00	6.67E-06
			LPG	1.47E-06	1.20E-04	6.16E-05	1.40E-05
		Euro 4	CNG	9.17E-07	4.67E-05	2.82E-05	5.00E-06
Passenger Car > 7	>20	Euro 2+1	Gasoline	1.92E-06	3.77E-04	6.74E-05	8.33E-06
			B7	8.90E-05	1.03E-03	1.00E-06	6.67E-06
			B20	0.00E+00	0.00E+00	0.00E+00	6.67E-06
			LPG	1.83E-06	2.80E-04	7.69E-05	1.40E-05
		Euro 4	CNG	9.17E-07	4.67E-05	2.82E-05	5.00E-06
Public Buses	1< to 5	Euro 3	Gasoline	0.00E+00	3.74E-04	1.16E-07	9.56E-07
			B7	7.69E-06	3.81E-04	1.16E-07	9.56E-07
			B20	7.01E-06	3.87E-04	1.16E-07	9.56E-07
			LPG	3.98E-07	3.98E-04	0.00E+00	5.58E-06
			CNG	3.98E-07	3.98E-04	0.00E+00	1.99E-06
Public Buses	6 to 10	Euro 3	Gasoline	0.00E+00	3.74E-04	1.16E-07	9.56E-07
			B7	7.69E-06	3.81E-04	1.16E-07	9.56E-07
			B20	0.00E+00	3.87E-04	1.16E-07	9.56E-07
			LPG	3.98E-07	3.98E-04	0.00E+00	5.58E-06
			CNG	3.98E-07	3.98E-04	0.00E+00	1.99E-06
Public Buses	11 to 15	Euro 3+2	Gasoline	0.00E+00	3.95E-04	1.16E-07	9.56E-07
			B7	7.88E-06	4.02E-04	1.16E-07	9.56E-07
			B20	0.00E+00	0.00E+00	0.00E+00	9.56E-07
			LPG	3.98E-07	4.78E-04	0.00E+00	5.58E-06
			CNG	3.98E-07	4.78E-04	0.00E+00	1.99E-06
Public Buses	16 to 20	Euro 2+1	Gasoline	0.00E+00	4.26E-04	1.16E-07	9.56E-07
			B7	8.17E-06	4.34E-04	1.16E-07	9.56E-07
			B20	0.00E+00	0.00E+00	0.00E+00	9.56E-07
			LPG	3.98E-07	5.98E-04	0.00E+00	5.58E-06
			CNG	3.98E-07	5.98E-04	0.00E+00	1.99E-06
Public Buses	>20	Euro 2+1	Gasoline	0.00E+00	4.08E-04	1.16E-07	9.56E-07
			B7	1.54E-05	4.16E-04	1.16E-07	9.56E-07
			B20	0.00E+00	0.00E+00	0.00E+00	9.56E-07
			LPG	6.97E-07	6.42E-04	0.00E+00	5.58E-06
			CNG	6.97E-07	6.42E-04	0.00E+00	1.99E-06
Motorcycle	1< to 5	Euro 3	Gasoline	3.18E-06	1.76E-04	1.73E-06	3.64E-06
Motorcycle	6 to 10	Euro 3	Gasoline	3.18E-06	1.76E-04	1.73E-06	3.64E-06
Motorcycle	11 to 15	Euro 3+2	Gasoline	8.36E-06	1.82E-04	1.73E-06	3.64E-06
Motorcycle	16 to 20	Euro 2	Gasoline	3.55E-05	1.82E-04	1.73E-06	3.64E-06
Motorcycle	>20	Euro 2+1	Gasoline	3.55E-05	1.82E-04	1.73E-06	3.64E-06

Note: Low pollution Medium pollution High pollution

$\text{Emission}_{(PM2.5,\ NOx,\ NH3)}$ = Emission Factor * Transport Volume (pkm) (1)

$\text{Emission}_{(SO2)}$ = 2 * Typical fuel consumption * Sulfur content in fuel * Transport Volume (pkm) (2)

where emission represents the total emissions of air pollutants (kg/year), emission factor denotes the emission factor for each type of pollutant (kg/pkm), fuel consumption is the amount of fuel consumption in (kg/pkm), transport volume (pkm) represents the passenger perkilometer (pkm/year).

Water transport

Pollution from water transport was calculated using the USEPA (2010) shown in equation 3 for $PM_{2.5}$, NO_x, NH_3. and SO_2. The emission factor of exhaust emissions from water transport is shown in Table 3.

$\text{Emission}_{(PM2.5,\ NOx,\ NH3,\ SO2)}$ = (Cruising Emission factor + Idling Emission factor) * Transport Volume (pkm) * 10^{-3} (3)

where emission represents the total emissions of air pollutants (kg/year), cruising emission factors denote the pollution during travel (kg/pkm), idling emission factors represent pollution during mooring between ports (kg/pkm), and transport volume (pkm) represents the passenger per kilometer (pkm/year).

Rail transport

Pollution from rail transport was calculated using the European Monitoring and Evaluation Program (EMEP)/European Environment Agency (EEA) Air Pollution Emission Inventory Guidebook 2019. The exhaust emission of electric trains and trains are calculated using equation 4 and 5. The emission factor of exhaust emissions from rail transport is shown in Table 4.

Emission of electric trains = Emission Factor * electricity * Transport Volume (pkm) (4)

Emission of train = Emission Factor * Fuel consumption * Transport Volume (pkm) (5)

where emission represents the total emissions of air pollutants (kg/year), electricity represent electricity consumption per 1 Km of a passenger car (kwh/pkm), fuel consumption denotes the consumption of fuel by the engine (tonnes/pkm), and transport volume (pkm) represent the passenger per kilometer (pkm/year).

4) Health impact assessment

Health impact assessment use LCA approach will be applied to find the characterization factors of $PM_{2.5}$ and secondary $PM_{2.5}$ both indoors and outdoors.

The health impact gained from the multiplication of the emission and characterization factor is shown in Equation 6.

Health Impacts = Emission from step 3 * Characterization factor (6)

The characterization factors were obtained from Chavanaves et al. [4], as shown in Table 5. The spatial differentiation in impact assessment of direct emissions and supply chain emissions in Thailand was considered based on the Thai Spatially Differentiated Life Cycle Impact Assessment (ThaiSD) method [5].

Table 3 Emission factor of exhaust emissions from water transport

Type of boat	Cruising Emission Factor (g/pkm)				Idling Factor (g/pkm)			
	Primary $PM_{2.5}$	NO_x	NH_3	SO_2	Primary $PM_{2.5}$	NO_x	NH_3	SO_2
Cross river ferries	1.13E-01	1.97E+00	2.30E-04	3.68E-03	2.82E-02	2.11E+00	2.30E-04	3.68E-03
Chao Phraya boats	4.60E-02	8.06E-01	9.39E-05	1.50E-03	1.15E-02	8.62E-01	9.39E-05	1.50E-03
Saen Saep boats	2.38E-02	4.17E-01	4.86E-05	7.78E-04	5.96E-03	4.46E-01	4.86E-05	7.78E-04

Table 4 Emission factor of exhaust emissions from rail transport

vehicle	Fuel	$PM_{2.5}$ Emission Factor (kg /tones)	NO_x Emission Factor (kg /tones)	NH_3 Emission Factor (kg /tones)	SO_2 Emission Factor (kg /tones)	Electricity (kWh/PKM)	Fuel consumption (tones /PKM)
Train	B7	1	39.9	0.01	0.05	-	3.00E-06
BTS	Electricity	0	0	0	0	5.60E-02	-
MRT	Electricity	0	0	0	0	7.81E-03	-

Table 5 Characterization factor for Bangkok Metropolitan Region and global average

Area	Characterization factor (DALY/kg of pollutants emitted)				Ref.
	$PM_{2.5}$	NH_3	SO_2	NO_x	
Bangkok	6.06E-03	1.45E-04	8.46E-05	1.71E-05	[4]
Pathum Thani	1.12E-03	1.45E-04	8.46E-05	1.71E-05	[4]
Nonthaburi	5.20E-04	1.45E-04	8.46E-05	1.71E-05	[4]
Samut Prakan	6.86E-04	1.45E-04	8.46E-05	1.71E-05	[4]
Nakhon Pathom	1.42E-03	1.45E-04	8.46E-05	1.71E-05	[4]
Samut Sakhon	1.61E-03	1.45E-04	8.46E-05	1.71E-05	[4]
Global average	4.90E-03	2.60E-04	1.50E-04	3.10E-05	[6]

5) Health costs assessment

The health cost assessment was based on the Budget Constraint method based on [7]. It is a way of considering the willingness to pay to regain good health.

The budget constraint method is considered using two indicators: quality-adjusted life year (QALY) represents the number of healthy years, and DALY represents the number of healthy years lost. For the above reasons it can be concluded that the value of 1QALY is equal to - 1DALY.

The health costs assessment is derived from the conversion of health impacts into the value of health costs in Baht, as shown in Equation 7.

Health cost = value of DALY * Health impact **(7)**

Results and Discussion

$PM_{2.5}$ emission in 2022

The calculated emission levels in the Bangkok Metropolitan Region in 2022 were determined to be consistent with business as usual (BAU). The exhaust emissions of $PM_{2.5}$, NH_3, SO_2, and NO_x were estimated to be 1,248, 1,766, 602, and 38,582 tonnes per year, respectively, In contrast energy production were estimated 1,288, 78, 23,535, and 11,695 tonnes per year, respectively. In comparison to various scenarios with BAU. It was found that scenario 4 (in 2022), due to the increased use of electric trains resulted in lower pollution emissions compared to business as usual in 2022. The $PM_{2.5,}$ NH_3, SO_2, and NO_x emissions generated by exhaust emissions and energy production were 13%, 26%, 14%, and 22%, respectively. The minimum reduction in 2022 is represented by scenario 3, resulting in increased use of water transport and a 26% reduction in NH_3 emissions from exhaust emissions and energy production. However, $PM_{2.5}$, SO_2, and NO_x emissions were increased by 67%, 26%, and 82%, respectively.

$PM_{2.5}$ emission projection in 2027

The results of the emission calculations for the Bangkok Metropolitan Region in 2027 were found in scenario 1 (2027). The exhaust emissions of $PM_{2.5}$, NH_3, SO_2, and NO_x were estimated at 1,139, 1,761, 714, and 38,981 tonnes/year, respectively, while energy production was estimated at 1,614, 97, 28,957, and 14,750 tonnes/year. In the comparison of various scenarios with scenario 1 (2027), it was found that scenario 4 (2027) resulted in the greater decrease in pollutant emissions due to the increased use of electric trains. There was a reduction in the exhaust emissions and energy production of $PM_{2.5}$, NH_3, SO_2, and NO_x by 11%, 27%, 14%, and 21%, respectively. The lowest reduction was found in scenario 3 (in 2027) because of an increase in water transportation, which led to an increase in $PM_{2.5}$, NH_3, SO_2, and NO_x exhaust emissions and energy production of 74%, 71%, 15%, and 96%, respectively.

The most notable decrease in pollutants occurred in scenario 4 in 2022 and 2027. Incorporating electric motors into rail transport has led to this result, as less fuel is burned and fewer airborne pollutants are emitted during operation. Higher levels of air pollutants emission and air pollution were observed under scenarios 3 in 2022 and 2027, compared to the BAU in 2022 and scenario 1 (2027), respectively. Modern automobiles use more emission-friendly engines (Euro 3 and Euro 4) than boats (Pre Euro), which emit significantly lower levels of pollutants. As a result, the older boat engines release more pollutants into the air [3].

NO_x is the air pollutant with the highest concentration in all scenarios. This is because most vehicles in the system use diesel fuel, which uses a compression-ignition method instead of the spark-ignition method used by gasoline and liquefied petroleum gas engines. This incomplete combustion process leads to the production of more NO_x than other types of fuels [8]. On the other hand, the lowest level of pollutants found is NH_3, which is generated from the three-way catalyst (TWC) process that can reduce CO and HC in the exhaust pipe. Vehicle types significantly increased total emissions of $PM_{2.5}$ in the Bangkok metropolitan Region in 2022 and 2027 [9].

Significant decreases in pollutant concentrations were observed in scenario 4 in both 2022 and 2027.This result is attributed to the use of electric motors to power rail transport, which reduced fuel combustion and, thus minimized the emission of airborne pollutants during operation.

Compared to the BAU in 2022 and scenario 1 in 2027, scenario 3 resulted in the least reduction in air pollutants and, thus, caused higher pollution levels. This is because current water transport engines use older technology (Pre Euro), and they emit more pollution than cars (Euro 3 and Euro 4), which use engines with lower emissions due to advanced technology. Consequently, the older ship engines emitted more pollutants into the air [3].

The study of road transport has compared the amount of pollution that occurs in Bangkok with the research of Kim Oanh (2020) [3] and Chavanaves et al. (2021) [4] found that the $PM_{2.5}$ NH_3 NO_x pollution was lower than the comparable research because the types of cars studied were different. But SO_2 is higher because our research involved a study of fuel production.

The study with the research of Hathairat et al. (2023) [10] found that No_x was the same in all scenarios.

Total emissions of $PM_{2.5}$ by pollution in the Bangkok Metropolitan Region in 2022 and 2027, are shown in Figure 1.

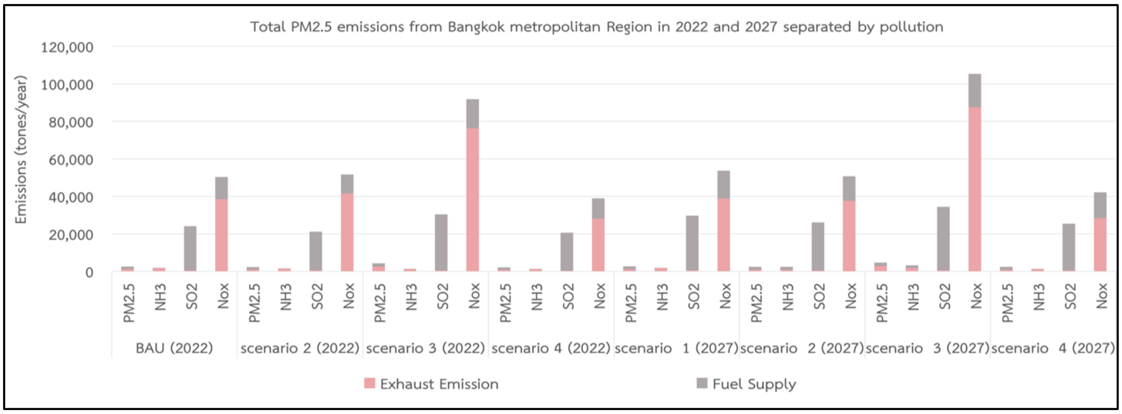

Figure 1 Total $PM_{2.5}$ emissions from various pollution in the Bangkok Metropolitan Region in 2022 and 2027

Health impacts and health costs, in 2022

The health impacts and health costs of air pollutants emitted by passenger's transport in the Bangkok Metropolitan Region have been calculated. Exhaust emissions has health impact of 7,613 DALY per year in 2022, which is equivalent to 4,513 million Baht. Energy production has a health impact of 10,225 DALYs per year, which is equivalent to 6,061 million Baht.

When comparing various scenarios with scenarios 1 (2022), it was found that scenario 4 (2022) resulted in a higher reduction in health impacts and health costs due to the increased use of electric trains. A 15% reduction was reported in both exhaust emissions and energy production. Scenario 3 in 2022, shows the minimum reduction in exhaust emissions and energy production, due to an increase in water transport resulting in an increase in health impact and health costs by 68%.

Health impacts and health cost, in 2027

The results of the health impacts of passenger transport in the Bangkok Metropolitan Region were estimated. In scenario 1 (2027), exhaust emissions have a health impact of 7,078 DALY/year, equivalent to 4,484 million Baht. On the other hand, energy production has a health impact of 12,737 DALY/year, equivalent to 8,070 million Baht.

When comparing various scenarios with scenario 1 (2027), it was found that scenario 4 (2027), due to the increased use of electric trains, resulted in a higher reduction in health impact and health cost. As a result, a 14% reduction in exhaust emissions and energy production was reported. There was a decrease in exhaust emission and energy production reported in scenario 3 in 2027, resulting in a 72% increase in health impacts and health costs due to increase in water transport.

