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Preliminary Study of Using Water Accounting Framework for Wastewater Utilization: Case Study in Samutprakarn Province, Thailand

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Abstract

The availability of water resources for economic purposes has declined because of increasing demands for water. This situation is also worsened by climate change and more stringent environmental regulations. Water scarcity and the increasing volume of wastewater resulting from better sewerage systems and wastewater treatment have given rise to opportunities for previously untapped wastewater reuse and recycling. In light of challenges in water resource planning and management, water accounting has emerged as a suitable method to enhance transparency and control in water management. This research focused on using water accounting as a tool for water management and emphasized the utilization of wastewater at the provincial level. Samut Prakan Province in Thailand was chosen as the study area according to its diverse range of activities, including residential areas, industrial zones, commercial sectors, paddy fields, and freshwater and coastal aquaculture. The results of water accounting in Samut Prakan from the 20 years of annual means (1999 - 2019) showed that the main water supply source of the study area was the Chao Phraya River. The gross inflow in the study area was 1,738.06 million cubic meters (MCM)/year. The inflow consisted of 1541.30 MCM/year of rainfall, 195.00 MCM/year of runoff (river and canals), and 1.76 MCM/year of subsurface water or groundwater. The total amount of the treated wastewater was 974.47 MCM/year. To incorporate wastewater into water accounts for the purpose of water reuse, the total cost of wastewater treatment and the total cost of municipal water supply production and provision were compared. The total cost of wastewater treatment was 4.83 Baht/m^3 (≈ 0.134 USD) and the total cost of municipal water supply production and provision was 0.97 Baht/m^3 (≈ 0.027 USD). The study found that wastewater could be added into water accounts due to the significant volume of wastewater available for reuse or recycling, which could provide higher returns on investments in water and sanitation. However, treating wastewater for reuse was more costly than producing municipal water. Nevertheless, wastewater reuse can contribute to environmental and health benefits. Furthermore, water accounting can provide essential information for addressing issues related to water demand and utilization, benefiting those responsible for water governance and management. It can play an important role in facilitating decision-making, problem recognition, solution design, implementation, monitoring, and adaptation, ultimately promoting sustainability and equity in water utilization.

Keywords: Water accounting; Water management; Wastewater utilization; Water reuse

1. Introduction

Water resources are fundamentally essential to human life and national development. The natural water used by people in every area includes (rainfall), surface water, and groundwater. Due to increases in agriculture, industry, tourism, and services, it is necessary to establish effective water resources management. One in ten people worldwide now lacks access to safe water, and about 2.3 billion people live without adequate water sanitation (World Economic Forum, 2021). Therefore, equitable, efficient, and sustainable management of water resources would be an approach that could promote water sanitation and access to safe and sufficient water for people. In addition, this approach to water management could also reduce the water pollution problems caused by wastewater releases from industrial sectors that affect the quality of surface and underground water, which these waters would be the water for drinking and utilization. Besides, Sustainable Development Goal 6 aims to ensure water availability and sustainable water management and sanitation for all (United Nations, 2021). This goal is a huge challenge to reach for Thailand and all other countries. However, the previous report revealed that 40% of the world's population is still affected by water scarcity (United Nations Development Programme, 2021).

Water accounting is a tool to support policymakers in making informed decisions related to water availability and use, water resources allocation, water infrastructure investment, water use efficiency improvement, users' understanding of the water management impacts, and setting an available standardized information system (United Nations, 2012). In Thailand, water accounting is used as a water management tool for river basins and provinces. It assists in understanding existing water supply costs and economic water demands. Apart from the natural water supply, wastewater from the community and industrial activities should also be considered for its utilization value. Wastewater from these sources can be treated using advanced technologies for reuse. This research focused on using water accounting as a tool for water management and emphasized the utilization of wastewater at the provincial level and the activity area, which was different from previous studies that examined the water and river basins (Bassi *et al.,* 2021; Momblanch *et al.,* 2014). Water accounting can indicate whether the amount of water in a country or activity area is low, high, or average. It also aids in managing both water provision and distribution, particularly during droughts. Water accounts can be compared across areas and countries regarding available water and water usage, water usage efficiency, and its possible connection to the water usage output. The outcomes of investments in water resource development would also be evaluated. While water accounting has numerous advantages, its implementation can be challenging, especially in developing countries where organizations for clean water management often lack effective water resource management (Tingey-Holyoak, 2019). Regarding water sources, water accounting faces uncertainties in both quantity and quality over time. Additionally, the absence of hydrometric monitoring stations and measuring instruments in clean water management leads to the inability to accurately measure the current and future water quantities in the water sources (Elmahdi *et al.,* 2015). Hence, it is critical for water suppliers to manage clean water effectively.

