COMPONENT 2

INTEGRATION OF NATURAL CAPITAL ACCOUNTING INTO LOCAL DEVELOPMENT PLANNING AND OPERATIONS

THE INTEGRATION OF NATURAL CAPITAL ACCOUNTING IN PUBLIC AND PRIVATE SECTOR POLICY AND DECISION-MAKING FOR SUSTAINABLE LANDSCAPES

NATURAL CAPITAL

Funded by

Executing Agencies

COMPONENT 2

INTEGRATION OF NATURAL CAPITAL ACCOUNTING INTO LOCAL DEVELOPMENT PLANNING

OUTPUT 2.3.5

PROVIDE TECHNICAL SUPPORT TO THE INSTALLATION OF SMALL-SCALE WASTEWATER TREATMENT TECHNOLOGIES IN SMALL-SCALE TOURISM ENTERPRISES

Author

Adis Israngkura, Thailand Development Research Institute (TDRI)

Suchanya Wongrod, King Mongkut's University of Technology Thonburi, Bangkok

Prinyarat Leangcharoen, Thailand Development Research Institute (TDRI)

Ramida Hansaward, Thailand Development Research Institute (TDRI)

Garch Sukcharoensin, Thailand Development Research Institute (TDRI)

THE INTEGRATION OF NATURAL CAPITAL ACCOUNTING IN PUBLIC AND PRIVATE SECTOR POLICY AND DECISION-MAKING FOR SUSTAINABLE LANDSCAPES

NATURAL CAPITAL

Funded by gef UN environment programme

Executing Agencies TDRI THAILAND DEVELOPMENT RESEARCH INSTITUTE

Acknowledgment

Providing technical support for the installation of small-scale wastewater treatment technologies in small-scale tourism enterprises under Output 2.3.5 addressed the current situation and challenges of wastewater management in the area. This included an overview of wastewater treatment systems in Krabi Province, covering both large-scale and small-scale systems, as well as case study areas examining the relationship between tourism activities and water quality in Ao Nang. The section also summarizes the outcomes of knowledge dissemination on small-scale wastewater treatment systems provided to local small-scale tourism business operators.

This part of the study would like to express sincere appreciation to the two principal researchers: Dr. Suchanya Wongrod and her research assistant, authors of the studies titled *"Small-Scale Wastewater Treatment Systems in Krabi"* and *"Water quality analysis in Ao Nang Subdistrict, Krabi,"* from the Environmental Technology Program, School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi, as well as Mr. Garch Sukcharoensin, author of *"Bridging the Gap: Wastewater Management and Treatment Challenges in Krabi Province."*

In addition, we would like to thank the Wastewater Management Authority, Krabi Office and the local administrative organizations—namely, Krabi City Municipality and the Ao Nang Subdistrict Administrative Organization—for providing valuable information that supported this study.

Executive Summary

This section examines the current situation and challenges of wastewater management in Krabi Province and reviews the technical data and costs associated with small-scale wastewater treatment systems. The dissemination and support of technical information for these technologies are divided into four parts.

1. **Situation Challenges and limitations in wastewater management in Krabi province.**

Trends in urban expansion and economic development, driven by population growth and increasing tourist numbers prior to 2020 and again in 2023 following the COVID-19 pandemic, have led to a rise in water demand from tourism-related businesses, as well as a corresponding increase in wastewater and sewage volumes in Krabi Province. Consequently, there is an urgent need to expand wastewater treatment capacity to accommodate the growing volume of wastewater generated by the tourism sector and the increasing population.

Estimates of the annual wastewater volume in Krabi Province, based on population and average per capita wastewater generation, are as follows: approximately 0.275 cubic meters per person per day (based on average values for Southern Thailand from a study on prioritizing community wastewater management conducted by the Office of Environmental Policy and Planning in 1995. The study indicated that wastewater generation showed an increasing trend over the period 2016–2023. It was estimated that by 2023, only 6.35% of the total wastewater generated in Krabi Province would be treated, while the current capacity of the centralized wastewater treatment system accounts for only approximately 13% of the total volume produced. The estimated cost of wastewater treatment in Krabi in 2023 is approximately 140 million baht, which is more than 13 times the budget allocated for managing the wastewater treatment system.