In short, the highest pollutant was found to be $PM_{2.5}$ in all scenarios due to its direct release from exhaust pipes and ability to enter the body immediately through the respiratory system and penetrate the lungs and bloodstream, causing various diseases. The least amount of pollution was caused by NH_3, a precursor to $PM_{2.5}$ that undergoes several atmospheric processes and is converted into $PM_{2.5}$.

The study with the research of Hathairat et al. (2023) [10] found that it was found that there are differences in health impact of $PM_{2.5}$ using the CF value that comes from the Thai Spatially Differentiated Life Cycle Impact Assessment (ThaiSD) method, but in the case of ozone, CF values from RcCiPe 2016 are used, which results in differences.

Figure 2 displays the health effects and health costs in the Bangkok Metropolitan Region in 2022 and 2027.

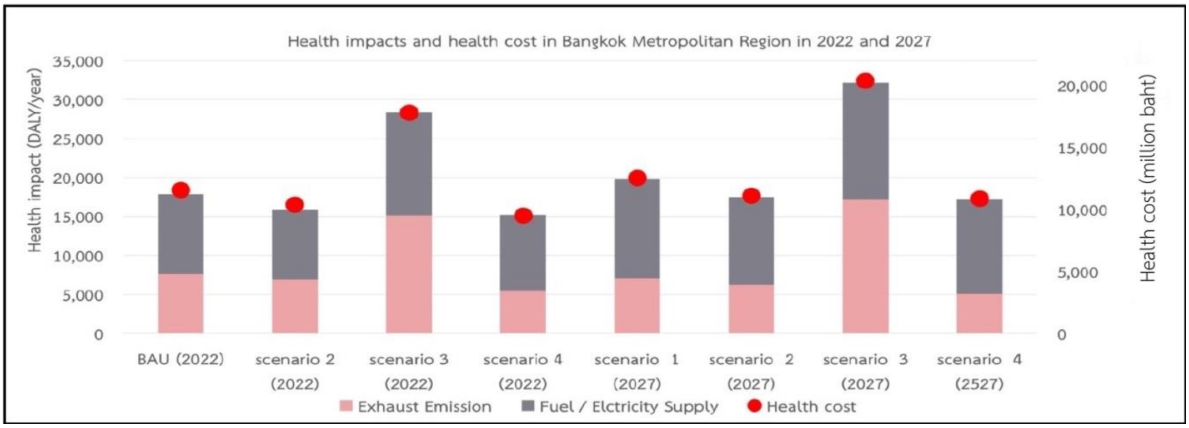

Figure 2 Health impacts and health costs in Bangkok Metropolitan Region in 2022 and 2027

Conclusions

The study examined commuters' transport habits in the Bangkok Metropolitan Region. The study examines $PM_{2.5}$, NO_x, SO_2, and NH_3 emissions. In 2022, the emissions of the exhaust pipe and energy production were 78,795 tonnes/year, with a health impact of 17,838 DALY/year and a health costs of 10,573 million Baht. Similarly, in 2027, the emissions projected were 88,013 tonnes/year, with the health impacts of 19,816 DALY/year and health costs of 12,554 million Baht.

The results of the comparison of various scenario revealed that the increase in rail transport by electric trains in 2022 and 2027 has the highest reduction in health impacts and health cost. Exhaust emissions and energy production contributed to a yearly decrease of 63,259 tonnes of $PM_{2.5}$ emissions in 2022. The health impact was 15,202 DALY, equivalent to 9,011 million Baht. Exhaust emissions and energy production are expected to decrease by 71,401 tonnes per year by 2027. The health impacts are expected to be 17,178 DALY/year, equivalent to 10,883 million Baht. The number of cars on the road is reduced and thus air pollution is reduced because of the high passenger capacity of electric trains. The electric trains are powered by electric motors, which do not emit pollutants into the atmosphere during operation.

The study results showed that reducing the number of passenger cars and increasing the use of electric trains by 30% can significantly reduce health impacts and costs. Therefore, future policy should promote and support the use of public transport, with a plan consisting of three phases: a short-term phase of reducing passenger cars and increasing public transportation with low emissions during the manufacturing process, a medium-term phase of modernizing and diversifying public transport systems to be convenient, fast, safe, and cost-effective from home to destination to encourage people to choose public transport; and a long-term phase of using full-scale public transport systems.

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Performance of Centralized Wastewater Treatment System in Thimphu, Bhutan

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Abstract

The main objective of this research was to provide an evaluation of the performance of the Sequential Batch Reactor (SBR) employed in the centralized wastewater treatment system of Babesa, Thimphu, the capital city of Bhutan. The performance was analyzed based on the respective plant's flow capacity, pH of effluent, and removal of Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Fecal Coliform (FC), using Standard Method of Examination of Wastewater, APHA, as well as the capital cost and sustainability of the treatment system. Removal efficiencies of the SBR for TSS, COD, and BOD ranged from 93-97±1.131, 67-84±4.791, and 65-89±6.662, respectively. In addition, the SBR effluent samples analyzed from April 2022 to August 2022 revealed a consistent and successful removal of TSS, BOD, COD, and FC with the effluent meeting the industrial effluent discharge standards set by the National Environment Commission (NEC). Not only was SBR found to be feasible economically and capacity-wise, but the success of the technology was a function of its compatibility with Thimphu's specific characteristics. The conclusion of this study hopes to encourage a more rigorous consideration of treatment options to invest in Bhutan's growing urban cities in the future, as well as a redefinition in how we evaluate the success of wastewater treatment systems.

Keywords : Babesa Thimphu; sequential batch reactor; sustainability

Introduction

Bhutan is a small, landlocked, Himalayan nation in South Asia with a population of 771,612 characterized with a diverse topology ranging from elevation of 200 meters of the southern foothills to more than 7,000 meters in the north. Thimphu, the capital city, is spread out longitudinally in a north-south direction on the west bank of Wang Chu, at Latitude 27°30' and Longitude 89°30' and the altitudinal elevation ranges between 2,248 meters and 2,648 meters. The valley is thinly forested and spread out to the north and west. Thimphu experiences the monsoon season from May to September, while the remaining is dry. The temperature ranges from 15 °C to 26 °C in summer/monsoon season and from -4 °C to 16 °C during winter. The summer monsoon rain originates from the Bay of Bengal and the annual rainfall ranges from 500 mm to 1,000 mm mostly occurring between June and September [1].

Proper sanitation management and treatment of wastewater remains an important and focal point within the discussion of urbanization as the uncontrolled discharge of sewage and untreated wastewater into water sources is responsible for contamination of the environment which can also act as carriers for disease. UNFPA has predicted that the majority of the projected population in urban settlements by 2030 will unfold in Asia and Africa, which calls for more efficient wastewater treatment systems as most wastewater treatment plants in developing countries fail to function properly Waste stabilization ponds are an extremely popular choice of treatment in developing countries due to the associated low-cost (usually least-cost), low maintenance, high efficiency, and entirely natural and highly sustainable operation [2]. It was under these justifications that Danish International Development Assistance (DANIDA) funded the construction and commissioning of a waste stabilization pond in the town of Thimphu in 1997 with the overall developmental objective of contributing to a reduction in the overall incidence of diseases related to water and hygiene [2].

The wastewater treatment plant in Thimphu was constructed in 1996 as a waste stabilization pond with a design capacity of 1.75 MLD. It was located about 10 km downstream of Thimphu city in Babesa, on the left bank of the Wang Chu river where the effluent would be released. In the year 2016, the plant accepted flows in excess of 1.6 MLD with a 325 mg/l BOD removal covering up to 13 acres of land [1]. It was also reported that 70% of Thimphu's houses were connected to septic tanks, and 30% were connected to the sewer network. Due to a lack of funding, Thimphu afforded only four minor extensions of the plant. Under the UIDP 2258BHU project, sewer pipelines were laid in the 4 southern areas of Lungtenphu, Simtokha, Babesa, and Changbangdu. However, these sewerage system developments in Southern Thimphu were not permitted to connect to the main treatment system due to the pond's limited capacity. Hence, this allowed the pond to treat only 18% of the city's incoming wastewater. The growing strain of pressure on the performance of the treatment plant began to increasingly mount as Thimphu rapidly urbanized [3]. Assuming that all housing in new developmental areas in Southern Thimphu would be connected by 2020 to the main plant with an infiltration rate of 5%, water production was estimated to be 25 MLD with wastewater production of 13 MLD. Despite the connection to 60% of the core area, only 30% reached the treatment plant as most houses relied on individual septic tanks or excess wastewater was diverted to the drainage system due to a lack of plant capacity [3].

While the pond treatment system boasted many advantages for a developing country such as low operation and maintenance costs, the performance was unsustainable due to the rapid urbanization, not to mention the impracticability of obtaining an additional 90 acres of land in a city located in a valley. Taking into consideration these factors, Thimphu transitioned towards the acquisition of a new wastewater treatment plant. Comparisons between various treatment options yielded the best choice of Sequencing Batch Reactor due to the minimum land requirement, less expensive capital and operation and maintenance (O&M) cost and activities, less power requirement, easier disposal of sludge, and better quality of treated effluent within the same budget against contemporary treatment options. The headworks of the wastewater treatment plant (WWTP) were designed for 2027 requirements while the process units i.e. tanks, reactors, dewatering, chlorination) were designed for 2020 flow requirements with a connection to about 13,000 residential units. The plant's automated trial period started in October 2021 [4]. The main objective of this study was to assess the performance of the sequential batch reactor plant and the waste stabilization pond in Babesa, Thimphu. The goals were to conclude the performance of SBR in terms of technical overview, effluent quality, working capacity, capital costs, and sustainability; and to assess the limitations and failure of the WSP technology within the context of Thimphu, Bhutan.

Methodology

The primary data which includes the biological parameters of the incoming and treated wastewater and the physical parameter of incoming flow to the new treatment system (SBR) were collected from the data maintained by the Thimphu Municipality of the SBR treatment plant. These data include TSS, COD, BOD, FC, pH, and flow rate. The sampling points, data collection period, and water quality analyses are displayed in Table 1.

Table 1 Measurement, sampling, and water quality analyses

Parameter	Sampling point	Data collection period	Standard Method
TSS	Influent and effluent	The 3rd wk. of April 2022-the 1st wk. of August 2022	Standard method 2540 [5]
COD	Influent and effluent	The 3rd wk. of April 2022-the 1st wk. of August 2022	Standard method 5220 [5]
BOD	Influent and effluent	The 3rd wk. of April 2022-the 1st wk. of August 2022	Standard method 5210 [5]
FC	Influent and effluent	The 3rd wk. of April 2022-the 1st wk. of August 2022	Standard method 9221 [5]
pH	Influent and effluent	October 2021-July 2022	Standard method 4500 [5]
Flow rate	Influent	October 2021-July 2022	Electromagnetic current meter

The secondary data, including climate and population analysis of the city, capital costs, and the biological and physical parameters of the treated wastewater from the old treatment system (WSP), were retrieved from relevant published literature and reports from the archive [1]. The WSP data was collected during 2006-2007.

Results and Discussions

The flow data of the SBR obtained shows an average monthly inflow of 7,700 m^3/d throughout November 2021-July 2022 as shown in Figure 1. While back then from January 2006 to May 2007, the average daily of the WSP was observed between 1,266 m^3 and 1,741 m^3 daily [1]. This jump in value can be explained due to the connection of the SBR plant to the new sewerage network as well as the urban growth in the area within the last decade. The minimum flow to the SBR plant occurred in May 2022 with 6,915 m^3/d while the average monthly flow peaked in June 2022 with 8,912 m^3/d.

The monthly pH of the influent ranged from 7.18 to 7.9 with an annual average of 7.57 while the effluent pH was recorded between 6.25 and 7.6 with an annual average of 6.92 (Figure 2). This is in contrast to the average effluent pH of 7.6 from WSP [1] which is low compared to higher values expected from maturation ponds. However, the SBR value is within the standard effluent range of 6.5-8.5 [6].

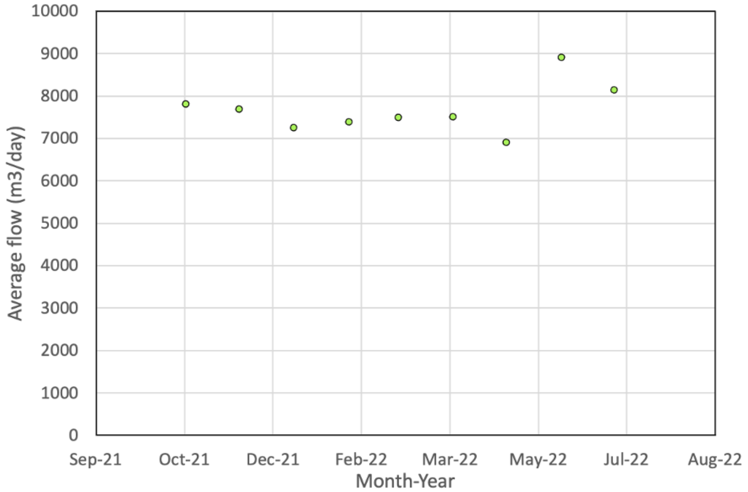

Figure 1 Average monthly flow to the plant

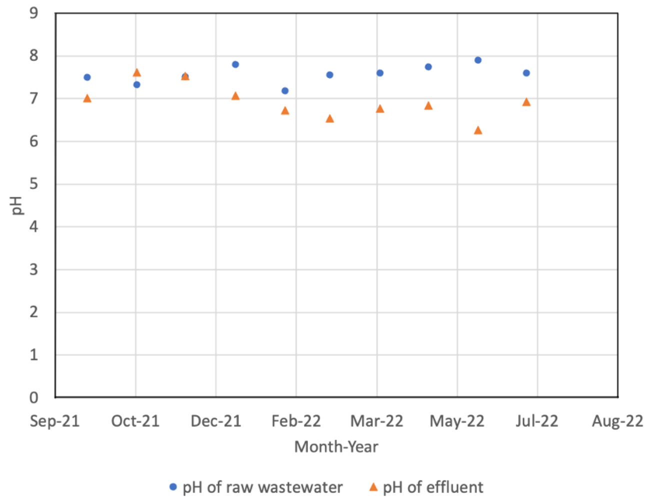

Figure 2 pH of influent to and effluent from SBR

The TSS of the influent samples collected for the duration of the third week of April 2022 to the first week of August 2022 was observed between 200 and 450 mg/L with an average of 323 mg/L (Figure 3). TSS removal by SBR was found to be consistent with an average of 95.11% with the effluent values between 12.5 and 17.5 mg/L meeting the National Environmental Commission (NEC) industrial effluent discharge standards of 80 mg/L [6].

Figure 4 shows the weekly variations of COD values from April to August 2022 varying from 194 to 297 mg/L for incoming wastewater with an average of 228.81 mg/L while treated effluent was observed to be within the ranges of 33.6-72 mg/L with an average of 50.78 mg/L meeting the NEC industrial effluent discharge standards of 150 mg/L [6].

The influent BOD values ranged from 52-156 mg/L with an average of 111.68 mg/L (Figure 5). The effluent BOD values ranged from 16-20 mg/L during the whole period meeting the NEC industrial effluent discharge standards of 30 mg/L [6]. The resulting average BOD removal rate was found to be 82.25%.