Samut Prakan Province in Thailand has residential, industrial, commercial, paddy fields, as well as freshwater and coastal aquaculture activities. These activities demand a significant amount of water and result in substantial wastewater discharges into the environment. According to the Royal Irrigation Department (2018), the average water shortage over the next ten years is expected to be 710.61 MCM/year and estimated to reach 408.0 MCM/year over the next twenty years. In addition, Samut Prakan Province also has soil resources, with a total area of approximately 604,422 Rai ($\approx$ 967 km^2), located in two basins, namely the Chao Phraya River Basin and the Bang Pakong Basin, the province area of 263,710 Rai ($\approx$ 422 km^2) is for agriculture (43.71%) and aquaculture (38.16%). Regarding the wastewater situation in Thailand, the amount of wastewater was

9.7 MCM/day from 21 million households across the country. Unfortunately, only 2.6 MCM/day of wastewater could be treated by the 105 community-based wastewater treatment systems (Pollution Control Department, 2019). Moreover, industrial wastewater management requires treatment during the production process and sewerage systems to meet standards before discharge into the environment. Therefore, if the quality of wastewater can be improved and reused for other activities, the use of water from natural water sources can be decreased. Nonetheless, no previous studies in Thailand have examined the wastewater reuse of each sector in terms of water accounting. As a result, the objectives of this study were to identify and quantify wastewater from the point sources and to apply water accounting as a tool for planning water management and wastewater utilization in Samut Prakan Province, Thailand.

2. Methodology

2.1 Study area

This research study was conducted in Samut Prakan Province on the banks of the Chao Phraya River in Thailand. The province is at the end of the Chao Phraya River and above the Gulf of Thailand. It is between Latitude: 13 - 14 ºN, Longitude: 100 - 101 ºE, with a total area of approximately 1,004.092 km². The distance from the southeast of Bangkok to Samut Prakan is about 30 km. Samut Prakan Province utilizes its areas for various purposes. Figure 1 illustrates different zones within the province. The residential zones are yellow, orange, brown, and red. Industrial and warehouse areas are purple. The warehouse areas are pink. Non-polluting industrial zones are in white with a purple border. Lastly, dark green, light green, and white with a green border represent industrial zones.

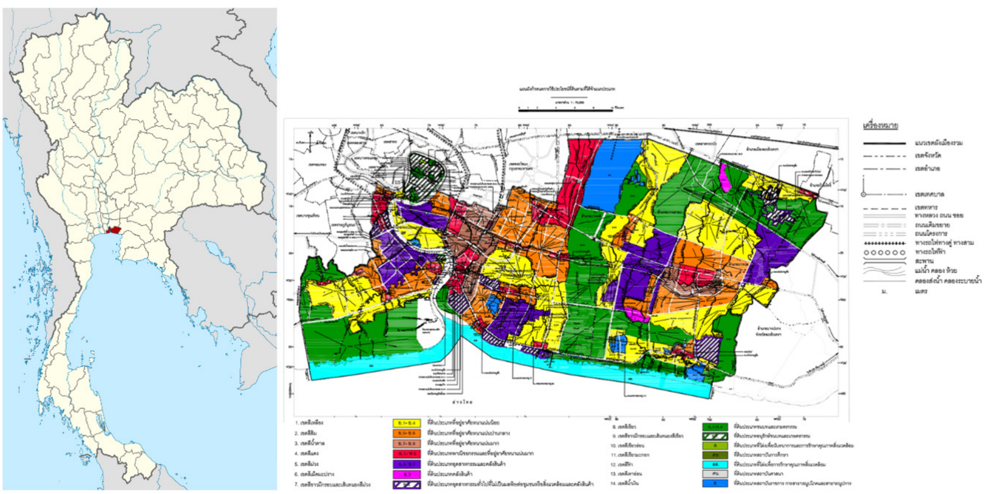
2.2 Methods

2.2.1 Water accounting

Concepts and principles of water accounting are an analysis of water consumption, loss, and units of water products, as shown in Figure 2. Water accounting has a basic principle similar to water balance, which considers the amount of water inflow and outflow from the domain. Water accounting can be analyzed in three levels including the basin, the irrigation service, and the field. The water balance equation is shown in eq.1 (Molden, 1997).

$$\Delta S = \sum \mathrm{I} - \sum \mathrm{o} \qquad \text{eq. 1}$$

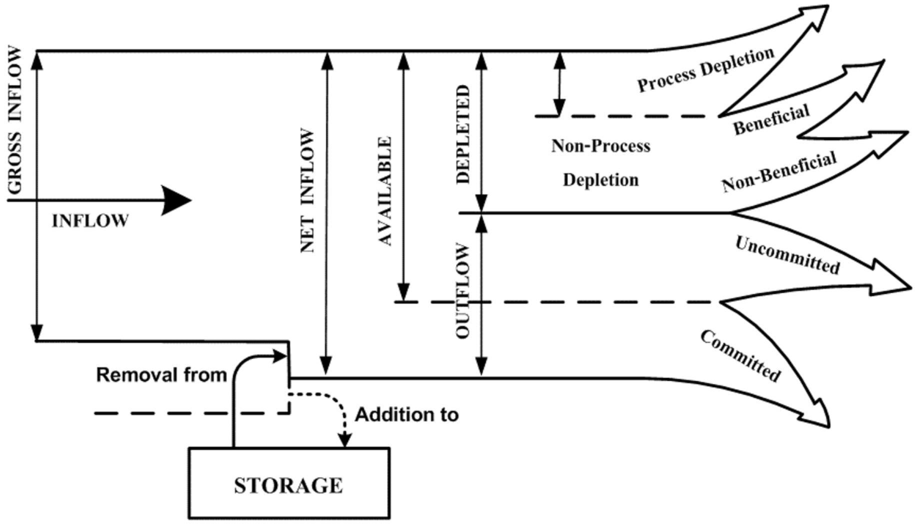
Where;
$\sum \mathrm{I}$ = Sum of the amount of water inflow
$\sum \mathrm{o}$ = Sum of the amount of water outflow
ΔS = Change in water volume



Source: Wikipedia, 2021; The Royal Gazette, 2013

Figure 1. Location of the study area

The terms related to water accounting and their definitions are separated according to the water usage activities and summarized in Table 1.