A significant challenge in wastewater management in Krabi Province is that the volume of wastewater entering the centralized treatment system operated by the Krabi Provincial Wastewater Management Organization is very low compared to the estimated total wastewater generation. This indicates that a substantial proportion of wastewater is discharged untreated into natural water bodies, such as rivers and canals, and ultimately flows into coastal and marine environments in an inappropriate manner. This has considerable environmental impacts on the province. Although primary wastewater treatment is commonly implemented through septic tanks, coverage remains incomplete, particularly in areas with dense communities and coastal tourism businesses. This situation can be attributed to limited funding, inadequate monitoring of wastewater discharge standards among businesses, weak enforcement of regulations, and insufficient public awareness regarding proper wastewater management practices.

For this reason, it is evident that wastewater management challenges in Krabi Province—arising from both the volume of wastewater generated and limited treatment capacity—are largely due to insufficient coverage of centralized wastewater treatment systems, as well as the lack of small-scale treatment systems for businesses and households in certain areas. These shortcomings have significant impacts on the province's natural resources and environment. Consequently, existing policies and planning frameworks play a critical role in determining the sustainability of Krabi as a major tourist destination. One essential approach to improving wastewater management is to enhance treatment capacity and infrastructure in both municipal and rural areas. This requires adequate budget allocation, effective enforcement of wastewater discharge regulations, and consistent monitoring. In addition, stricter penalties for non-compliance could help reduce the gap between wastewater generation and treatment capacity.

2. **A review of the technical and cost aspects of small-scale wastewater treatment systems for communities and small homestays in non-municipal areas of Krabi Province.**

Currently, trends in nature-based tourism have shifted, resulting in the growing popularity of homestays in natural settings, particularly in rural areas. This trend may have implications for natural resources, environmental quality, and wastewater management in these areas. Accordingly, this research aims to propose guidelines for improving wastewater management for small-scale tourism businesses, particularly homestays in rural areas of Krabi Province. It also seeks to promote investment in small-scale wastewater treatment systems that are appropriate for the local context, especially in communities and homestays outside municipal areas that are not yet connected to centralized wastewater treatment systems.

Currently, ecotourism and nature-based tourism are becoming increasingly popular, particularly in areas with abundant natural resources that have not been intensively developed, such as those outside municipal boundaries. These areas often feature diverse natural and cultural landscapes as their defining characteristics. As a result, homestay tourism—where visitors stay with local communities—has become a popular choice among both domestic and international tourists. However, while the growth of this type of tourism generates income and economic opportunities for local communities, it also places increasing pressure on natural resources, the environment, and basic public infrastructure, particularly in relation to wastewater management. This represents a significant challenge that may affect the long-term sustainability of tourism if not addressed through appropriate management systems.

This research focuses on a technical and cost-effective comparison of small-scale wastewater treatment systems suitable for the context of small communities and homestays in non-municipal areas of Krabi Province, an important tourism destination in southern Thailand. The target group consists of communities or homestays accommodating approximately 10 to 15 guests per day. This study employs a comparative analysis of system structure, treatment technologies, wastewater treatment efficiency, and suitability for practical application, including installation and long-term maintenance costs. The aim is to provide guidance for selecting treatment systems that are appropriate to the constraints and capacities of each area.

The wastewater treatment systems analyzed consisted of four main types. namely

(1) **Concrete drainage wells or Septic Tank with Sand Filter**, which is a semi-natural system that uses a filtration mechanism combined with physical and chemical adsorption through filter materials in a concrete well. It can handle approximately 1.0 - 1.5 cubic meters of wastewater per day. The total cost is 41,000 - 60,000 baht per unit. The main advantage of this system is that it is easy to construct. Low maintenance Suitable for rural areas. However, its efficiency in reducing organic matter, or the biochemical oxygen demand (BOD) used by microorganisms to break down organic matter in water, and pathogens may be lower than other systems.

(2) **Integrated Septic Tank with Anaerobic Filter** is a ready-made system that combines the septic tank and the filter tank in one unit. It is suitable for installation in limited spaces and has a cost of approximately 28,000-48,000 baht per unit. Overall, this second system, incorporating a grease trap, can reduce organic matter by approximately 100%. 60-70 units are easy to maintain and have a sediment removal interval of approximately 1.5-2 years.