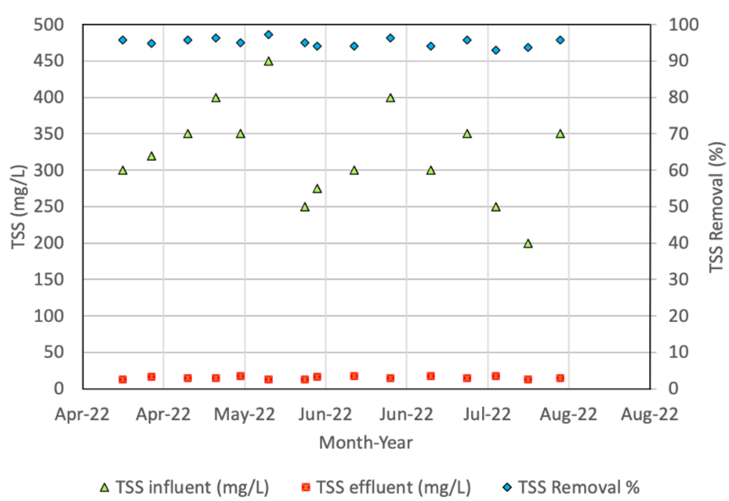

Figure 3 TSS content in influent, effluent, and removal in SBR

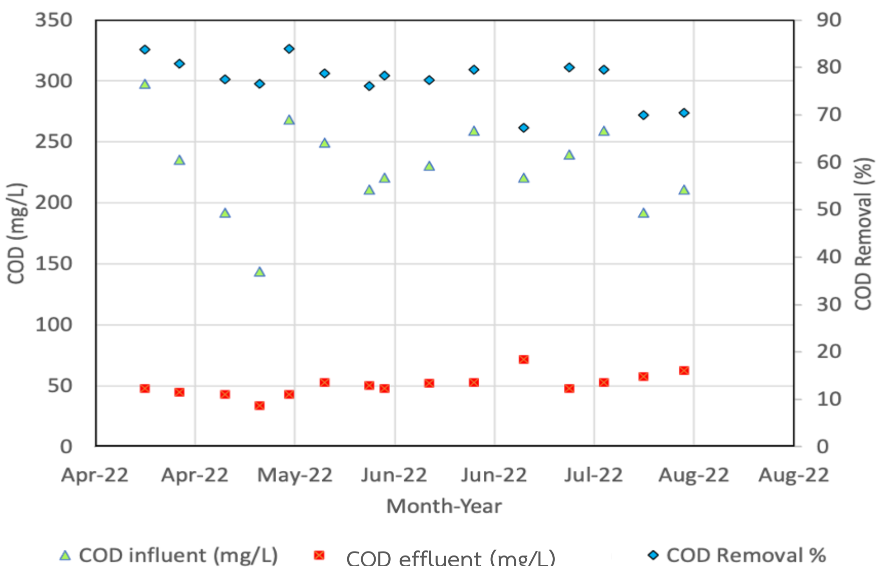

Figure 4 COD content in influent, effluent, and removal in SBR

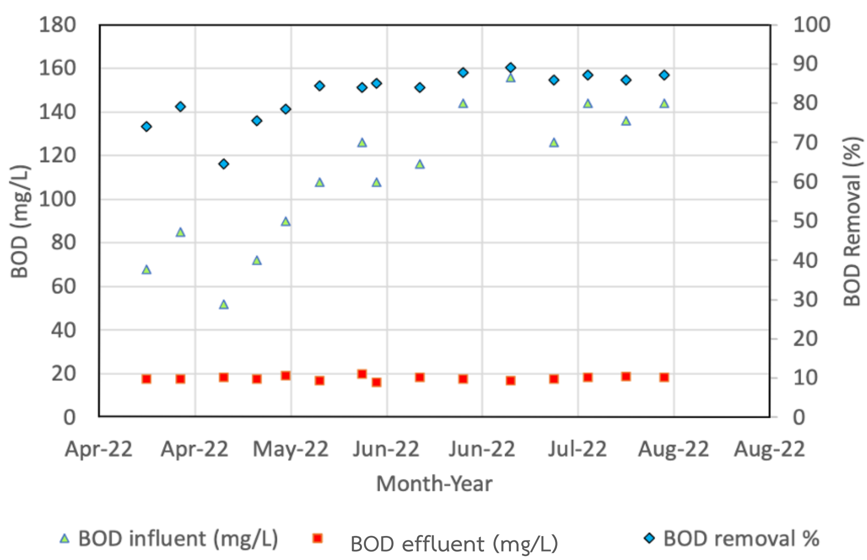

Figure 5 BOD content in influent, effluent, and removal in SBR

Table 2 describes the removal efficiency of TSS, COD, and BOD of the wastewater using the SBR and WSP technologies. Removal efficiencies of the SBR for TSS, COD, and BOD ranged from 93-97±1.131, 67-84±4.791, and 65-89±6.662, respectively. While the TSS, COD, and BOD of the WSP were in the range of 30-80%, 83-95%, and 78-90%, respectively [1].

Table 2 Removal efficiency of two WTTPs

Parameter	SBR	WSP
TSS Removal Efficiency (%)	93-97±1.131	30-80
COD Removal Efficiency (%)	67-84±4.791	83-95
BOD Removal Efficiency. (%)	65-89±6.662	78-90

However, a closer look at the actual parameter values reveals good quality of effluent from SBR, in which all parameters meet the industrial effluent discharge standards set by the NEC (Table 3). Whereas, WSP effluent of poor quality that does not meet industrial effluent discharge standards was observed. The TSS of effluent from SBR ranged from 12.5-17.5 mg/L. The SBR achieved effluent with a COD and BOD content of 33.6-72 mg/L and 16-20 mg/L, respectively.

Kochanek, A. et al. [7] evaluated the wastewater treatment efficiency of the WWTP using the SBR technology in the mountain area (Poland) and found that the removal efficiencies of TSS, BOD, and COD were 95.25%, 97.72%, and 95.58%, respectively. Hydraulic load of wastewater ranged from 2,644 m^3/d to 4,001 m^3/d. The TSS removal efficiency received from this research was comparable with the one from Kochanek A. et al. [7]. While the BOD and COD removal efficiencies of our work were slightly lower than the ones from their work. Wilk, B. K. and Cimochowicz-Rybicka, M. [8] determined the efficiency of the Biovac® wastewater treatment plants operating in the mountain areas of the Polish national parks (NP): Tatrzanski NP and Babiogórski NP as well as in the West Spitsbergen NP. The wastewater treatment plant was evaluated during the off-peak tourist season. The research revealed that the Biovac® treatment plants (SBR technology) objected to treating sewage discharged from mountain hostels yielded a high level of removal of pollutants. The average values of BOD and COD removal efficiencies ranged from 94% to 99% and 92% to 97%, respectively. In addition to the comparison of the same wastewater treatment technology (SBR), the findings of this work are also compared with the WWTP using different technologies. Bachi, O. E. et al. [9] studied the performance of aerated lagoons (AL), activated sludge (AS), and constructed wetlands (CW) under an arid Algerian climate. The minimum and maximum temperatures were observed to be about 12 ^oC and 36 ^oC for winter and summer time. The BOD removal efficiencies for the studied processes were 61.2–82.7%, 89.0–94.2%, and 87.9–91.2% for AL, AS, and CW, respectively. These values are in good agreement with our findings. The efficiencies of 65.5–69.1% (AL), 84.0–89.9% (AS), and 85.0–90.2% (CW) were obtained for the removal of COD. While the SS removal efficiencies of 39.2–67%, 93.4-96.9%, and 87.7–95.2% were received for AL, AS, and CW, respectively. The results suggested that the performance of SBR for Thimphu city is effective regarding the removal efficiency of pollution.

Table 3 Physical and biological parameters of effluent from two WWTPs against NEC standards [6]

Parameter	SBR	WSP	NEC standards
TSS Range (mg/L)	12.5-17.5	90	<80
COD Range (mg/L)	33.6-72	<80	<150
BOD Range (mg/L)	16-20	30-48	<30
FC (MPN/100 mL)	11-70	6.0×10^4-2.0×10^5	<1000

The justifications for these adverse differences in initial BOD and COD values can be that the sample origin is not of the same population nor within the same period. The WSP data was collected between 2006-2007 while the SBR data was collected in the year 2022. It is also important to note that one of the primary reasons for replacing the WSP was its insufficient capacity to handle the loadings of the new sewerage network of recent urban developments in the area, which was promptly connected to the new SBR STP after completion.

The estimated construction cost of the waste stabilization pond system and associated river training works funded by DANIDA in 1997 was approximately DKK 38.5 million (USD 7 million). Adjusting for inflation, this value is equal to USD 10.5 million in 2016. Approximately USD 2 million was expended for technical assistance and the training component with an additional USD 2 million also expended for upgrading of the water supply system and associated technical assistance, including a computerized billing system [2]. The estimated capitalized cost of the SBR plant with mechanical dewatering offered by the project consultant was RS 452.2 million (USD 5.48 million). The total contract bill was summarized as USD 10.5 million. Given that these figures are similar, the advantages offered by the SBR make the technology a more viable and economic option compared to the WSP. The figures for operational costs were not available for retrieval and hence were not included in the discussion.

One of the three principal reasons put forward by Parr and Horan [10] for the failure of WWTP in developing nations is the failure to consider all relevant local factors at the pre-design stage, leading to the selection of inappropriate treatment options. The WSP capacity of 1.75 MLD was already exceeded by the 30% of the city connected to the core sewer network, which allowed the treatment of only 18% of the total incoming sewage. While USD 2.28 million was allocated through an ADB loan agreement for the expansion of the WSP, the agency consultant concluded in 2007 that the expansion would be inadequate as the pond technology is a function of depth and deepening the ponds would be impossible, and installation of aerators was not expected to improve the pond performance. This intermediate solution, if pursued, was also projected to last only a few years and a new treatment plant was deemed necessary, as spatial expansion would require an additional 90 acres of land to treat the total incoming sewage. As Thimphu is located on a narrow strip of land at the base of a valley, this land requirement is unfeasible and so, treatment options that are spatially concentrated such as the SBR technology that congregates much of the unit operations into one tank, is a more suitable option.

Furthermore, the temperate climate of Thimphu where temperatures can plunge into negatives is not compatible with the waste stabilization pond technology where the performance is a direct function of microbial activity which is inhibited by cold temperatures. This incomplete degradation of organic matter would cause foul odor to be emitted especially during the winter which became a common source of complaint from the settlements nearby. Thus, investment in the SBR technology is not only a more economical but also a sustainable and compatible option.

Conclusion

Despite the selection of waste stabilization pond technology in 1997 due to its economic and operational feasibility, overloading of the plant's capacity due to rapid expansion in the urban area of Thimphu within the last decade and failure of effluent to meet discharge standards caused the municipality to seek options for replacement. The SBR plant replaced the pond technology with the automated trial period starting in October 2021. Not only is SBR technology a more compact treatment system compatible with Thimphu's limited availability of land, but the technology is also independent of Thimphu's temperate climates and high altitude, and capital cost figures are similar to that associated with the pond technology. Data of SBR samples collected from April 2022 to August 2022 were compared against the values of WSP data collected in 2006-2007 as well as July 2011. Despite the COD and BOD removal rates of SBR being lower than that of the WSP, it is not a reliable parameter to determine the success of wastewater treatment as unusually high and low initial values of COD and BOD affect the removal rate. High COD and BOD values, possibly due to analytical errors, were recorded for WSP influent while wastewater incoming to SBR had lower values, which explains the discrepancy in removal rates. However, despite the high removal rates of the WSP, the effluent failed to meet the discharge standards set by NEC and WHO. Meanwhile, SBR samples analyzed from April 2022 to August 2022 revealed a consistent and successful removal of TSS, BOD, COD, and FC with the effluent meeting discharge standards set by both the NEC and the contract. The incoming flow was also within the plant's operating capacity and is expected to handle future projected loadings, making the project a successful and sustainable form of wastewater treatment in urban Thimphu. While the waste stabilization pond technology is still an economically feasible option for developing nations with a lack of access to resources, it is recommended that the sites and settlements be studied more thoroughly to gauge the compatibility of the treatment option as evaluated in this study before investment, especially within Bhutan's growing urban cities in need of more centralized sewage treatment systems. This study also calls for a redefinition of how we evaluate the success of wastewater treatment systems, as removal efficiency is an unreliable parameter that does not accurately indicate effluent of high quality. Rather, the final parameter values of the effluent are a much better indicator of wastewater treatment success.

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Municipal Solid Waste Management Development Model through Participatory Process based on Circular Economy in Highland Tourism Area

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Abstract

The goal of waste management in Pai District's highland areas is to learn from local initiatives for participatory rubbish management. In this study, the following questionnaires were used: (1) the questionnaire on prototype project satisfaction (public/private), (2) the questionnaire on prototype research project satisfaction (Entrepreneurs), (3) the questionnaire on overall project satisfaction, and (4) the questionnaire on the level of satisfaction with the project's promotion aspects. A 300-person purposive sample was used. The descriptive statistics used in the analytical data included percentages, means, and standard deviations. As a result, the level of satisfaction with the prototype research project was high for public/private and moderate for entrepreneurs. The assessment of satisfaction with the research extension project revealed a very high degree of satisfaction with both the overview project and the promoted project elements. Furthermore, this study tracks recycled garbage sales and the outcomes of waste separation operations for 18 months, indicating the success of operations in the Pai district. The proceeds from the sale of recycled garbage have been set aside for community purposes such as funeral expenses. It is a management strategy that can result in a more sustainable approach to Municipal Solid Waste Management.

Keywords : Circular economy; Municipal Solid Waste; Lesson learned

Introduction

Currently, tourism is being promoted in numerous nations throughout the world in several ways, which has caused the service industry that supports it to grow. It gives substantial financial support to landlords everywhere. The fastest-growing industries were the hotel industry, travel agencies, retail, restaurant, service, and exchange companies [1]. When there is tourism in the area or a gathering of people anywhere, especially at a well-known tourist destination, environmental pollution, especially trash pollution, always happens [2-3]. In tourist destinations with surrounding mountains of great height or in high-altitude regions, we frequently battle with the problem of managing solid trash due to tourism and a variety of community activities, which includes waste from homes, hotels, markets, shops, and other commercial facilities as well as from activities on roadside vendors [4]. Most of these wastes have negative immediate and long-term effects on both human life and the environment [5]. Additional activities have a big impact on the rise of specific waste types, too, according to visitor preferences [6].

Therefore, it is essential to assess the region's capacity for waste management. Particularly in urban areas where the tourism industry is quickly growing, which could link development in three key areas: economy, social, and environment [7-8], and when utilizing a sustainable development-based system for environmental assessments. The importance of ecological issues has been found to be such that they can be taken into account in conjunction with land use and urban planning. In addition to other ways, we could link economic, social, and environmental concerns together [9]. The 11th National Economic and Social Development Plan of Thailand has a policy on transport networks that is intended to assist and go hand in hand with Pai's expansion, encouraging it to serve as the province of Mae Hong Son's hub for ecotourism.

Ministerial Regulations' contents The Royal Gazette reports that in 2015 and 2017, enhancements and alterations were made in order to promote tourism in Mae Hong Son Province. The ministerial regulations specify Royal Gazette advertise Mae Hong Son Province as a resource-efficient metropolis with a wealth of natural resources, promote an organic agriculture, ecotourism, develop a community economy, land utilization along riverbanks and allocate an area for waste disposal, including a hazardous substance disposal area complies with the Hazardous Substances Act. This is an area that may be affected by the tourism industry and rapid urbanization.

The responsible organizations' waste disposal methods are divided into 8 administrative areas, consisting of 1 municipality and administrative organizations in 7 sub-districts i.e., trench method without lining techniques, uncontrolled or open dump method and open burning method. Some of the crucial elements influencing waste management from tourism in the highlands are public collaboration, has the highest priority, followed by entrepreneur cooperation, which is more significant than economic and social aspects. In terms of the economy and society, it was discovered that the strength of the community has the highest priority, followed by economic growth, the number of waste buyers and prices, the number of tourists, tourist behavior, events or festivals, and the number of days stay overnight [9]. Tourist cooperation, waste segregation at source, recycling and reuse, and separation from operators are also important considerations [10-12]. The goal of this study was to draw conclusions on waste management practices in communities as a result of the application of research data to the prototype study project in Pai Walking Street, which looked at the effectiveness of garbage separation there. This study examined data utilizing surveys, questionnaires, and in-depth interviews on important factors that support effective community trash management. The study's findings can be examined to identify the advantages and disadvantages of waste management. It can be used to establish a clear policy that can lead to environmentally friendly activities in the region. The findings from this study can be beneficial to the planning and design of sustainable urban development based on the concept of livable cities to control the growth of tourism waste in the future.

Material and Methods

1. Study Area

Pai is a district in the province of Mae Hong Son. It is located in the coordinates 19°21′31″N 98°26′24″E. It is a small region with an area of 2,244.7 square kilometers that resembles a pan-basin surrounded by mountains or a valley city. Doi Mae Ya is the highest mountain peak in Thailand, rising 2,005 meters above sea level. It is located in Mae Hong Son Province's northeast, around 100 kilometers from Mueang Mae Hong Son district and 820 kilometers from Bangkok. Pai is a district in Thailand that borders Myanmar and consists of 66 villages under the jurisdiction of seven sub-districts and one municipality. It has a city area of 11.27 square kilometers and a municipal responsibility area of 2.4 square kilometers. Figure 1 depicts the research area. According to a summary of visitor conditions for the year 2018, Mae Hong Son saw 1,004,967 visitors, up 0.027 percent, and generated 4,980.71 million baht in revenue from tourism, up 2.40 percent [10].