Source: Talaluxmana & Kwanyuen, 2012

Figure 2. Water accounting

Table 1. Water accounting terminology (Charoenjiratrakool & Kositsakulchai, 2005)

Terminology	Definitions
1.Gross inflow (GI)	The total amount of water inflow in a considered domain, consisting of rainwater, surface runoff, and groundwater.
2. Net inflow (NI)	The amount of water inflow in a considered domain, combined with any changes in reservoirs.
3. Water depletion (WD)	Used or lost water that cannot be reused. There are 4 categories of water depletion: - Evaporation; water that is lost due to evaporation from the soil surface water, and plant transpiration - Flow to sink; water flowing into an area that makes the water not reusable or not worth reusing such as areas with high salinity - Pollution; substandard water that is not suitable for use - Incorporation into a product; water included into both agricultural and industrial products such as bottled water or water that becomes a part of a plant.
4. Process consumption (P)	Water used to create products for human needs
5. Non-process depletion (NP)	Lost water that does not create the products for human needs. This water may be lost beneficially (beneficial) or uselessly (non-beneficial).
6. Committed water (C)	Determined amount of water that flows out of a considered domain under various agreements, for example, maintaining ecological balance or downstream water users' rights.
7. Uncommitted outflow (UC)	Water flowing out of a considered domain. This portion of the water is the remainder of a loss and has no binding commitments. There are utilizable outflow (UO) and non-utilizable outflow (NUO), depending on management and tools
8. Available water (AW)	The net inflow (NI) deducted by the water with binding commitments (C) and non-utilizable outflow (NUO) (AW = NI – C - NUO), or the sum of lost utilized water (P), lost non-utilized water (NP) and utilizable outflow (UO) (AW = P + NP + UO)

2.2.2 Application of Water Evaluation and Planning system (WEAP)

The Water Evaluation and Planning System (WEAP) is an integrated water resource planning tool that supports experts in database planning for forecasting and water management policy analysis (Lévite *et al.,* 2003). The WEAP approach operates on the water balance principles by arranging the demand side equations including water usage patterns, equipment efficiency, reuse, price, and allocation equal to the supply side including water in waterways, groundwater, reservoirs, and diversions. The approach can be applied to urban and agricultural systems, single basin, or river systems with complex boundaries (Talaluxmana & Kwanyuen, 2012). The WEAP calculates water balance and pollution for all needs each month during the study period. Inflow and outflow volumes at each point are calculated to find linear programming. The goal is to achieve maximum satisfaction for the demand site and water demand in the stream determined by users, which must be under the order of rights for needs, order of rights for water sources, mass balance, and other constraints (Talaluxmana & Kwanyuen, 2012).

In this study, the concepts of the WEAP model were applied as follows.

1) To conduct water accounting according to the actual water demands, water supply sources, and the system's water reservoirs.

2) To create a project to simulate the usage of wastewater or effluents in the study area as a source for water supply based on actual water volume and demand.

3) To evaluate the simulated project by considering conditions such as water supply adequacy, investment costs and expenses, payoffs, and environmental impact.

2.2.3 Data collection

This study conducted a retrospective analysis of the data over a 20-year period through surveys, data collection, and literary works. The collected data comprehensively covered aspects of water and wastewater management, as well as water utilization. Natural capital, such as surface water, groundwater, and rainwater, was sampled, and data on their quantity, quality, and utilization were collected. In terms of the public sector, surveys and data collection were carried out to assess water usage needs. For wastewater, data on sources, quantity, and characteristics were collected to determine sources, characteristics, quantity, and current wastewater management practices based on the definite sources in the study area. The necessary data collected on water and wastewater management was subsequently employed in water and wastewater accounting. Primary and secondary data from 1999 to 2019 were obtained from relevant organizations, including the Meteorological Department, industrial estates, Metropolitan Waterworks Authority, Royal Irrigation Department, and Department of Water Resources. Additionally, various reports on water management in Samut Prakan Province were examined.

3. Results and discussion

3.1 Data analysis for water balance

3.1.1 Amount of rainfall

Rainfall is the main component for measuring the amount of water inflow in a considered domain. An accurate assessment of this component is the foundation of water accounting. From the rainfall data collection in the study area, there were only three rain gauge stations, namely Bang Yor Subdistrict Administrative Organization, Khlong Dan Municipality, and Sisa Chorakhe Yai Subdistrict Administrative Organization. The rainfall totals for 20 years from 1999 to 2019 were recorded. Therefore, the average annual rainfall data (1990-2019) were used to evaluate the water inflow in the study area, which amounted to 1,535 ± 287 mm/year. The total rainfall amount in the study area was calculated considering the province's total area of 1,004.09 km^2. The stations could support the total amount of average rainfall of 1541.30 MCM/year. The formula to calculate the amount of rainfall is as follows:

Amount of rainfall = size of the area receiving rainfall × height of rainfall

3.1.2 Amount of runoff

The water flowing in waterways or runoff was also a component for gauging the amount of inflow or outflow in the study area by using the data on the amounts and volumes (MCM) of waterways and natural water resources in the study area. The Chao Phraya River flows through Samut Prakan Province for 30 km into the districts of Phra Pradaeng, Phra Samut Chedi, and Mueang Samut Prakan. In addition, there are 542 natural canals with a total length of 1,553 km. They consist of 335 natural canals in the east of the river, with a total length of 1,168.00 km and an estimated volume of 180 MCM, and 200 canals in the west, with a total length of 385 km and an estimated volume of 15 MCM.