(3) **Septic Tank with Aerobic Filter**, This is a highly efficient system suitable for areas with strict wastewater quality requirements. By separating the septic tank and aeration system, it can reduce organic matter by more than a certain percentage. 80-90, but there are limitations in terms of electricity consumption for aeration, as well as the need for regular maintenance of the aeration equipment. The total cost of the system is approximately 41,000-68,000 baht per unit.

(4) **Constructed wetland wastewater treatment** are natural systems that rely on aquatic plants and filter materials in a horizontal or vertical arrangement. It uses approximately 10-15 square meters per unit. It can handle 1-2 cubic meters of wastewater per day. The construction code is approximately 27,000 - 44,000 baht. Suitable for areas with sufficient space and requiring a low-maintenance system.

Comparative studies have shown that integrated septic tanks with anaerobic filters and constructed wetlands wastewater treatment are suitable options for small homestays in areas outside municipal boundaries. This is because they are low-cost, easy to use, and flexible enough to adapt to different site conditions. Septic tank systems combined with aerated filtration systems are highly effective in wastewater treatment. However, it is still necessary to consider long-term operating costs and energy requirements. Septic tank systems combined with sand filters are suitable for rural areas that require a basic system that is easy to construct and has a moderate cost. However, selecting the most appropriate system should primarily consider the local context, including site size, population density, available resources, and maintenance capacity.

Promoting the selection of appropriate wastewater treatment systems therefore requires clear guidelines and may also require budgetary support from the government or local authorities to encourage investment in environmental infrastructure for small communities. This will help reduce the impact on natural resources and promote sustainable tourism development at the local level in a tangible way.

3. Water quality analysis based on surveys in Ao Nang Subdistrict

This study assesses wastewater quality at 28 monitoring locations across Ao Nang, Krabi Province, including canals, drainage outlets, and coastal discharge points influenced by tourism-related activities such as homestays, restaurants, markets, and laundry services. The results indicate widespread deterioration of surface water quality, particularly in canal systems that discharge directly into Ao Nang coastal waters.

When evaluated against Thailand’s surface water quality standards established by the Pollution Control Department (PCD), most sampling locations do not meet the criteria for Class 2 or Class 3 water bodies, which are generally intended for recreation and environmental protection. Biochemical oxygen demand (BOD) concentrations at several sites, particularly L13–L16 and L18, exceeded 100 mg/L, far above the recommended limits of ≤ 1.5–2 mg/L. In parallel, dissolved oxygen (DO) concentrations at multiple locations were below 3 mg/L, falling short of the minimum threshold of 4 mg/L required to support aquatic life. These conditions indicate substantial organic pollution and oxygen depletion within the canal system. Elevated concentrations of chemical oxygen demand (COD), nutrients (NH_4^+-N) and PO_4^{3-}-P), and fecal coliform bacteria (FCB) were also observed. Distinct pollution hotspots were identified at drainage points such as the pavilion-side drainage (L6), areas surrounding hotel clusters prior to discharge into Ao Nang Bay (L13–L16), and the drainage outlet at Phra Nang Curve (L18). At L6, COD reached 565 mg/L, indicating strong organic loading, likely associated with commercial wastewater from food service activities. At L18, FCB levels exceeded 4.9 x 106 MPN/100 mL, suggesting severe contamination consistent with untreated or poorly treated domestic wastewater.

Nutrient enrichment is another key concern. NH_4^+-N concentrations frequently exceeded 0.5 mg/L, indicating recent inputs of untreated wastewater. Elevated PO_4^{3-}-P concentrations, likely linked to detergents and cleaning agents, further point to contributions from laundry operations and hospitality services. These nutrient conditions create a high potential for eutrophication, particularly in canals with limited flow and flushing capacity. Microbial contamination represents the most critical issue identified in this study. FCB concentrations at many sites exceed Thai standards for Class 3 waters (≤ 4,000 MPN/100 mL) by a substantial margin. The extreme value recorded at L18 is more than three orders of magnitude above the regulatory threshold, indicating direct or near-direct discharge of untreated sewage. This poses a significant public health risk, especially in areas where contaminated canal water reaches recreational coastal zones.