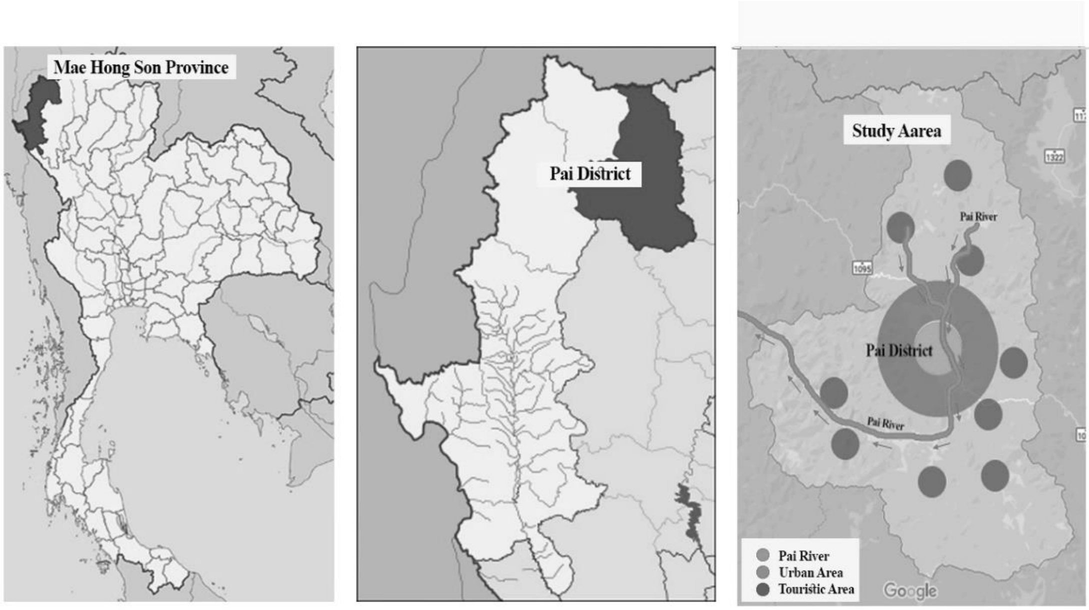

Figure 1 Study Area

2. Study Process

Based on Jessadanan's previous research [10, 12] used the environmental education approach to create a waste management prototype for Pai Municipality (Figure 2, left panel) and tested the prototype. Throughout 18 months, we expanded that prototype into a participatory solid waste management process (Figure 2, right panel).

1) Prototype Model to investigate the effectiveness of garbage separation in pedestrian-friendly streets Implement the project using an analytical procedure and following the research methodology, creating patterns and functional systems that fall under the purview of the work. Statistical analysis and the study of crucial components using the Analytic Hierarchy Process are both crucial tools for research evaluation. Analyses of urban planning and the volume and type of waste using accepted techniques. A survey of public opinion was used to assess the prototype research project's findings.

2) Model Implementation continuing research projects by collaborating with community organizations, for instance, by establishing a community waste management project as a sub-project under the Clean Homes, Pleasant Communities, Good Environment, Happy Lives project and adapting the activities to the local context until it can be developed into a community waste management project using funds under the name of the cremation fund to help communities. Figure 2 depicts the conceptual framework of the activities.

3. Method

1) This research used purposive sampling from the communities of 1 municipality and 7 sub-districts in the Pai district area by selecting from the citizen leaders who work on the waste separation project in Pai District 300 people. We studied the amount of waste data that has been sorted over 18 months. In addition, statistics on the sale of various types of waste that were extracted throughout the study period were displayed for comparison.

2) Using questionnaires to (1) Evaluation of satisfaction of prototype projects in research (public/private), (2) Evaluation of satisfaction of the prototype research project (Entrepreneurs), (3) the results of the study of the characteristics of the research extension project, (4) the assessment of satisfaction with the research extension project.

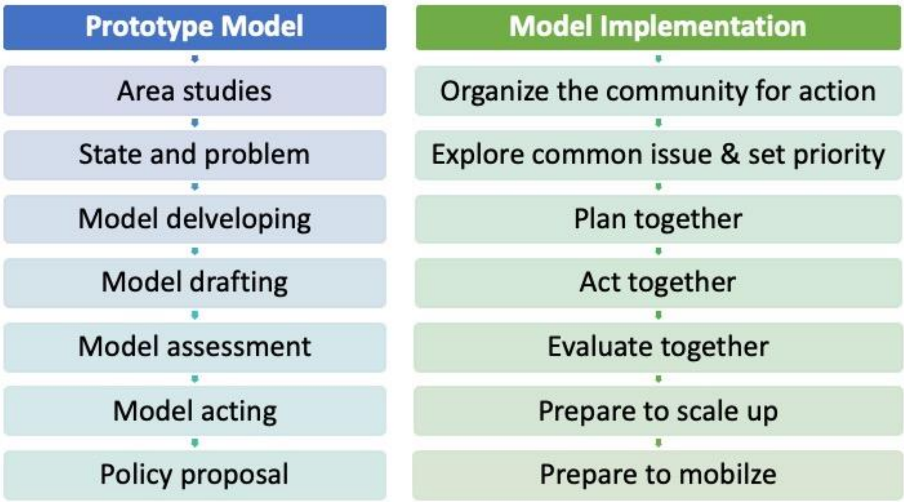

Figure 2 Conceptual Framework

3.1 Research tools

A total of 4 satisfaction questionnaires include: (1) The questionnaire on satisfaction of prototype projects (public/private), (2) the questionnaire on satisfaction of the prototype research project (Entrepreneurs), (3) the questionnaire on overall project satisfaction, and (4) the questionnaire on the project's promotion aspects' level of satisfaction.

3.2 Verification of the quality of the tools

To verify the quality of all questionnaires, the researcher verified content validity and the appropriate use of language with the help of 5 experts, the item-objective congruence or IOC = 0.85 and reliability level = 0.92.

Results and Discussion

In this study, we divided recycled waste into 10 categories: (1) PET plastic, (2) PP plastic, (3) colored PET plastic, (4) clear glass, (5) green glass, (6) brown glass, (7) colored paper, (8) cartons, (9) aluminum, and (10) metal.

1. Proportion of recycled waste of the prototype research project

According to the study, green glass makes up the largest percentage of recycled waste, or about 27% of all recycled waste, and is the most abundant type of recycled waste. The next two greatest kinds, brown and clear glass, account for roughly 26% and 18% of total recycled waste, respectively. The lowest category of recycled waste is colored PET plastic waste, which accounts for about 1% of your overall recycled waste (Figure 3).

2. Income from the recycled waste of the prototype research project

The study in Figure 4 shows that aluminum is the product that is most overall profitable because it makes the greatest money from recycled waste—roughly 1,410 baht. The next three categories are a PET plastic, which is worth approximately 1,046.8 baths, green glass, and brown glass, which are each worth approximately 655.47 baths and 642.06 baht. The whole earnings from recycled waste is just about 105.4 baht, with metal being the least profitable product.

3. The assessment of satisfaction with the prototype research project

3.1 Evaluation of satisfaction of prototype projects in research (public/private)

The project satisfaction assessment form's average scores, according to the study's Table 1, showed a high level of satisfaction. The average score of overall community benefits was 4.47 which was among the top 4 satisfaction assessment items with the highest average scores. The advantages to tourism's reputation were 4.40, and the suitability of the application in conjunction with other initiatives and the project's overall success were 4.33 respectively.

3.2 Evaluation of the satisfaction of the prototype research project (Entrepreneurs)

According to the survey, there was a moderate level of satisfaction with the average scores on the project satisfaction assessment form. As shown in Table 2, the first 4 satisfaction assessment criteria with the highest average scores were the appropriateness of the operational period (90 days) at 3.62, overall benefits to the community at 3.56, the appropriateness of the recyclable waste collection station and the appropriate working frequency at 3.46 respectively.

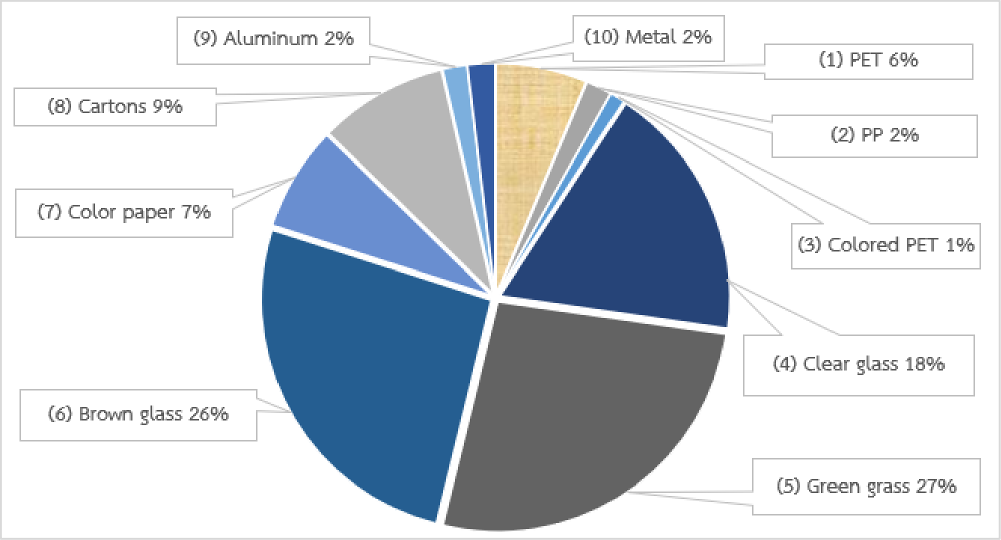

Figure 3 The proportion of recycled waste of the prototype project (%)

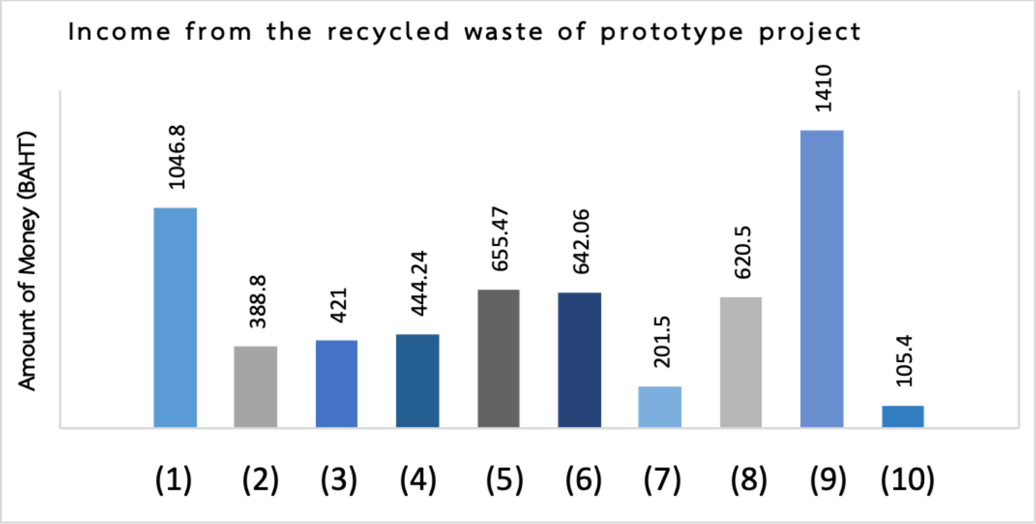

Figure 4 The income from the recycled waste of the prototype project (Bath)

Table 1 Evaluation of satisfaction of prototype projects (public/private)

Satisfaction assessment issues	$\bar{x}$	S.D.	Satisfaction level
1. Appropriateness of the operational period (90 days)	4.07	0.96	High
2. Appropriateness of complexity in the work system	3.93	1.03	High
3. Appropriateness of the project to the nature of the area / topography	4.27	0.80	High
4. Appropriateness of the project for public/private work	4.07	0.70	High
5. Management suitability and waste management from tourism	4.13	0.83	High
6. Appropriateness of recyclable waste collection station	4.00	0.85	High
7. Appropriate number of recycling collection station	3.87	0.99	High
8. Appropriateness of food waste collection station	3.73	0.96	High
9. Appropriate number of food waste collection station	3.87	0.99	High
10. Appropriate working frequency and number of operators	4.07	0.88	High
11. Overall Benefits to the community	4.47	0.64	High
12. Beneficial to the image of tourism	4.40	0.83	High
13. Appropriateness as a model for waste management from tourism	4.07	0.80	High
14. Appropriateness of application in conjunction with other projects	4.33	0.82	High
15. Overall project success	4.33	0.49	High

Table 2 Evaluation of the satisfaction of the prototype research project (Entrepreneurs)

Satisfaction assessment issues	$\bar{x}$	S.D.	Satisfaction level
1. Appropriateness of the operational period (90 days)	3.62	0.96	High
2. Appropriateness of complexity in the work system	3.38	0.85	Medium
3. Appropriateness of the project to the nature of the area / topography	3.44	0.85	Medium
4. Appropriateness of the project for public/private work	3.26	0.97	Medium
5. Management suitability and waste management from tourism	3.26	0.88	Medium
6. Appropriateness of recyclable waste collection station	3.46	0.91	Medium
7. Appropriate number of recycling collection station	3.44	0.75	Medium
8. Appropriateness of food waste collection station	3.33	0.81	Medium
9. Appropriate number of food waste collection station	3.26	0.85	Medium
10. Appropriate working frequency and number of operators	3.46	0.72	Medium
11. Overall Benefits to the community	3.56	0.68	High
12. Beneficial to the image of tourism	3.38	0.81	Medium
13. Appropriateness as a model for waste management from tourism	3.41	0.91	Medium
14. Appropriateness of application in conjunction with other projects	3.33	0.98	Medium
15. Overall project success	3.23	1.04	Medium

3.3 The results of the study of the characteristics of the research extension project

The amount of waste in January 2021 was 12,096 kg, the highest amount of waste during the research period and the income from selling waste was only 6,850 baht, which is a moderate amount compared to the amount of income over the course of the entire 18-month survey period. On the other hand, there were only 3,425 kg of waste quantity in January 2022 which decreased 8,671 kg compared with January 2021. But it has revenue from the sale of waste was 7,169 baht, which increase of 294 baht compared to revenue from the sale of waste in January 2021. According to Figure 5, May 2022 will bring in the highest income from recycled waste during the research period (7,170 baths).

4. The assessment of satisfaction with the research extension project

4.1 Summary review of the project

At a very high level of satisfaction, the average score for the satisfaction analysis criteria was 4.67. According to Table 3, the satisfaction assessment question with the highest average score was item 6: beneficial for the community (4.83 points), followed by item 3: appropriate place/purchase point of recyclable waste same as item 8: project success (4.67 points), and item 1: activity duration (4.58 points).