3.1.3 Amount of subsurface water or groundwater

The amount of subsurface water or groundwater was another important component used to estimate the amount of inflow in the study area. To assess this component accurately is crucial for water accounting. According to the data on the artesian wells by both public and private sectors, and petroleum drilling in Phasi Charoen District, eight aquifers were identified. There are two aquifers significant for use in the study area including Phra Pradaeng Aquifer and Pak Nam Aquifer, with depth of 100 and 550 m, respectively. The amount of inflow could be evaluated with the total of active 18 artesian wells in the study area, which could obtain an average of 1.76 MCM/year in total.

3.1.4 Amount of wastewater

Wastewater is also a source of water that can be considered and assessed as the water supply of inflow in the study area. A vital component of sustainable water accounting is to accurately estimate the amount of wastewater after being treated at the sources in the study area. There are three important wastewater sources in the study area consisting of domestic wastewater, industrial wastewater, and agricultural wastewater. The majority of wastewater in the study area was from factories in every district in the province. In the study area, there are two industrial estates, namely Bangplee Industrial Estate and Bang Pu Industrial Estate. The total number of factories with a contract to use the land in each industrial estate was 160 and 510, respectively. Based on the average wastewater discharged from the treatment plants of both industrial estate offices, the estimated amount of wastewater was 3,984.76 m^3/day/ factory. The total amount of the treated wastewater was 974.47 MCM/year.

3.1.5 Amount of water depletion

The amount of water that was depleted from the watersheds in the study area was determined from the two main components consisting of municipal and industrial use and evapotranspiration.

1) Domestic and industrial use of municipal water

In terms of the domestic use, the statistical data for population and water use rates of Mueang Samut Prakan District, Phra Pradaeng District, and Phra Samut Chedi District were assessed. As of 2021, there were 961,268 people in Samut Prakan Province (DoH Dashboard of Department of Health, 2021). According to the data on water use rates from Samut Prakan waterworks office, the mean of annual water use rates from 2015 to 2019 was approximately 1,027.45 MCM/capita. The amount of water for domestic use in the study area was 71.75 MCM/year. The data in the summary report on the wastewater treatment operation from the industrial estate offices were collected for the evaluation of industrial use of municipal water in 670 factories in the study area. The total industrial water use in the study area was discovered to be 227.82 MCM/year.

2) Use of subsurface water or groundwater

The statistical data for groundwater use was evaluated based on the usage types including domestic use, commercial and industrial use, and agricultural use. Since the study area is densely occupied by factories, the groundwater was mainly used for commerce and industry. The amount of groundwater for commercial and industrial use was very high at 94.92% or more than 8.11 MCM/year. For domestic use and agricultural use, the amounts of used groundwater were 1.42 and 2.92 MCM/year, respectively.

3) Evapotranspiration

The evapotranspiration of the main plants in the river basins was evaluated using the data on the agricultural water use in the agricultural area both inside and outside irrigation area during rainy and dry seasons. The depleted water from the river basins due to evapotranspiration was divided into two types: 1) the used water in the agricultural area and 2) the unused water beneficial for forest use. It was revealed that the amount of depleted water in agriculture in the study area was 387.69 MCM/year.

3.1.6 Amount of outflow

Water usually flows out of the watershed and enters estuaries and drainage canals. In this study, the water poured into the only Chao Phraya River, an important river flowing through the province from the north to the south. Continuing from Bangkok, the river flows through the districts of Phra Pradaeng, Phra Samut Chedi, and Mueang Samut Prakan before going into the Gulf of Thailand. The amount of discharged water from canals was calculated based on an analysis of the water balance in the study area using the WEAP.

3.1.7 Amount of water demand for water balance

The use of water to protect the downstream ecosystem was evaluated by comparing the water demands for downstream ecosystem preservation of the main river basins. The water demand was disclosed in the project report on data warehouse development for the 25 river basins, and flood and drought simulation by the Hydro-Informatics Institute (Public Organization) in 2012. The total area of Samut Prakan Province was compared to the total basin area in the province. Following the assessment, the water demand for the downstream ecosystem preservation in Samut Prakan was 30 MCM/year.

3.2 Water accounting, economic evaluation, and environmental benefits of wastewater utilization

3.2.1 Water accounting in the area of Samut Prakan Province based on the actual water supply sources

The results of water accounting in Samut Prakan from the 20 years of annual means (1999-2019) showed that the main water supply source of the study area was the Chao Phraya River. The gross inflow in the study area was 1,738.06 MCM/year. The inflow consisted of 1541.30 MCM/year of rainfall, 195.00 MCM/year of runoff (river and canals), and 1.76 MCM/year of subsurface water or groundwater. The major surface reservoir in the study area was under the administration and management of the Royal Irrigation Department. According to Charoenjiratrakool and Kositsakulchai (2005), the changes of the water volumes in the reservoir in the same duration throughout the year were analyzed using the WEAP and the differences were minimal. Therefore, this study set the value as zero or no change of the water volume in the reservoir. While the net inflow in the study area was 1,738.06 MCM/year, the water depletion was 752.36 MCM/year, or equal to 43.3% of the net inflow in the study area. The water depletion was caused by domestic and industrial uses for 312.02 MCM/year, evapotranspiration from the agricultural use for 387.69 MCM/year, and the unused water beneficial for forest use for 52.65 MCM/year. Meanwhile, the total outflow was 1,015.70 MCM/year, which included 30.00 MCM/year of committed outflow for ecological balance preservation and 985.70 MCM/year of uncommitted outflow as the utilizable outflow for all municipal water supply production. Moreover, the results unfolded that the available water in Samut Prakan Province was 1,738.06 MCM/year as presented in Table 2 and Figure 3.