Overall, the water quality observed across the study area corresponds to Class 4–5 surface water, indicating degraded conditions that are unsuitable for ecological or recreational use without treatment. The spatial distribution of pollutants suggests cumulative impacts from multiple sources, including domestic wastewater, commercial activities, and inadequate on-site treatment systems. The findings highlight the need for immediate improvements in wastewater management in Ao Nang. Priority actions include the implementation of decentralized treatment systems suitable for small-scale tourism operations, stricter control of wastewater discharge, and enhanced monitoring of key pollution indicators. Without timely intervention, continued water quality degradation may affect coastal ecosystems, public health, and the long-term sustainability of tourism in Krabi Province.

4. A technical information dissemination meeting on the installation of small-scale wastewater treatment technologies.

A technical information dissemination meeting on the installation of small-scale wastewater treatment technologies for small tourism businesses, including hotels, resorts, laundry and dry-cleaning shops, and restaurants, was held on October 28, 2025, from 9:30 a.m. to 1:00 p.m. at Hornbill Ballroom 2, Deevana Plaza Ao Nang Krabi Hotel. The meeting was attended by 36 participants representing various types of small tourism businesses (hotels, resorts, laundry and dry-cleaning shops, and restaurants), as well as representatives from Subdistrict Administrative Organizations, independent researchers in the area, and the research team.

The dissemination meeting began with an opening speech introducing the project and emphasizing the importance of resource conservation, delivered by Assoc. Prof. Dr. Adis Isarangkoon na Ayutthaya from the Thailand Development Research Institute. This was followed by a presentation on the installation of small-scale wastewater treatment technologies for small tourism businesses, including system installation costs, system performance, and the readiness and suitability of each type of technology, delivered by Dr. Suchanya Wongrod from the Faculty of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi. After the presentations, a question-and-answer session was held with participants representing tourism businesses and a representative from the Ao Nang Subdistrict Administrative Organization. The discussion focused on scientifically grounded principles of small-scale wastewater treatment, operational challenges faced by tourism businesses in using such systems, and preliminary solutions, including system inspection and maintenance. Dr. Suchanya also provided recommendations on appropriate small-scale wastewater treatment technologies for tourism operators.

Key points of the general discussion

- The current wastewater treatment situation among various types of small-scale businesses, including hotels, resorts, laundry and dry-cleaning shops, and restaurants.
    - Participants shared their initial experiences with small-scale wastewater treatment in their businesses, such as grease trap systems and other small-scale wastewater treatment technologies. These discussions highlighted the importance of selecting wastewater treatment systems that are appropriate for the specific characteristics of wastewater generated by each type of business.
    - Wastewater treatment technologies generally involve relatively high installation and maintenance costs. This is a limitation for small businesses that do not have sufficient capital to install appropriate small-scale wastewater treatment systems.
- Problems or obstacles encountered in managing existing wastewater treatment systems in tourism businesses, such as difficulties in dissolving or removing grease that may accumulate in pipes and the lack of regular inspection of grease trap systems, particularly in restaurants.
- Representatives from the Subdistrict Administrative Organization (SAO) engaged in discussions with entrepreneurs regarding challenges, obstacles, and recommendations, including the annual assessment and inspection of wastewater treatment systems conducted by the Ao Nang Subdistrict Administrative Organization. A key issue identified was the insufficient number of personnel, particularly for the annual monitoring and evaluation of small-scale wastewater treatment systems.
- Participants suggested enhancing the dissemination of knowledge on wastewater management and treatment for small-scale businesses through local agencies, expanding the inspection coverage of small-scale wastewater treatment systems to include more establishments, and implementing random inspections of such systems in businesses.