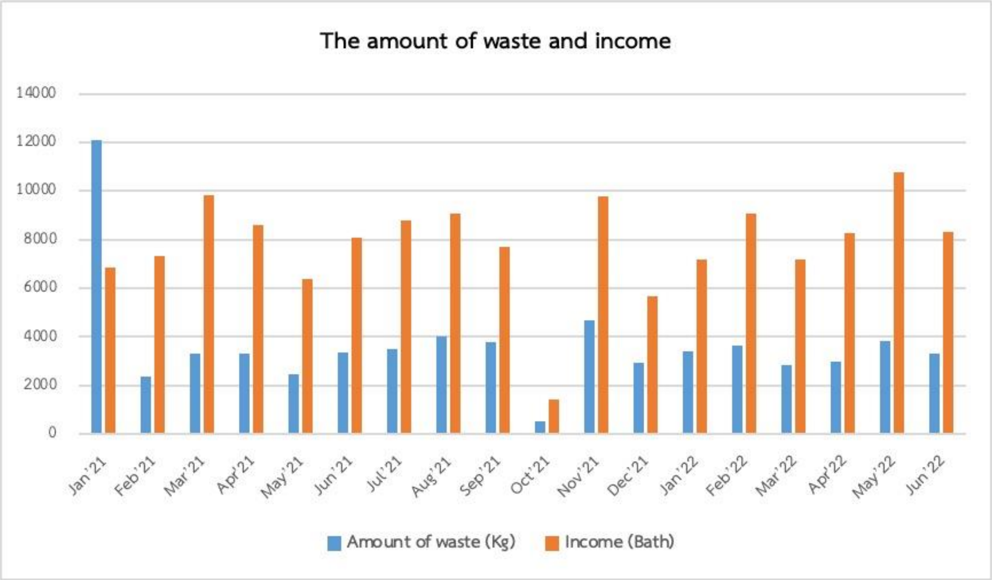

Figure 5 The amount of waste and income in January 2021 – June 2022

Table 3 Analyzing the overall level of project satisfaction

Satisfaction evaluation issues	x̄	S.D.	Satisfaction level
1. Duration of activity	4.58	0.49	Very High
2. The complexity of the system	3.92	0.76	High
3. Appropriate place/purchase point of recyclable waste	4.67	0.47	Very High
4. Enough worker	4.08	0.95	High
5. Working frequency	4.50	0.50	Very High
6. Beneficial for the community	4.83	0.55	Very High
7. Applying with other projects	4.50	0.50	Very High
8. Project success	4.67	0.47	Very High

4.2 The project's promotion aspects' level of satisfaction

The satisfaction analysis criterion had an average score of 4.19 a very high level of satisfaction. According to Table 4, Item 16: the growth of community strength had the highest average score on the satisfaction rating scale (4.75 points), followed by item 2: employees providing care or advice (4.67 points). Whereas item 1: received promotion/support from executives, item 4: officers provide additional knowledge, and item 9: places and collection points are convenient and easy to access had the same average score (4.58 points).

Table 4 The project's promotion aspects' level of satisfaction

Satisfaction of factors that promote project success	$\bar{x}$	S.D.	Satisfaction level
1. Received promotion/support from executives	4.58	0.49	Very High
2. There is a staff to look after / give advice / advice	4.67	0.47	Very High
3. Get cooperation from other groups / or organizations	4.00	0.58	High
4. Officers provide additional knowledge	4.58	0.49	Very High
5. People gain more knowledge from activities	4.33	0.62	High
6. Get promoted/supported by community leaders	4.50	0.64	High
7. There is a budget for activities	3.33	1.18	Medium
8. Adequate materials and equipment	3.83	0.90	High
9. Places and collection points are convenient and easy to access	4.58	0.49	Very High
10. There is a policy of government agencies to support	3.58	1.26	High
11. There are ordinances. promote/support water	3.92	1.26	High
12. There is an ongoing campaign and public relations	4.50	0.50	Very High
13. Get cooperation from the public	4.17	0.90	High
14. Get cooperation from entrepreneurs / shops / others	3.25	0.92	Medium
15. There is a clear separation of household waste	4.58	0.64	Very High
16. The development of community strength	4.75	0.43	Very High
17. There is an economic stimulus in the community	4.25	0.60	High
18. There is an increase in the number of buyers who buy garbage and the price of garbage	3.58	0.95	High
19. Various traditional festivals / seasons have a positive effect on activities	4.42	0.49	High
20. Number of other activities in the area have a positive effect on activities	4.33	0.62	High

The Municipal Solid Waste Management Establishment Model through the Participatory Approach Based on the Circular Economy in the Highland Tourism Area is a study of the establishment of a systematic waste management approach. The revenues from the sale of recycled rubbish can be used to fund community projects. This research result is consistent with the case study in Lae City, the second largest city in Papua New Guinea and is rich in natural resources. The city's expansion led the human population to move. The rise in population caused by industrial expansion has increased municipal solid garbage. As a result, economic, social, and geographic aspects must be investigated. To develop potential approaches to trash management that are both efficient and sustainable. It is possible to launch a zero-waste resource recovery campaign that effectively engages stakeholders [14].

The community participation process yields outstanding benefits. Increasing engagement, education, and individual knowledge. The governmental and commercial sectors must provide adequate facilities and equipment, as well as undertake systematic recycling programs. It is crucial in solid waste management. With a greater emphasis on education, particularly through municipalities, and by developing involvement and promotion programs between families and municipalities. It is thus possible to enhance citizens' practices by increasing their knowledge. Simultaneously, effective initiatives are done to encourage environmental activities. As in the study on the same subject in Kermanshah, Iran [15-16].

Conclusions

Northern Thailand's picturesque mountain resort of Pai is widely recognized for its stunning natural settings. The Mae Hong Son Loop is a popular tourist destination despite being a popular backpacker location. With a 27% recycling waste proportion, green glass, which is mostly made from alcoholic beverages but is not a valued recyclable waste, is the most common recyclable waste in the community. The most valuable recyclable waste is aluminum, a low-volume municipal waste that makes up 2% of total beverage package waste that can be recycled. This research supports the principles of the circular economy. In a circular economy, resources are used less, materials, goods, and services are redesigned to be less resource-intensive, and "waste" is recovered and repurposed to create new goods and materials [13].

The highest average scores are overall benefits to the community, which are used to measure the success and happiness of prototype projects for the public or private sector. For business owners, a moderate level of satisfaction by the highest average score indicates that the operational time (90 days) is adequate. According to data from the research project, the biggest amount of waste was generated in January 2021, and the highest amount of money was earned from recycled waste in May 2022.

There is a very high level of satisfaction with the research extension project according to the project overview's assessment, with the benefits to the community receiving the highest scores.

Recommendation

The research period was during COVID-19. There was a critical situation in the survey area affected by the amount of municipal solid waste in January 2021 than usual and the amount of waste will gradually return to normal at the time of the research. We recommend that you re-collect the research data once the research area returns to normal for more accuracy.

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Improving Indoor Air Quality: Utilizing Tropical Ornamental Plants for Carbon Dioxide Reduction

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Abstract

This study investigates types of ornamental plants for improve indoor air quality by specifically reducing CO_2 levels. The fourteen plant types examined are *Epipremnum aureum*, *Spathiphyllum* sp., *Nephrolepis Exaltata*, *Chlorophytum Comosum*, *Codiaeum Variegatum Blume*, *Epipremnum Aureum* (Linden & André) *G. S. Bunting*, Crinum asiaticum, *Dracaena trifasciata*, *Diffenbachia picta Schott*, *Portulacaria afra f. variegata*, *Peperomia obtusifolia (L.) F.Dietr*, *Aglaonema cochinchinense*, *Pilea Cadierei*, and *Cordyline fruticose (L.) A.Chev*. The ability of each ornamental plant to reduce CO_2 levels was recorded over a 24-hour period. It was observed that *Epipremnum aureum* exhibited superior CO_2 absorption capabilities compared to other ornamental plants in this study. It had an average CO_2 absorption and release of -36 and 2 ppm, respectively, in the closed chamber, both during the daytime and nighttime. It is suggested to incorporate these plants in various living areas such as the living room, kitchen, bedroom, or office spaces.

Keywords : Indoor Air Quality; Reducing Carbon Dioxide; Ornamental Plants

Introduction

The quality of indoor air in urban environments is a growing concern, with potential health implications for those who spend significant time indoors. One key pollutant of concern is carbon dioxide (CO_2). Elevated levels of CO_2 can lead to discomfort, reduced cognitive function, and even health problems. Fortunately, nature offers a solution: the use of ornamental plants for indoor air purification. In enclosed environments with a large number of inhabitants, CO_2 buildup can occur. Humans produce and exhale higher concentrations of CO_2 in occupied indoor spaces than they do outdoors [1]. CO_2 concentration in living areas increases as people live indoors for extended periods without sufficient ventilation. Typically, living areas are equipped with air conditioning units but lack proper ventilation systems. Prolonged exposure to high CO_2 concentrations can cause occupants to experience headaches, nausea, fatigue, and listlessness. Therefore, the removal of CO_2 from enclosed environments is essential [2-3]. However, the installation of ventilating fans can bring hot air into the room, resulting in increased electricity consumption. The issue of indoor air quality is exacerbated by the fact that people are spending more time indoors, combined with reduced building ventilation aimed at conserving energy [4]. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers standard (ASHRAE Standard 62.1) recommends that the maximum acceptable CO_2 concentration for comfort should not exceed 700 ppm [5]. The CO_2 setpoint of a ventilation fan system can significantly impact energy consumption. In a typical 30 m^2 office with 1–3 occupants, it appears that growing plants vertically can reduce carbon dioxide concentrations within buildings could reduce indoor CO_2 concentrations by

25.7%–34.3%, resulting in approximately a 12.7%–58.4% reduction in building ventilating energy consumption [6-7]. An alternative method to reduce high concentrations of CO_2 without relying on ventilation fans is the use of ornamental plants. Green walls not only provide aesthetic benefits but also possess the ability to remove indoor CO_2. Therefore, using ornamental plants to reduce CO_2 levels in urban indoor air is a viable solution. Numerous studies have indicated that vertical plant walls have the potential to remove indoor air pollution. They not only enhance aesthetics but also possess the ability to remove indoor CO_2. Su and Lin [8] found that Bird's nest fern has the ability to remove CO_2 at a rate of 1.984 ppm/hr. One alternative to reduce high CO_2 concentrations without the use of ventilation fans is to employ ornamental plants. Plants offer a sustainable but underexploited solution for enhancing indoor air quality [9]. Yarn et al. [10] demonstrated that *Spathiphyllum kochii* can absorb CO_2 from human respiration. Husti et al. [11] investigated the removal of indoor air pollutants by ornamental plants in a workplace and found that they can reduce CO_2 concentrations by 58.33%. Jamaludin et al. [12] reported significant reductions in relative humidity, total volatile organic compounds (TVOC), and CO_2 levels in a university classroom after introducing a landscape. Torpy et al. [13] studied the reduction of high CO_2 concentrations using two plants in a green wall application. They found that *Chlorophytum comosum* and *Epipremnum aureum* are effective for CO_2 removal at specific light densities. Torpy et al. [14] discovered that *HL-acclimatized D. lutescens* is the most efficient species per unit leaf area in removing high CO_2 concentrations, even in low light conditions. *Epipremnum aureum* and *Spathiphyllum sp*. plants are the most effective species in reducing CO_2 [15]. Furthermore, plants also absorb other indoor air pollutants, such as volatile organic compounds (VOCs), making them versatile air purifiers [16]. The highest toluene removal was found in *Sansevieria trifasciata* while the ethylbenzene removal from air was with *Chlorophytum comosum* [17]. Integrating ornamental plants for CO_2 reduction in urban settings presents unique challenges, including limited space and potential outdoor pollutants. Nevertheless, creative solutions like vertical gardens and rooftop gardens have shown promise in urban areas [18]. Green building initiatives are increasingly concerned with indoor air quality. Living in green buildings not only promises good health and lower electricity bills but also provides a better indoor environment while reducing energy demands. The effect of CO_2 absorption is influenced by various factors, including intense light and relative humidity (RH). In these real environments, the intensity of natural light exceeded that of controlled artificial lighting, consistent with most previous studies using light intensities ranging from 100 to 2,000 Lux [15, 19, 20-22]. However, few of these studies focused on the plant's ability to reduce CO_2 emission under natural light, a condition that can cause stress to plants. Light stress negatively impacts photosynthetic efficiency, leading to stress conditions when the plant cannot move, affecting various metabolic processes and causing decreased growth. For instance, high light stress occurs when light intensity exceeds the plant's capacity for photosynthesis and other metabolic processes, potentially damaging cell components like membranes, proteins, and DNA due to the accumulation of reactive oxygen species (ROS). Photoinhibition may also occur, reducing photosynthetic efficiency by inactivating photosystem II (PSII) in chloroplasts. On the other hand, low light stress happens when light intensity falls below the level needed for optimal photosynthesis and growth. In such conditions, limited energy is available for plant metabolism, resulting in reduced photosynthesis rates and growth. Additionally, low light stress may lead to a decrease in photosynthetic pigments like chlorophyll, further hampering the plant's ability to absorb and utilize light energy [19, 23-25]. Additionally, Thailand offers a wide variety of ornamental plants; however, determining which plants are most effective at reducing indoor CO_2 levels is not well-established. Therefore, the objective of this study is to investigate ornamental plant species for indoor CO_2 reduction in both light and dark conditions in a real environment. The study's findings can be applied to enhance indoor air quality using ornamental plants, contributing to green building practices.

Methodology

The experiment involved screening fourteen ornamental plant species to reduce CO_2 levels. Subsequently, a real room experiment was conducted to investigate the performance of the plants that showed the best results in reducing CO_2 levels in the previous experiment.

1. Plant Preparation

The screening of plants for CO_2 removal involved an experiment with fourteen ornamental plant species: *Crinum asiaticum*, *Epipremnum aureum*, *Nephrolepis exaltata*, *Dracaena trifasciata*, *Chlorophytum comosum*, *Diffenbachid picta Schott*, *Spathiphyllum* sp., *Portulacaria afra*, *Peperomia obtusifolia*, *Aglaonema cochinchinense*, *Epipremnum aureum (Linden & André) G. S. Bunting)*, *Codiaeum Variegatum Blume*, *Pilea* Cadierei, and *Cordyline fruticosa (L.) A.Chev*. When selecting plants, consideration was given to choosing sizes that could fit well in the closed chamber. These plants were cultivated in plastic pots measuring 4 inches, each containing a mixture of 200 g of soil and coco coir in a 1:1 ratio as the growth medium. Additionally, the pots were covered with aluminum foil to eliminate any potential interference from factors such as soil and pot absorption [17]. In this experiment, the leaf area of all ornamental plants was quantified using a data processing image method with the Petiole program (Figure. 1) following the methodology outlined by Hrytsak et al. [11].

2. Experimental setup

The experiment involved screening ornamental plant species to reduce CO_2 levels and assessing their CO_2 absorption and emission abilities. Fourteen plant species were placed inside an acrylic closed chamber measuring 0.30 m in diameter, 0.50 m in height, with a total volume of 3.5 m^2. A fan was installed inside the chamber, as shown in Figure 2. There were two conditions: one with an unplanted chamber as a control, and the other with plants inside the chamber. Each plant species was studied in an uninhabited room using natural light to ensure the applicability of the results to real environments. The experiment lasted for 24 hours, during which the plants were exposed to natural daytime from 06.00 to 18.00, and nighttime from 18.00 to 06.00. Light intensity was measured using an Extech Lux meter. The plants inside the closed chamber were positioned approximately 10 cm away from a window, with a window size of 2.5 m by 1.5 m and a height of 20 m on the northeast side, as shown in Figure 3. CO_2 concentration was released into the chamber, and CO_2 concentration (ppm), relative humidity; RH (%), and temperature (°C) were recorded for analysis.

The experiment assessed the ability of ornamental plants to absorb CO_2, based on the results from previous experiments. It was conducted in a classroom with dimensions of 190 m^2 and a height of 2.91 m. In this experiment, there were zero plots of ornamental plants in the control group (C) and 100 plots throughout the room (P), with CO_2 meters installed in designated areas. The CO_2 meters were positioned between 60 cm and 120 cm above the floor level.

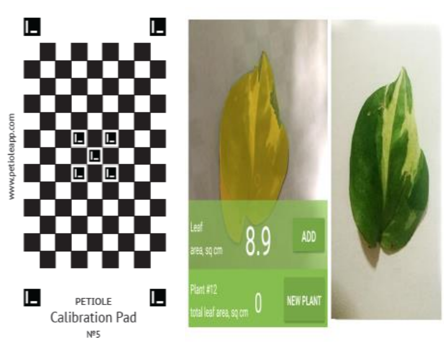


Figure 1 Petiole program

Figure 2 Experimental closed chamber

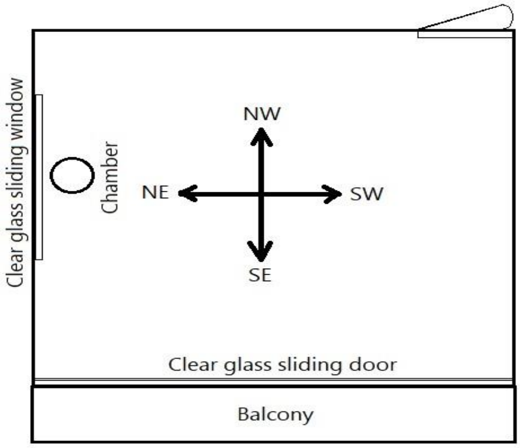


Figure 3 the positioning of the plants and the closed chamber

3. Carbon dioxide Assessment

Measure CO_2 concentration (ppm), RH (%), and temperature (°C) continuously using a Lutron air quality meter (AQ-9901SD) inside the chamber to collect data over 24 hours. Record readings with a monitoring device equipped with a data logger, as depicted in Figure 2. To maintain comfort, the CO_2 concentration should not exceed 700 ppm, following the guidelines of ASHRAE Standard 62.1 [5]. Evaluate the plants' ability to absorb or emit CO_2 over this 24-hour period by comparing CO_2 levels at different times with the CO_2 levels in the ambient air at 0 minutes. A negative value indicates CO_2 absorption, while a positive value suggests CO_2 emission.