3.2.2 Water accounting in the area of Samut Prakan Province based on the actual water supply sources and the water supply of wastewater

The results of water accounting found showed that the gross inflow was 2,712.53 MCM/year which increased due to the 974.47 MCM/year of actual water supply. Hence, the net flow was 2,712.53 MCM/year. The available water was 2,682.53 MCM/year. In terms of the total water depletion caused by the actual water use, the total outflow in the study area was 1,960.17 MCM/year as seen in Table 2 and Figure 4.

Table 2. Water Accounts of Samut Prakan evaluated from the annual average data in 1999-2019 (in MCM)

No.	Components	MCM/year
1	Gross inflow (GI)	1,738.06
	1.1 Rainfall	1541.30
	1.2 Runoff (rivers and tributaries)	195.00
	1.3 Subsurface water or groundwater	1.76
	Gross inflow (GI) including the water supply of wastewater sources	2,712.53
	1.4 Water supply of wastewater sources	974.47
2	Change of the water volume in the reservoirs	0.00
3	Net inflow (NI)	
	3.1 Water supply from wastewater sources excluded	1,738.06
	3.2 Water supply from wastewater sources included	2,712.53
4	Water depletion (WD)	752.36
	4.1 Process consumption (P) 4.1.1 Municipal and industrial uses - Domestic use of municipal water - Industrial use of municipal water - Domestic use of subsurface water - Industrial use of subsurface water - Agricultural use of subsurface water 4.1.2 Evapotranspiration - The water used in the agricultural area	699.71 312.02 71.75 227.82 1.42 8.11 2.92 387.69
	4.2 Non-process depletion (NP) - Unused water beneficial for forest use - Unused and nonbeneficial water	 52.65* 0.00
7	Total outflow - Water supply from wastewater sources excluded - Water supply from wastewater sources included	 1,015.70 1,960.17
	7.1 Committed outflow (C) - For ecological balance	 30.00
	7.2 Uncommitted outflow (UC) - Water supply from wastewater sources excluded - Water supply from wastewater sources included	 985.70 1,930.17
	7.2.1 Utilizable outflow (UO) - Water for municipal water supply	 985.70
	7.2.2 Non-utilizable outflow (NUO)	0.00
8	Available water (AW) Net inflow after removing committed outflow and non-utilizable outflow (AW = N – C - NUO)	
	8.1 Water supply from wastewater sources excluded	1,738.06
	8.2 Water supply from wastewater sources included	2,682.53

Remark: * The amount of unused water that was beneficial for forest use was equal to 27% of the total runoff (Tangtham, 1999)

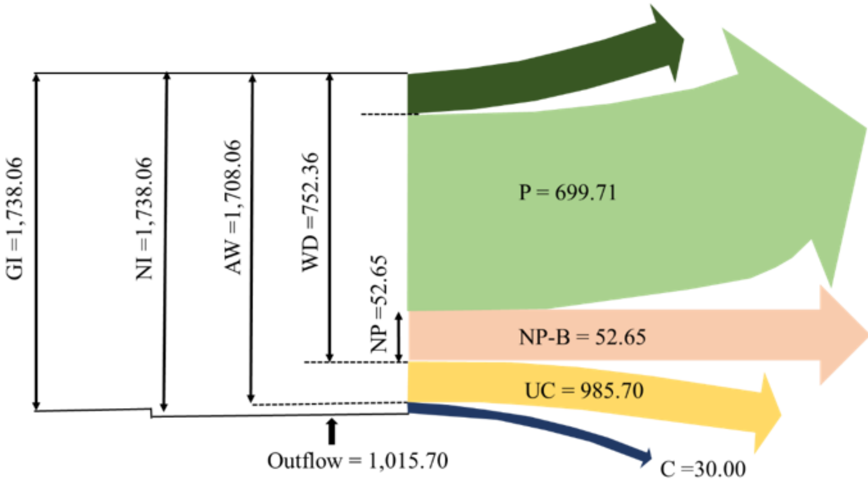


Figure 3. Annual water accounting of the area in Samut Prakan Province

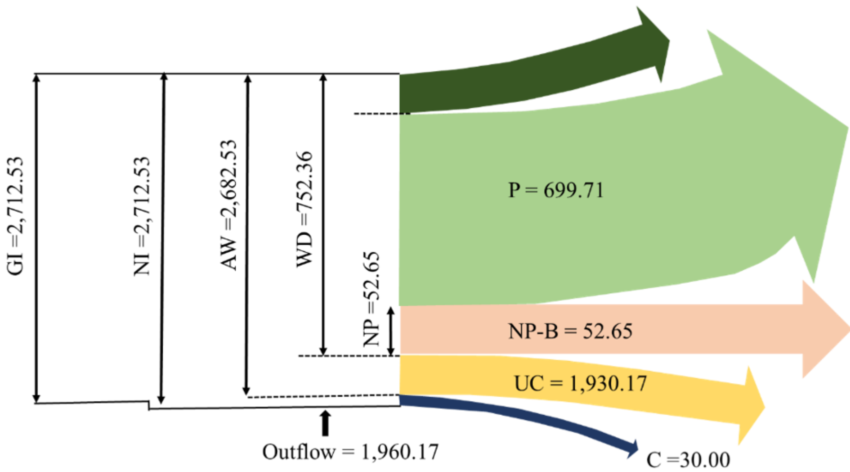


Figure 4. Annual water accounting of the area in Samut Prakan Province including the water supply of wastewater