4. Statistical analysis

Microsoft Excel to calculate the average CO_2 concentrations, and T-test was employed, with a significance level set at 95%, to assess the significance of CO_2 concentrations for each plant, using SPSS version 22.0.

Results and Discussion

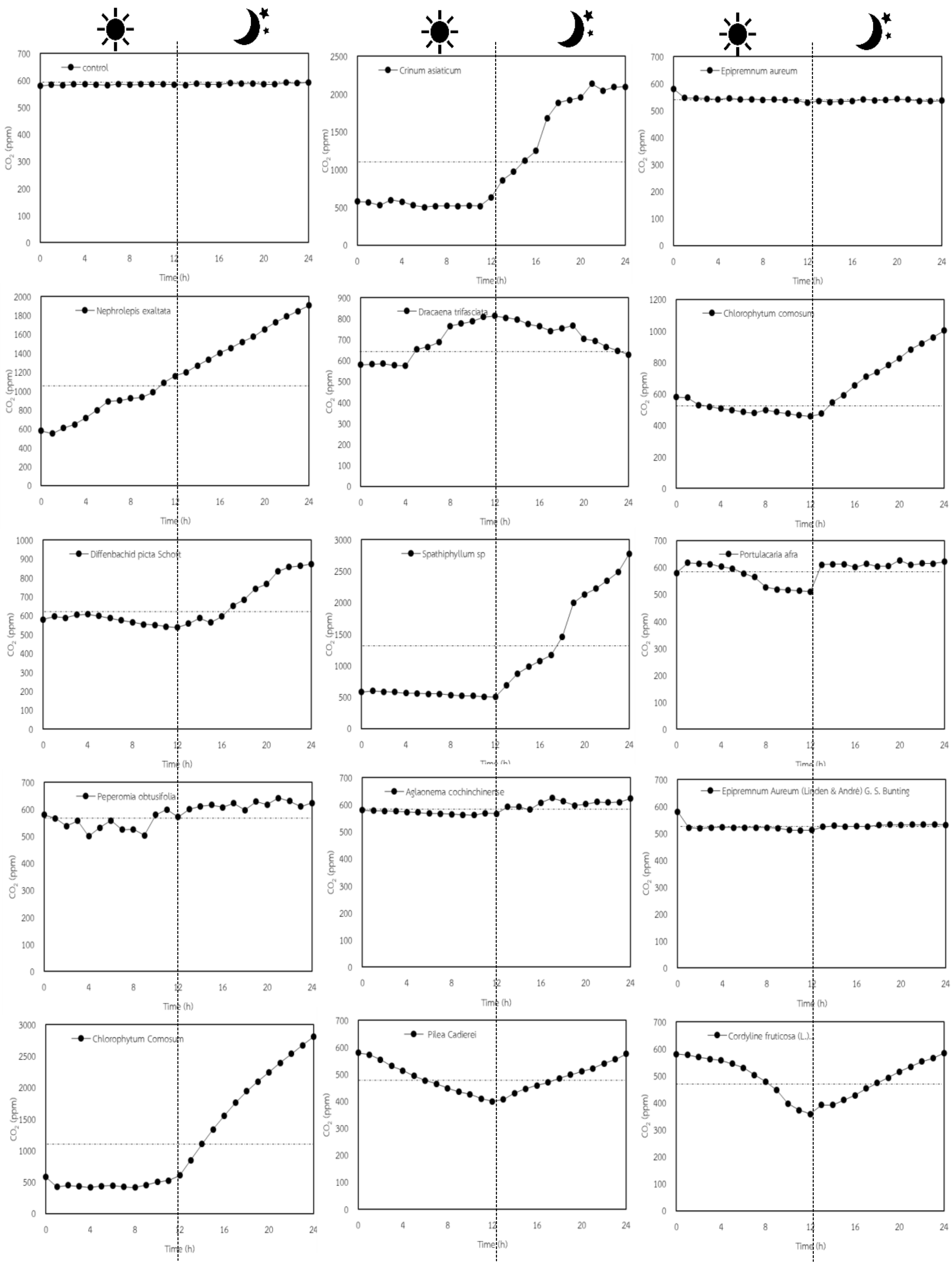
Room Environment

During the experiment in a real environment, daytime light intensity ranged from 407 to 4,454 Lux, with an average of 2,670 Lux, which was higher than the 1,643 Lux observed in natural light [15]. This variance may be attributed to the plant's positioning and the environmental conditions within the room. At night, there was no light. The average RH and temperature room environment were 62±4%, and 32.1±17°C, respectively. Inside the chamber, the average RH and temperature were 59.7±2.3%, and 30.2±0.6°C. A suitable lighting environment is essential for plant growth, as plants use photosynthesis to provide energy for their growth. Therefore, it can be inferred that the lighting conditions in this experiment did not have a negative impact on the visible growth of indoor plants over a short period of time [21, 26].

Screening ornamental plants for CO_2 emission reduction

The natural light duration was 12 hours (06.00-18.00) in the natural lighting environment. The initial CO_2 concentration in the controlled chamber was approximately 586 ppm as shown in Figure 4.

The effect of screening fourteen plant species on CO_2 concentration emission within the closed chamber is shown in Figure 4. Significance was observed for each plant ($p<0.05$). Over 24 hours, *Nephrolepis exaltata* exhibited rapidly changing net CO_2 emission rates, with an average of 1,178 ppm. In contrast, *Epipremnum aureum* exhibited a decrease of 8%, with an average CO_2 concentration of 541 ppm. This finding aligns with the results of Plitsiri and Taemthong (2022), who observed that in experiments conducted under natural daylight conditions, *Epipremnum aureum* displayed the highest CO_2 removal capability [15]. While *Dracaena trifasciata* had an average net CO_2 emission of 703 ppm. CO_2 emissions gradually increased during the day but decreased quickly during the night. This variation could be due to the Crassulacean Acid Metabolism (CAM) photosynthetic pathway of the Snake plant [19], CAM is a photosynthetic pathway that temporally separates nocturnal CO_2 uptake via phosphoenolpyruvate carboxylase (PEPC, C4 carboxylation) from diurnal refixation by Rubisco (C3 carboxylation) thus CAM plants showed the phenomenon that carbon dioxide decreases during the dark period and increases during the bright period [27], whereas the other plants have C3 pathway, which is a plant that lacks photosynthetic adaptations to reduce photorespiration is called a C3 plant. In the Calvin cycle, the initial step involves the fixation



Remark: ……. represents the average CO_2 level throughout the day

Figure 4 CO_2 concentration for fourteen plants at 24 hours of carbon dioxide by rubisco. Plants that exclusively employ this 'standard' mechanism of carbon fixation are termed C3 plants, named after the three-carbon compound (3-PGA) produced in the reaction or C4 pathway. In C4 plants, the light-dependent reactions and the Calvin cycle are physically separated. The light-dependent reactions occur in the mesophyll cells (spongy tissue in the middle of the leaf), while the Calvin cycle takes place in specialized cells around the leaf veins known as bundle-sheath cells. C4 photosynthesis in action. Initially, atmospheric CO_2 is fixed in the mesophyll cells, forming a simple 4-carbon organic acid (oxaloacetate). This crucial step is carried out by a non-rubisco enzyme called PEP carboxylase, which lacks the tendency to bind oxygen (O_2). Subsequently, oxaloacetate is converted into a similar molecule, malate, which can be transported into the bundle-sheath cells. Within the bundle-sheath cells, malate undergoes breakdown, releasing a molecule of CO_2. This released CO_2 is then fixed by rubisco and transformed into sugars through the Calvin cycle, mirroring the process of C3 photosynthesis, CO_2 levels increase during the dark period and decrease noticeably during the light period [19, 27]. The remaining plants showed a trend of decreasing CO_2 emissions during the day and increasing during the night. This result suggests that among the 14 species, *Epipremnum aureum*, *Epipremnum Aureum (Linden & André) G. S. Bunting*, and *Pilea Cadierei* exhibited a reduction in CO_2 levels during the day ranging from 1% to 8%.

The CO_2 concentration emission of ornamental plants

Table 1 shows the ability of ornamental plants to absorb CO_2 per leaf area. The average CO_2 levels for each plant over 24 hours were determined *Epipremnum aureum*, *Epipremnum aureum (Linden & André) G. S. Bunting*, *Pilea Cadierei*, and *Cordyline fruticosa (L.) A. Chev.* exhibited equal abilities to absorb CO_2, with rates of 0.03 ppm/cm^2, 0.005 ppm/cm^2, and 0.28 ppm/cm^2, respectively. *Epipremnum aureum*, when placed as a green wall, is considered suitable for minimizing energy usage in buildings [15]. Other plants in the study emitted CO_2.

The CO_2 absorption and emission abilities of ornamental plants

The plants were ranked based on their CO_2 emissions and absorptions during both daytime and nighttime, as illustrated in Figure 5. During the daytime, *Nephrolepis exaltata* and *Dracaena trifasciata* were found to emit CO_2 at rates of 249 ppm and 101 ppm, respectively, while other plants exhibited CO_2 absorption

Table 1 CO_2 concentration emission of each plant over 24 hours

Type of plants	Leaf area (cm^2)	CO_2 (ppm)	ppm/cm^2
Crinum asiaticum	1,720	504	0.29
Epipremnum aureum	1,318	-39	-0.03
Nephrolepis Exaltata	697	598	0.86
Dracaena trifasciata	2,069	123	0.06
Chlorophytum Comosum	1,366	46	0.03
Diffenbachid picta Schott	2,537	63	0.03
Spathiphyllum sp.	1,796	513	0.28
Portulacaria afra f. variegata	114	8	0.07
Peperomia obtusifolia (L.) F. Dietr	378	2	0.005
Aglaonema cochinchinense	356	7	0.02
Epipremnum aureum (Linden & André) *G. S. Bunting*	1,183	-6	-0.005
Cordyline fruticosa (L.) A. Chev.	2,653	596	0.22
Pilea Cadierei	224	-90	-0.41
Cordyline fruticosa (L.) A. Chev.	238	-66	-0.28

Remark: - to indicate an adsorption of CO_2

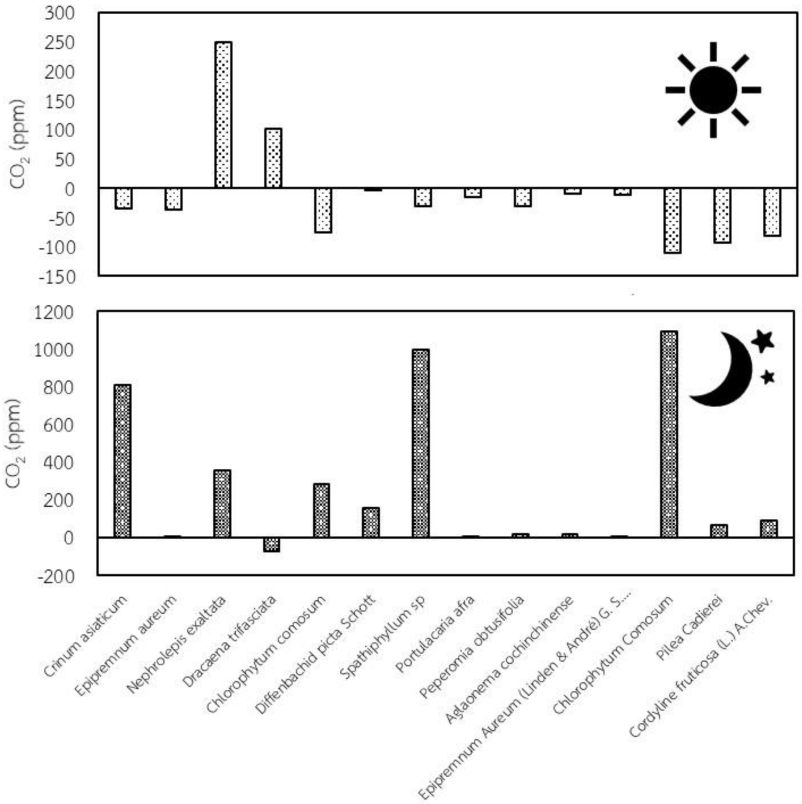


Figure 5 CO_2 concentration in day and night time

capabilities. The top four performers in CO_2 absorption during the daytime were *Chlorophytum Comosum* (110 ppm), *Pilea Cadierei* (94 ppm), *Cordyline fruticosa (L.) A.Chev.* (82 ppm), and *Epipremnum aureum* (36 ppm). Conversely, during nighttime, most plants emitted CO_2. However, *Epipremnum aureum* and *Portulacaria afra* emitted the least amount of CO_2 (2 ppm) Additionally, *Dracaena trifasciata* showed CO_2 absorption due to the Crassulacean Acid Metabolism (CAM) photosynthetic pathway, which decreases CO_2 during nighttime. When comparing CO_2 absorption under both conditions, *Epipremnum aureum* emerged as the most effective among the fourteen plants, exhibiting the lowest CO_2 accumulation in the closed chamber over 24 hours.

The Experiment for Classroom Application

From the experiment, Figure 6, it was observed *Epipremnum aureum* in classroom that the presence of 100 spotted betel plants, with a total leaf area of 108,943 cm^2, in a classroom setting led to a reduction in CO_2 levels. In a room without plants, the CO_2 concentration averaged 542 ppm over the 24-hour period. The CO_2 concentration was found to remain relatively constant 24 hours a day. However, humidity gradually increases during the night, and the temperature drops slightly. Comparison with plant, over 24-hour period, decreased at 407 ppm. It indicates that the potential of *Epipremnum aureum* can help improve the carbon dioxide levels in the air inside the classroom (Figure 7). Humidity, temperature, and carbon dioxide exhibited a relationship during daylight hours. In the morning, there is a higher absorption of carbon dioxide, correlating with increased humidity. This relationship is less pronounced in the afternoon when temperatures are higher. Stomata partially close to prevent water loss, hindering the tree's ability to fully exchange gases [28]. The rate of carbon dioxide absorption varies depending on factors such as the plant's type, age, structural characteristics, leaf arrangement, stomata distribution, and environmental conditions. External factors, including light, temperature, and humidity, also play a significant role [29-30].

Figure 6 *Epipremnum aureum* in classroom

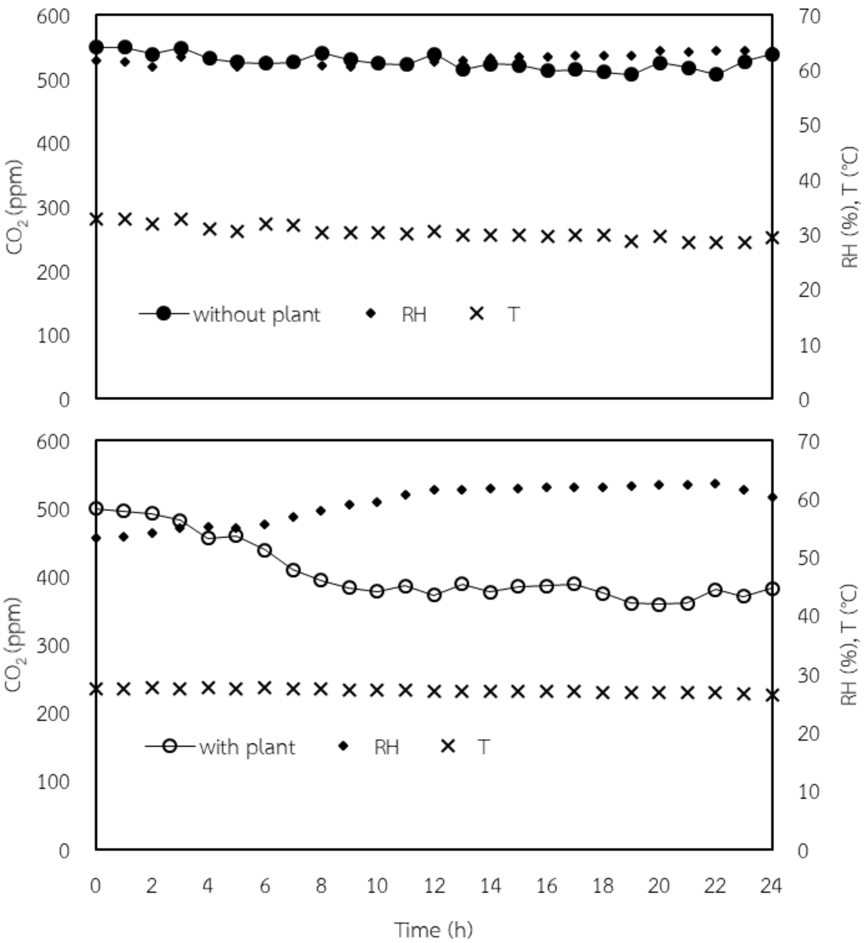


Figure 7 Average CO_2 concentration in the classroom over a 24-hour period

Conclusion

This study effectively demonstrated the potential of plant-based air purification in reducing CO_2 indoor air. As urbanization continues, it becomes increasingly important for individuals, businesses, and governments to consider incorporating ornamental plants as a practical and aesthetically pleasing strategy for improving indoor air quality.

Epipremnum aureum and Epipremnum aureum (Linden & André) G. S. Bunting are suitable for decorating living areas such as the living room or bedroom, as they effectively reduce accumulated CO_2 in these spaces. *Cordyline fruticosa (L.) A.Chev*., *Pilea Cadierei*, *Diffenbachid picta Schott*, and *Peperomia obtusifolia (L.) F. Dietr* are also well-suited for daytime living areas like offices or classrooms due to their exceptional CO_2 absorption capabilities. However, *Crinum asiaticum*, *Nephrolepis Exaltata*, *Dracaena trifasciata*, *Spathiphyllum* sp., *Portulacaria afra f. variegate*, and *Codiaeum Variegatum Blume* are not recommended for indoor use.

In conclusion, this research recommends planting *Epipremnum aureum* or *Epipremnum aureum (Linden & André) G. S. Bunting* to decorate living rooms, bedrooms, and office areas, promoting healthier and happier indoor environments. This advice aims to encourage people to choose specific types of ornamental plants for planting to reduce carbon dioxide, a greenhouse gas that is currently an environmental problem and may pose challenges in the future.

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Creating Alternative Model to Developed Municipal Solid Waste Management Pratices for Local Government Organization with Analytical Hierarchy Process

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Abstract

This study aimed to find factors used in the selection of appropriate waste management systems and guidelines of Lam Ta Sao municipality, Lamtasao town municipality, Ayutthaya province, Thailand to create a choice of project formats that guide the future of municipal solid waste development. The Analytical Hierarchy Process (AHP) is used to analyze important factors and the results of prioritization are used to determine guidelines for creating final municipal solid waste management system options. The study found that personnel and cognitive factors have the highest priority (14.95%), followed by cooperation and process factors (14.34%), area conditions factors (12.90%), strategic waste management support factors (11.03%), economic factors (10.36%), social conditions factors (9.56%), waste management systems factors (8.53%), personnel potential factors (8.38%), budget factors (5.14%) and material factor (4.81%) respectively. The results of prioritizing factors can be used to create alternative models to develop waste management guidelines, which can be divided into 5 characteristics: (1) Options for determining personnel development guidelines. (2) Choice of various methods and processes for waste disposal to support the disposal of each type of waste. (3) Appropriate waste management options through participatory processes. (4) Options for setting waste management guidelines in multiple situations with a spatially integrated method and (5) Choice of concepts and working principles that are consistent with the waste management strategy. The factors obtained from this study can be used as the main guideline for selecting a waste management model in the study area. Other related spatial data can also be added as supplementary data for determining the other necessary details. However, this study still requires the use of many working mechanisms, especially those of the government sector. Moreover, this study also requires the use of up-to-date studies of all dimensions of data to be able to develop better efficiency.

Keywords : waste management; Analytic Hierarchy Process; alternative model

Introduction

At present, the waste management model that is often chosen in various areas is usually chosen according to the characteristics of the area in which particular activity is the only main activity and there are not many choices to choose. General methods include generally area where solid waste categorized into agricultural waste, municipal waste, industrial waste, house hold waste, and special waste (e-waste, medical waste, plastic waste, and construction waste) [1]. All around the world solid waste management is a challenge for the cities' authorities in developing countries mainly due to the increasing generation of waste, the burden posed on the municipal budget as a result of the high costs associated to its management, the diversity of factors that affect the different stages of waste management and linkages necessary to enable the entire handling system's functioning [2]. Most developed countries have effectively implemented the solid waste management (SWM) hierarchy and are now focusing heavily on reducing, reusing, and recycling of MSW. On the other hand, SWM has become very serious in low-income and low-middle-income countries because most of the MSW are open dumping and most countries are dependent on inadequate waste infrastructure [3]. The amount of municipal solid waste will rapidly increase in each area or in each city and it will inevitably affect the various aspects, especially in areas which have more people and many activities. These wastes have a negative impact on humans and the environment. There are difficulties in managing the environmental impact. Spatial management is therefore an important factor in solving environmental problems [4].

The environmental quality situation in Thailand in 2020, it was found that the solid waste situation generated was approximately 25.37 million tons, a decrease of 4% from 2019. Hazardous waste from the community generated approximately 658,651 tons, an increase of 1.6% from 2019. Infectious waste was generated at 47,962 tons, a decrease of 10 percent from 2019 in which 8.36 million tons of waste has been reused. Solid waste properly disposed was 9.13 million tons. 7.88 million tons of improperly disposed solid waste and 4.25 million tons of residual waste were classified, according to management, as being usable by 33%, correct disposal by 36% and incorrect disposal by 31.1%. Bangkok, the capital city of Thailand, has given importance to waste management from the past to the present. It has been found that the densely populated capital uses a large amount of budget to manage solid waste [5]. The above information, it is shown that the government has to spend a large amount of money to manage the community solid waste problem. Budget expenditures are for development and normal operations according to the classification by work type (2012-2021) of the National Statistical Office in the Government Finance Statistics (GFS) standards of 2001. In 2021, the environmental budget amounts to 16, 143.4 million baht. Preparation of annual expenditure budget for fiscal year 2020 of the Budget Office for fiscal year 2021. The government has given importance to carrying out missions to drive the national strategy according to the master plan. National strategies and government policies have been established with the goal of reducing inequality, promoting the quality of life, strengthen the domestic economy to create development while protecting the environment. This creates a balanced development in terms of economy, society, culture, security, natural resources and the environment. In waste management, every country, especially developing countries including Thailand, is facing waste management problems. This is because, in many areas, it was found out that there was a problem of residual garbage. This will cause a large amount of garbage to remain in the area and increase every year, causing the problem of garbage overflowing in the city [6]. Phra Nakhon Si Ayutthaya Province is located in the central region. The province's Gross Provincial Product (GPP) value is the third highest within the country and is classified as an important industrial economic zone. The resulting in the amount of solid waste generated in the province. In 2021, there was 1,287 tons/day of waste, divided into 197 tons/day of solid waste that was recycled 644 tons/day of correctly disposed solid waste, and 446 tons/day of incorrectly disposed waste. In 2021, the Environment Office Region 6, Phra Nakhon Si Ayutthaya Province, has taken steps to promote and develop efficient and appropriate management of waste disposal sites according to academic principles. It was found out that in Phra Nakhon Si Ayutthaya province, waste separation is promoted from the sources and decomposed wastes are used for their maximum benefit such as plastic waste, metal, glass are used for recycling and some food scraps are used for household compost or sold for extra income. The government agencies should issue measures or policies on waste separation to promote a clear and strict community such as promoting people for waste separation by themselves. This will help reduce waste disposal costs of responsible agencies.

Lam Ta Sao Municipality is located in the Wang Noi District area, Phra Nakhon Si Ayutthaya Province. It is located approximately 65 kilometers from Bangkok along Phahonyothin Road. The area consists of 4 sub-districts and 17 villages, with a total population of 21,510 people. The municipality's waste management model involves collection of waste, generated by the community and various sources, to a waste disposal site and the disposal of municipal solid waste using a hygienic landfill method for areas under the responsibility of the municipality. It consists of land use zones with a wide range of activities. The important activities are industrial area. The area has a dense population due to the increase in industrial factories and other activities that follow from having an industrial community. For analyze key factors for waste management in this study, the analytical hierarchy process (AHP) was used in considering guidelines for selecting a waste management system. The study data can be developed and used for further consideration of alternatives and waste management methods which may lead to studies of other related dimensions. Overall, this can eventually lead to an effective action plan or setting up of a project to request an operating budget.

Material and Methods

Tools and data collection

Tools for collecting primary data include using a hierarchical analysis process assessment form from experts for considering and deciding on alternative methods for solid waste management. It was used to group the importance of factors in evaluating waste management systems of Lam Ta Sao Municipality, Wang Noi District, Phra Nakhon Si Ayutthaya Province. The theory, concepts, research, and various related documents data collection was done in 2 main formats as follows: (1) Primary Data, data collection was carried out and selecting relevant factors from the documents to summarize before sending to 8 experts and grouping them to priority. (2) Secondary Data, collects information from a literature review, including theories, concepts, researchs, and various related documents of relevant agencies.

Data analysis

For this study, an analytical tool was used to determine the Index of Item Objective Congruence (IOC) to check the quality of research tools including a survey of factors used in selecting waste management methods. 5 experts were asked to check the accuracy of the instrument using the IOC as the consistency index between factors affecting solid waste management. Factors that are consistent with scores greater than 0.6-1.0 were used in the hierarchical analysis process, which can be grouped into 10 main factors and consisted of 38 secondary factors. They are people with qualifications related to solid waste management. A total of 5 people having 2 groups of experts complete the questionnaire, divided into solid waste management experts and engagement experts.

Hierarchical analysis process

This study collected data from a survey area. Study information from documents were studied and analyzed for important factors of the solid waste management system of Lam Ta Sao subdistrict Municipality, Wang Noi district, Phra Nakhon Si Ayutthaya province. Data were analyzed by experts who evaluate important factors in waste management in order to use important factors to create guidelines for selecting appropriate management models. The importance value for comparing each factor which can be converted to numbers Between 1 and 9 results from each pair of comparisons when completed the weight of each factor can be calculated as a number to clearly show the importance of each factor using the technique of hierarchical analysis process. (This is the average score from 8 experts) The analysis steps are as follows.

Step 1 : Determine the purpose of the problem to be decided, study documents and review literature by considering guidelines, principles, adetermining options and factors affecting solid waste management of Lam Ta Sao Municipality, Wang Noi District, Phra Nakhon Si Ayutthaya Province.

Step 2 : determine the factors used as decision criteria for using in the hierarchical analysis process. The selection of criteria or key factors, to be used in the analytical hierarchy process, are based on the results of the current data analysis of the study area and this is done by selecting criteria or factors related to solid waste management of Lam Ta Sao Municipality, Wang Noi District, Phra Nakhon Si Ayutthaya province from related theories and literature review in the field of solid waste management. Then, the collect criteria or factors related to solid waste management of Lam Ta Sao Municipality, Wang Noi District, Phra Nakhon Si Ayutthaya province came out which can be grouped into 10 main factors and 38 secondary factors as shown in Figure 1.

Step 3 : Data factors, used in analytical hierarchical process analysis, consists of primary and secondary factors and were defined from studying related theories and literature review. These factors were then used to create a hierarchy chart in solid waste management field. The top layer is the objective. Next are the main factors affecting the choice of method. The second order is even lower and the secondary factors was a component of the main factors. Summary of factors was obtained to prioritize the solid waste management system of Lam Ta Sao Municipality, Wang Noi District, Pranakhon Si Ayutthaya province. To prioritize each factor, factors are created into groups and analyzed for their importance by experts with the hierarchical analysis process (AHP) using a questionnaire as a tool and the principle of pairwise comparison (Pairwise Comparison) of factors, in which it is divided into ratings of the importance of the comparison between the two factors. By replacing values with numbers 1 to 9, it shows that the first factor is more important than the factors being compared at the low level, the medium level, the high level, and the highest level. The questionnaire was sent to 8 experts to evaluate and rate the created questionnaire. For the results, the average weight score are calculated for the main factors, secondary factors and priorities in developing the waste management system of Lam Ta Sao municipality, Wang Noi district, Phra Nakhon Si Ayutthaya province.

Analysis of the results of scores from expert questionnaire evaluation using the Expert Choice 11 program. It is a tool to support multi-criteria decision making based on a hierarchical analysis process. The scores obtained from the assessment show the importance of the main factors. The results of important factors from the analysis are ranked by using the prioritization process. There are ten main factor groups, which are divided into the secondary factors as shown in the picture.

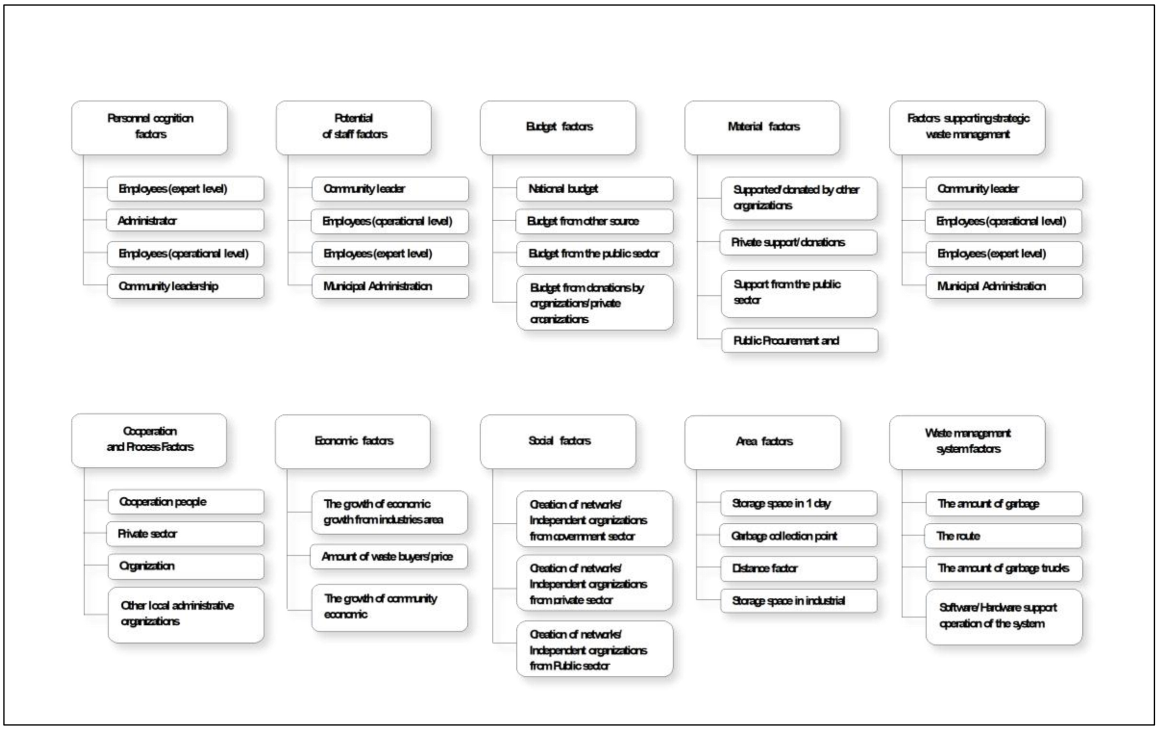

Figure 1 Factors related to urban waste management systems of Lam Ta Sao Municipality, Wang Noi District, Phra Nakhon Si Ayutthaya Province

Results and Discussion

The important factors of the waste management system of Lam Ta Sao Municipality, Wang Noi District, Phra Nakhon Si Ayutthaya province are analyzed by using a hierarchical analysis process to find guidelines for application. By analytical hierarchical process using a questionnaire that has passed the tool quality checking process. The questionnaire was sent to experts for consideration and in-depth interviews of 8 people from main factor analysis using the Expert Choice 11 program. The results of the analysis were obtained as follows: 1. Analysis results of main factors for urban waste management system in Lam Ta Sao Municipality, Wang Noi District, Phra Nakhon Si Ayutthaya province are as follows: A = Personnel cognition factors, B = Potential of staff factors, C = Budget factor, D = Material factor, E = Factors supporting strategic waste management, F = Cooperation and process factors, G = Economic factors, H = Social factors, I = Area factor and J = Waste management system factors.