3.2.3 Economic evaluation and environmental benefits from wastewater reuse

The economic assessment of wastewater reuse relied on a comparison of the costs of greywater quality analysis, wastewater treatment, municipal water supply production, water resource location, and the calculation of differences (United Nations Statistics Division, 2011). These various aspects were weighed against one another.

1)The estimation of wastewater treatment costs (Baht/MCM)

For the cost estimation of wastewater treatment, the average amount of wastewater or the water supply of wastewater in the study area was 2.67 MCM/day. The sequencing batch reactor (SBR) was applied for wastewater treatment. The system consisted of an aeration tank that could aerate to decompose organic matter as well as filter sludge by sedimentation, and a sewage tank as shown in the detail in Figure 5. Then, to study the economic costs of wastewater treatment in the study area, the determined project duration was 20 years. All the nominal costs were converted to economic costs as net present value, using a 5% rate for calculation.

1.1) Costs included, for example, construction, design, consulting site engineer, operation and maintenance, and annual machine replacement.

1.2) Average Marginal Costs/unit were as follows.

Financial aspect; to determine the water value based on nominal costs, an analysis of nominal costs and analysis to find the average financial marginal costs were conducted.

Economic aspect, to determine the water value based on economic costs, an analysis of the economic costs and analysis to discover the average economic marginal costs were conducted.

The details of the wastewater treatment plant costs are shown in Figure 6.

2)The cost evaluation for the water supply production and distribution (Baht/MCM)

The cost evaluation for the water supply production and provision was based on the production and distribution of municipal water. The main cost of the organization was its operation cost, which accounted for 72% of the total cost. While the production cost was about 40% of the total cost, the distribution cost was approximately 32%. The costs included water purchase, production materials, energy cost, repair and outsourcing for the production system, distribution cost, depreciation, electricity cost, and chemicals for the production. The average total cost to produce a cubic meter of water was 0.3931 Baht (≈ 0.011 USD), excluding the costs of raw water transfer, municipal water distribution system, investment, and all other expenses (Rojanapisuth, 1993). From the total cost for producing one cubic meter of water, the average costs were divided into proportions, namely electricity (51.1%), chemicals (37.2%), salaries (7.7%), and others (4%).

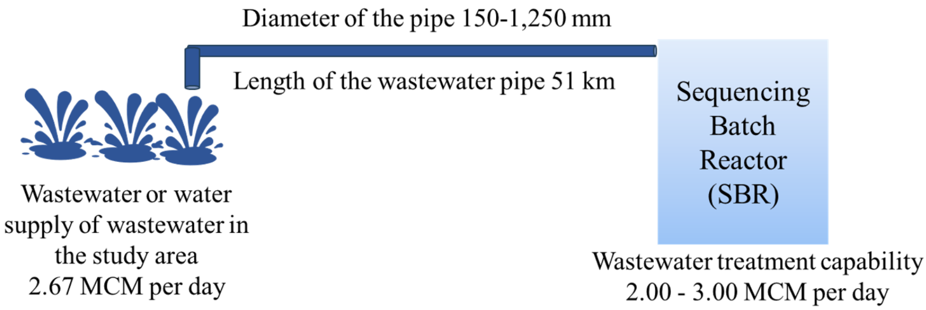


Figure 5. Schematic diagram of the wastewater treatment system for reuse

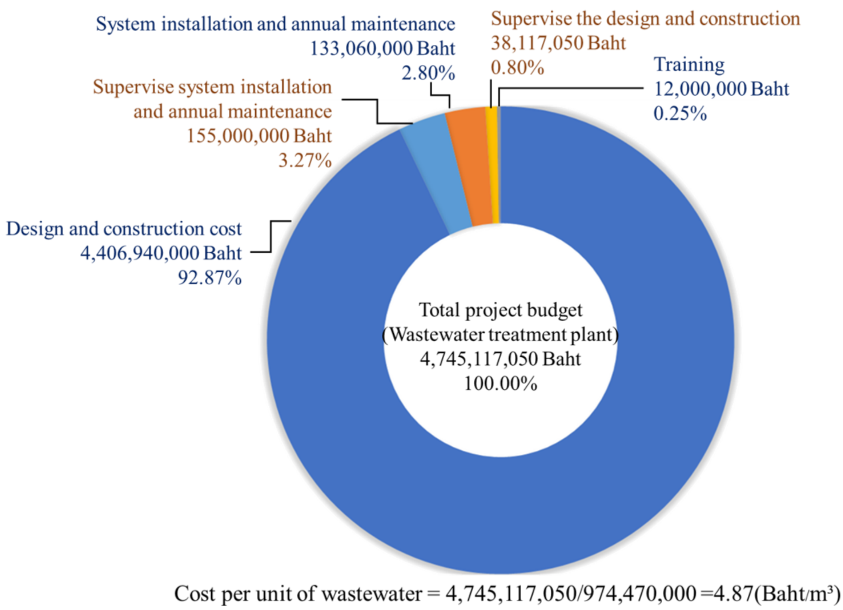
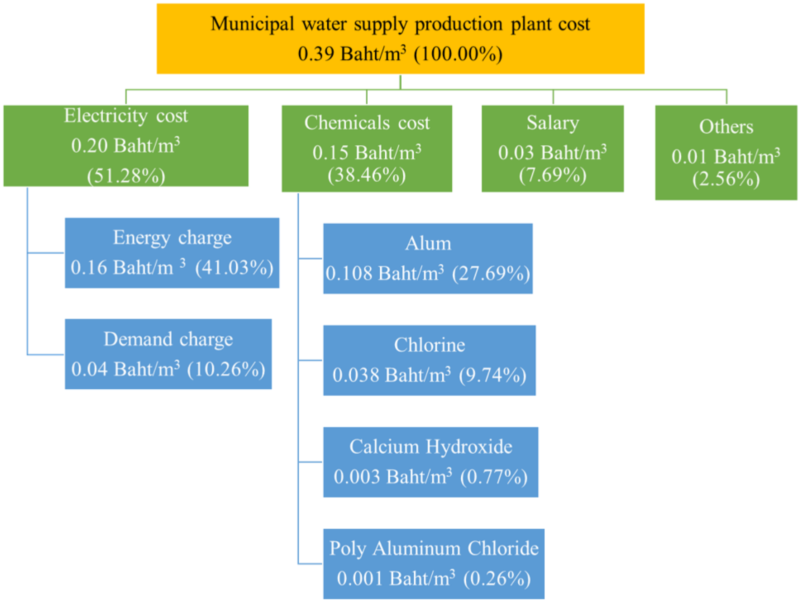


Figure 6. Cost of wastewater treatment plant (1 USD≈36 Thai Baht)

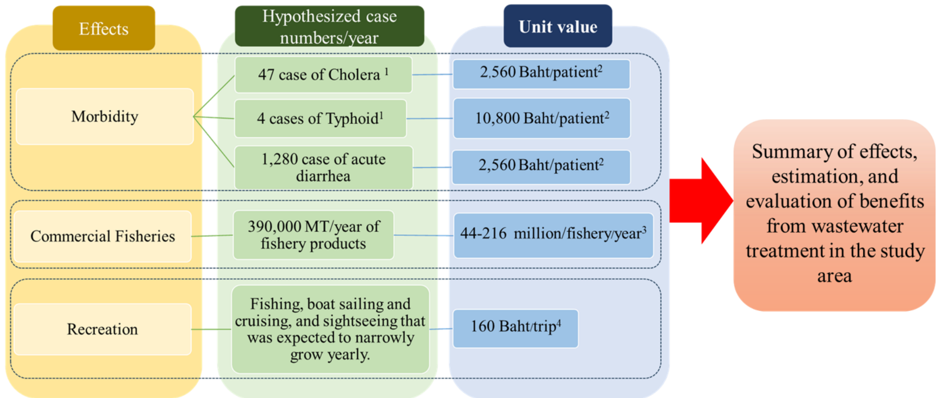


- Average total cost of production = 0.39 Baht/ m³
- Average total cost of distribution = 0.31 Baht/ m³
- Total cost of the municipal water supply production plant = 0.97 Baht/ m³

Figure 7. Costs of municipal water supply production (1 USD ≈ 36 Thai Baht)

The total cost of wastewater treatment was compared to the total cost of municipal water supply production and provision. The wastewater treatment cost was 4.83 Baht/m³ (≈ 0.134 USD), whereas the average total cost of municipal water production was 0.97 Baht/m³ (≈ 0.027 USD). The wastewater treatment involved the costs of electricity needed for aeration in the wastewater treatment system. Moreover, the costs of operation and maintenance were relatively high. Consequently, treating wastewater for reuse was more costly than producing municipal water from natural water sources. Nevertheless, when considering the advantages of wastewater reuse for the environment and health, it holds value for both the physical and biological aspects of the environment and enhances quality of life. Environmentally, it prevents water pollution, reduces the impact on aquatic life, decreases environmental resources affecting human habitats or biodiversity. It also reduces the health effects of water pollution and waterborne diseases. These effects were considered as loss value. Meanwhile, the wastewater treatment in the study area offered the benefits shown in Figure 8.

Most research on water accounting primarily focuses on natural water resource data without incorporating data on wastewater as a natural capital in their works. The majority of wastewater-related studies mainly examine its potential for reuse and assess its value, with only a few examining wastewater accounting. The study on Samut Prakan's water accounts showed that wastewater could be a substitute water for domestic use because of its abundant quantity Similarly, the Netherlands has included the amount of wastewater as a natural capital for water accounting. The Netherlands was one of the first countries to use SEEA Water to fulfill the need for integrated hydro-economic data and WFD requirements (Schenau & ten Ham, 2005). According to Brouwer *et al.* (2005), the Dutch accounts contribute insights into the relationships between the physical water system and the economy at the national and river basin scales. There were accounts for physical and monetary flow, emission, and valuation (Edens & Gravland, 2014). The country's water accounts comprise economic statistics on production, value added, and employment, along with physical data on water consumption and wastewater distribution (van Berkel *et al.,* 2022).