1. Results of weight analysis and prioritization for main factors. The data obtained from questionnaire responses from 8 experts and from the analytical hierarchy process using the Expert Choice 11 program that is used to calculate the importance of the main factors. It can be seen that personnel factors cognition has the highest importance value of 14.95% compared to other factors. The second highest important factor is the cooperation factor and process (14.34%). It was followed by the area conditions factor (12.90%), waste management support factor according to strategy (11.03%), economic factors (10.36%), social conditions factors (9.56%), waste management system factors (8.53%), personnel potential factor (8.38%), budget factor (5.14%) and material equipment factor (4.81%), respectively.

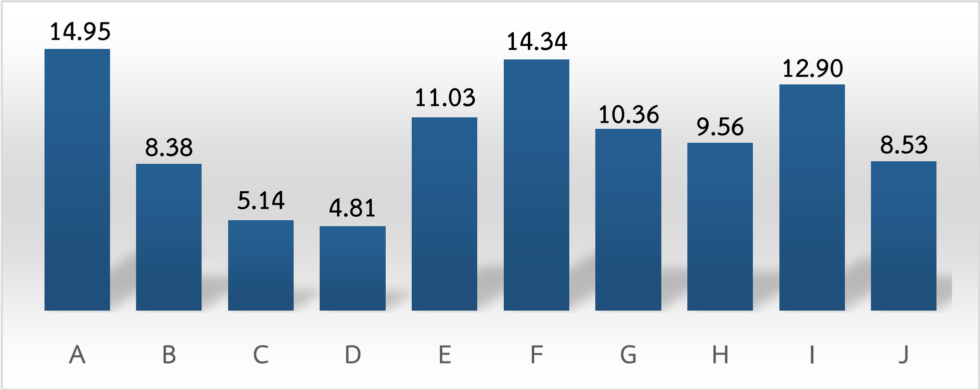

Figure 2 Bar chart showing the priority of key factor groups

2. Results of weight analysis and prioritization of secondary factors

1) For secondary factors under the main personnel factor cognition, it was found that the employee factors (Expert level) has the highest importance value of 38.68% compared to other factors, followed by municipal administrators' factors at 31.35%, employee factors (operational level) (15.05%) and community leadership factors (14.94%), respectively.

2) In terms of the secondary factors under the main potential factors Personnel aspect, it was found that the factors of municipal administrators has the highest importance value (40.06%) when compared to other factors next is the employee factor (expert level) (32.73%), employee factors (Operational level) (14.01%), and community leadership factors (13.21%), respectively.

3) Regarding the secondary factors under budget factor, it was found that the national budget factor has the highest importance value of 49.63% compared to other factors. Followed by budget factors from donations by organizations/private organizations at 22.09%. Budget factors from other channels and from the public sector were 15.88% and 12.38%, respectively.

4) For secondary factors under material and equipment factors, it was found that factors from purchasing according to budget regulations. It has the highest importance value of 30.03% compared to other factors. This was followed by factors from support from the public sector (26.33%), factors from support/donations by the private sector (22.99%) and from support/donations by other organizations/ independent/networks (20.65%) respectively.

5) For secondary factors under the factor of supporting strategic waste management, it was found that the agency policy factor has the highest importance value of 30.61% compared to other factors, and was followed by local development plan factors at 30.38%, the agency's municipal ordinance factor at 21.46%, and the regulations/practice factor at 17.55%, respectively.

6) In terms of secondary factors section under the side factors Collaboration and process support, It was found that factors from the people has the highest importance value of 33.74% compared to other factors. It was followed by agency/departmental/organizational factors (22.86%), private sector factors (21.86%), and surrounding local government factors (21.54%) respectively.

7) Regarding the secondary factors under economic factors, it was found that the economic growth factor is from having industry in the area. It has the highest importance value of 49% compared to other factors. Followed by the factor of number of waste purchasers/price at 29.26% and community economic growth factors of 21.73%, respectively.

8) As per social factors score information for secondary factors, it was found that the factors for creating networks/independent organizations from the public sector has the highest importance value of 41.25% compared to other factors Followed by the factor of creating networks/independent organizations from the

private sector at 30.78% and factors for creating networks/independent organizations from the government sector 27.91%, respectively.

9) For area factors conditions score information for secondary factors, it was found that the number of fur collection areas in 1 day is a factor, the highest importance value of 31.54% compared to other factors. The second highest importance factor is the factor of garbage collection points (garbage resting points), waiting for collection (29.26%), distance factor between the municipality and waste management site (26.11%), and the factors of collecting hair in a specific area (industrial zone) (13.08%), respectively.

10) For factors of waste management system score information for secondary factors, it was found that factor for software/ hardware support of system operation has the highest importance value of 30.45 % compared to other factors, followed by the bus route factor at 28.21%, the factor of the number of garbage collection vehicles is 26.33% and the number of garbage collection employees is 15%, respectively.

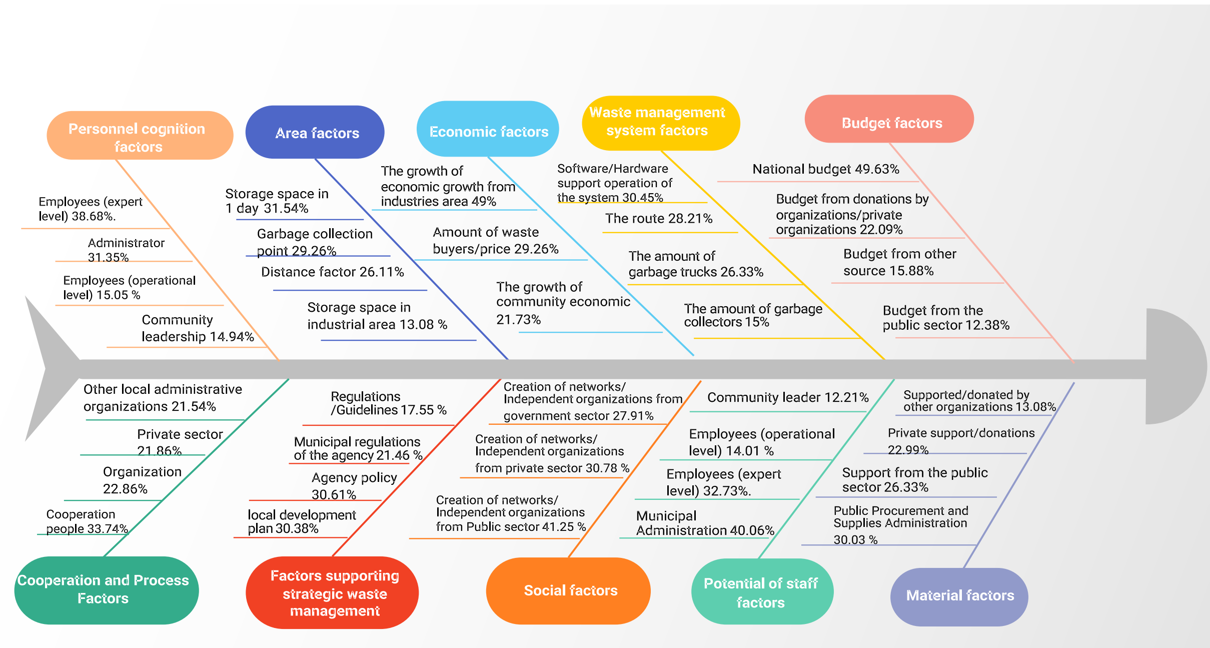

Figure 3 Analysis of factors used in managing waste management systems of Lam Ta Sao Municipality, Wang Noi District, Phra Nakhon Si Ayutthaya province

The study analysis of factors used in managing waste management systems of Lam Ta Sao Municipality, Wang Noi District, Phra Nakhon Si Ayutthaya province using the analytical hierarchy process. In analyzing important factors examine the analysis results using the analytical hierarchy method to be used to consider guidelines and solid waste management systems. The prioritize the main factors with importance to use as an appropriate waste management guideline, it was found that the main factors with the highest average importance values were (1) Personnel factors cognition It has the highest importance value of 14.95% compared to other factors, followed by Cooperation and process factors (14.34%), Area condition factor (12.90%), Factors supporting waste management according to strategy (11.03%), Economic factors (10.36%), Social factors (9.56%), Waste management system factor (8.53%), Personnel potential factor (8.38%), Budget factor (5.14%), and Materials and equipment factors (4.81%), respectively.

For the secondary factors under the main factors with the highest averages, the top 3 factors are as follows : Personnel factors cognition has the highest priority value with the average of the secondary factors of employees which has an importance value of 38.68%, the highest compared to other factors followed by municipal administrators' factors at 31.35 % and employee factors, (Operational level) (15.05%), and community leadership factors (14.94%) respectively.

For the ranking 2, secondary factors under the main factors are cooperation and process factors by the average of the secondary factors in the part of cooperation from the people factor, it has the highest importance value of 33.74%, followed by the factors of organization factor (22.86%), private sector factor (21.86%) and the other local administrative organization factors (21.54%) respectively. The next one is the main factor of area factors, there was an average of the secondary factors in terms of storage space in 1 day factor (31.54%), followed by the factor of garbage collection points (29.26%). The factor of distance between the municipality and the waste management facility, and collecting hair in a specific area (industrial zone) were 26.11% and 13.08% respectively. The research results, the main factors with the highest average importance values from the ratings by experts is the personnel factor. Cognition the second factor with the highest average importance is the employee factors (expert level) with an average value of 38.68%. The study of theories, concepts, research, and various related documents, it was found that the research results were consistent with the SWOT analysis in the local development plan with 2023-2027 year of Lam Ta Sao Municipality. From the analysis of strategy number 1: infrastructure development, number 2: development of quality of life and environment, which are obstacles (Threat) in work or projects that require special expertise Lam Ta Sao Municipality does not have the expertise and personnel. Therefore, it can be concluded that the important factors that will affect the success of waste management are: Focusing on developing personnel to work with understanding and has direct expertise in waste management and executives must have a broad vision and systematic thinking Including allowing people to participate in operations.

The results of prioritizing factors can be used to create alternative models to develop waste management guidelines, which can be divided into 5 characteristics: (1) Options for determining personnel development guidelines, (2) Choice of various methods and processes for waste disposal to support the disposal of each type of waste, (3) Appropriate waste management options through participatory processes, (4) Options for setting waste management guidelines in multiple situations with a spatially integrated method and (5) Choice of concepts and working principles that are consistent with the waste management strategy.

1. Options for determining personnel development guidelines using main factors to determine development guidelines. The results of the study of the main factors found that the 3 main factors are most important: (1) personnel cognition factors, (2) cooperation and process factors and (3) area factors. It can be seen that supporting and encouraging personnel to develop their potential is important. If personnel have activities or continuous development of their potential, especially workers, it will create a process of development of cooperation and working with good results. Activities for developing personnel to be effective may not just include study tours but may also include promoting workers to have the opportunity to increase their knowledge and abilities in the field.

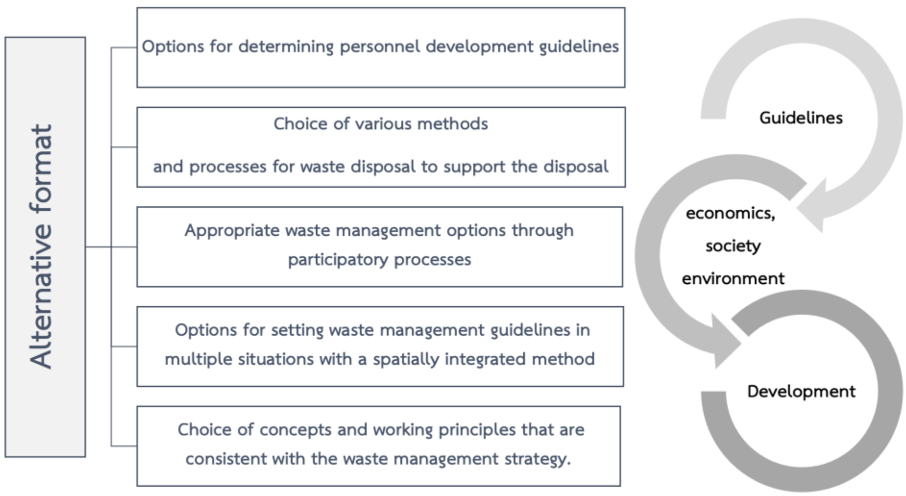

Figure 3 Alternative waste management models to develop waste management systems

2. Choice of various methods and processes for waste disposal to support the disposal of each type of waste that has different quantities and proportions in each connected area. Selecting a disposal method can integrate more than just one method. There are various methods of elimination. In some processes, it may not require a large budget but is highly efficient. And some methods can invest in creating a system that is not too expensive but can manage waste in the long term. This will be beneficial to areas that have a variety of activities as a result of the activities of people in the area, such as urban area with industries, town with tourist attractions, city with large agricultural, operations port or economic city. A city that has a unique context for economic development in various dimensions [7].

3. Appropriate waste management options through participatory processes. It is necessary to study the current management conditions in order to extract lessons and use the results of the study to develop other models. Lesson taking process by using relevant people, if the same methods or management styles are used, problems and limitations can be analyzed more accurately than using just one department [8].

4. Options for setting waste management guidelines in multiple situations with a spatially integrated method. Determining situations that are likely to occur, such as migration for work in industrial areas will inevitably cause dense communities concentrated in the area or the outbreak of certain types of diseases in community areas. Industrial zones must have measures to support specific areas. However, having various types of spatial data will allow formulas or guidelines for waste management to be determined based on such spatial data [9].

5. Choice of concepts and working principles that are consistent with the waste management strategy. An important point for selecting concepts or principles is that although concepts can be practically implemented according to the local context, it should be selected in order to be consistent with the physical characteristics of the area, topography, and people's way of life, which is considered an important part in development [10]. Because the selection of waste management principles and concepts must be appropriate to the local context in order to make waste management reach its goals more quickly. Applying various principles should choose an approach that has a variety of methods. Being able to be flexible according to the situation will allow work to be adjusted in different periods of time, which is an advantage of having a work process that is constantly changing which is suitable for diverse areas and can make waste management sustainable [11].

Although the results of data analysis can lead to options of creating a waste management system, the process of determining the details of the system still requires to study their suitability in many other related parts [12]. This requires important statistical data to be up to date so that the data can be connected and found relationships among each variable [13]. The planning to create a management system with good options may choose to carry out more than one option if it is not beyond the potential of the operating agency and the operator can drive it [14]. This can be done by adding secondary options or sub-alternatives that may be able to support or enhance the potential of the main system options obtained from this study or there can be further development of other alternative studies that can be done with reliable educational information to support them [15].

Conclusion

The decision on the form and method of waste management of local administrative organizations in areas, with a variety of activities and high economic growth, is a challenge. There are a number of limitations in the area that may pose risks and result in management and operational failures. Even though the government has a policy with a clear operational plan, selecting a management method for spatial problems may be considered a burden that the agency must manage on its own. Using up-to-date, accurate and reliable information and having a high possibility of action makes a very attractive option for small organizations to choose an integrated waste management approach. Obtaining guidelines for choosing a waste management model is, therefore, very important in terms of management because it is relevant to future work. In addition, the appropriate management style still need to rely on various data sets to consider various processes that do not include social processes. Creating the right guidelines can help the organization develop in the right direction, answers various policies and strategies very well, and it can also raise the organization's ability to keep up with the situation. It is considered one of the achievements in environmental management of the local government.

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