Note:
[1] Suppose that the morbidity rates of Cholera and Typhoid decrease by 40% and by 22% for the rate of acute diarrhea.
[2] The unit value included the direct medical treatment fees, and loss of working and leisure time. The losses of working and leisure time was estimated from the wage rates.
[3] The metric ton used for estimation was equal to 1,120 baht, considering the value of current fishery per year. The increase in the fishery production partly contributed to the total fishery's annual income of 428 million baht.
[4] The price reflected the average value of fishery and recreation in saltwater area. The value was calculated by adjusting the rates in the USA based on the GDP per capita in USA and Samut Prakan.

Figure 8. Summary of effects, estimation, and evaluation of benefits from wastewater treatment in the study area

However, the cost of wastewater treatment and establishing systems for wastewater reuse were higher than using natural water resources. This aligns with the findings of the prior study, which supported the inclusion of wastewater in water accounting and investigated the potential advantages of reuse and recycling alternatives. While reusing wastewater for irrigation might be a viable temporary option, it may not produce the most substantial economic returns (Arntzen & Setlhogile, 2007). Nevertheless, the cost-effectiveness of using wastewater as a natural capital within the framework of water accounting remains a matter for consideration. As a result, environmental and health advantages should be considered to make wastewater reuse more noteworthy, especially in attaining the Sustainable Development Goals (SDGs), notably SDG 6 on clean water and sanitation. For example, the Philippines, also aiming to achieve the SDGs, was one of the first nations to start compiling water accounts through their Environmental and Natural Resources Accounting Project (ENRAP) in 1991 (Angeles & Peskin, 1998). A series of water accounts for financial and physical assets from 1988 to 1998, and the physical supply and use tables from 2010 to 2020, were the results of ENRAP and succeeding projects. There were also regional ecosystem reports from the years 2001 to 2014. These accounts included water availability and quality for the Laguna de Bay Basin, the largest inland water body in the Philippines (LBTWG, 2016). Two indicators for SDG 6 on water and sanitation, including SDG 6.4.1 Change in Water Use Efficiency (WUE) and SDG 6.4.2 Level of Water Stress (LWS), have been calculated using data from the Water Accounts of the Philippines (PSA, 2020).

Furthermore, including wastewater in water accounting calculations has both advantages and disadvantages. In terms of strength, water accounting provides a framework for combining various data on water with other environmental and economic data. On the other hand, obtaining a significant amount of the necessary data to support the accounts can be challenging. For instance, some types of water accounts are produced, including those for underrepresented surface, ground, and soil water resources and low-level industries.

Accounting has the benefit of revealing data gaps and shortages that can be mended (Salminen *et al.,* 2018). However, although water consumption is included in accounts, a limitation still exists. While data on the amount of water extracted from the environment and water usage in the water supply industry are normally available, there is frequently a lack of data on the flows discharged by industries and sectors to the wastewater systems or directly into the environment. As a result, the accounts often reflect water consumption based on partial data, which increases the likelihood of data misinterpretation. Weckström *et al.* (2020) also asserted that without complete data, water consumption could not be accurately estimated on an expansive level across numerous industries. Water account creation typically follows a stop-start pattern. The Philippines, for example, began creating water accounts in the 1990s (Angeles & Peskin, 1998); however, there was a significant hiatus between those and the most recent accounts (PSA, 2020). Namibia, likewise, started creating fragmentary water accounts in 1980 (Lange, 1997), but it was not until the 2000s that the creation was resumed (MET, 2015), and there has been no continuation since then. This pattern poses a disadvantage because it suggests that the government lacks the capacity, resources, and high-level commitment that are necessary to create natural capital accounts successfully (World Bank, 2021).

The studies conducted at the municipal or provincial level using wastewater as a natural capital for water production have found that the production cost of recycling water is high, making it economically inefficient. Therefore, further research should focus on setting targets to increase reuse and recycling. Additionally, there should be an exploration of wastewater treatment systems or approaches for wastewater reuse at lower costs, such as small-scale wastewater reuse in households, villages, markets, department stores, and establishments. Furthermore, the utilization of alternative low-cost natural treatment systems like wetlands for wastewater treatment should be investigated (Setlhogile *et al.,* 2011; Setlhogile *et al.,* 2017; Pasukphun *et al.,* 2017).

In the development of water accounting in Thailand, it remains essential to have accurate and updated data from all relevant sectors. More information is required to support future water resource planning to ensure an adequate water supply. Therefore, the natural resource and wastewater management database systems should be integrated to identify cross-sector water issues and enhance integration and transparency. This will help policymakers in water governance for sustainable development, enabling prudent water management to foster economic growth, meet human needs, and protect the environment.

4. Conclusion

This research aimed to apply the water accounting framework for urban water management, based on the idea that wastewater can be treated and reused for other activities to reduce the use of water from natural water sources. The identification and quantification of natural water resources and wastewater from point sources were applied in water accounting as tools for planning water management and wastewater utilization in Samut Prakan Province, Thailand. The study revealed that it was possible to incorporate wastewater into the water accounts due to its substantial volume to achieve significant cost savings through reuse and recycling, along with the potential for higher returns on investments in water and sanitation. Furthermore, it is technically feasible to include wastewater in various water accounting frameworks such as wastewater supply account, wastewater use account and wastewater stock account.

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