Contents

Page

Acknowledgment i

Executive Summary iii

Contents viii

Tables xi

Figures xii

1. Wastewater Management and Treatment Challenges in Krabi Province 1

1.1 Population and Tourism Trends 1

1.2 Wastewater Emission 2

1.2.1 Wastewater from Population 2

1.2.2 Wastewater from Building Type 3

1.3 Wastewater Treatment 4

1.3.1 Wastewater Entering System 4

1.3.2 Wastewater Treatment System Capacity 6

1.3.3 Wastewater Treatment Option 8

1.4 Wastewater Treatment Cost 9

1.4.1 Wastewater Production by Population Type (Municipalities vs. Rural) 10

1.4.2 Total Necessary Wastewater Treatment Cost by Subtraction 12

1.4.3 Total Necessary Wastewater Treatment Cost by Population 13

1.5 Wastewater Treatment Needed Facility Requirement 13

1.5.1 Wastewater Treatment Systems for Municipalities 13

1.5.2 Wastewater Treatment Systems for Rural Areas 17

1.6 Wastewater Treatment: Policy and Enforcement 18

1.6.1 Current Policy and Laws 18

1.6.2 Enforcement 20

1.6.3 Funding 20

1.6.4 The future operation of Krabi's wastewater treatment system 20

Page

1.7 Conclusion ... 22

2. Small-Scale Wastewater Treatment Systems in Krabi ... 22

2.1 Introduction ... 22

2.2 Water Quality Standards ... 24

2.3 Wastewater Treatment Technologies for Small-scale Decentralized Wastewater Treatment System ... 25

2.3.1 Septic Tank with Sand Filter ... 26

2.3.2 Integrated Septic Tank with Anaerobic Filter ... 29

2.3.3 Septic Tank with Aerobic Filter ... 31

2.3.4 Constructed Wetland ... 33

2.4 Comparative Analysis of Small-Scale Wastewater Treatment Options ... 36

2.4.1 Technical Performance ... 36

2.4.2 Economic Considerations ... 37

2.4.3 Operational Feasibility ... 37

2.4.4 Land and Energy Requirements ... 39

2.5 Recommendations for Krabi Province ... 39

3. Water quality analysis in Ao Nang Subdistrict, Krabi ... 40

3.1 Introduction ... 40

3.2 Sampling Locations and Study Design ... 41

3.3 Analytical Methods ... 44

3.4 Results and Analysis ... 45

3.4.1 Overview of Water Quality Conditions ... 45

3.4.2 Organic Pollution (BOD and COD) ... 49

3.4.3 Dissolved Oxygen (DO) ... 51

3.4.4 Nutrient Concentrations (NH4+-N and PO43--P) ... 53

3.4.5 Microbial Contamination (Fecal Coliform Bacteria, FCB) ... 53

3.4.6 Oil and Grease ... 54

3.4.7 Spatial Patterns and Hotspot Identification ... 55

Page

4. Summary of Providing Technical Support to the Installation of Small-scale Wastewater Treatment Technologies in Small-scale Tourism Enterprises 56

4.1 Introduction 56

4.2 Meeting Attendees 58

4.3 Meeting Agenda 61

4.4 Discussion with Participants 62

4.5 Key Takeaways 67

4.6 Remaining Issues (Challenges) 67

4.7 Meeting documents and photos 68

4.7.1 Presentation Slides Sample 68

4.7.2 Meeting Agenda in Thai 69

4.7.3 Images from the Focus Group 70

4.7.4 Attendee Signature Sheet 71

5. References 78

Tables

Page

Table 1 Population of Krabi (2558-2566) ... 1

Table 2 Amount of Wastewater Produced in Krabi (2559-2566) ... 3

Table 3 Wastewater of Various Building Types in Krabi ... 3

Table 4 Wastewater Entering the System in Krabi (2559-2566) ... 5

Table 5 Gap in Wastewater Produced vs. in System, Krabi (2559-2566) ... 5

Table 6 Wastewater Treatment System Capacity in Krabi * ... 7

Table 7 Gap in Wastewater Produced vs. Capacity, Krabi (2559-2566) ... 7

Table 8 Population of Krabi (Municipalities vs. Rural) (2559-2566) ... 10

Table 9 Amount of Wastewater Produced in Krabi (Municipalities vs. Rural) (2559-2566) ... 10

Table 10 Cost of Wastewater Treatment in Krabi (Municipalities vs. Rural) (2559-2566) ... 11

Table 11 Cost of Necessary Wastewater Treatment in Krabi (Municipalities vs. Rural) (2559-2566) ... 13

Table 12 Total Cost of Wastewater Treatment Systems (AS vs. OD vs. AL vs. WSP) ... 15

Table 13 Efficiency of Wastewater Treatment Systems (AS vs. OD vs. AL vs. WSP) ... 16

Table 14 Total Cost of Wastewater Treatment Systems (AS vs. OD vs. AL vs. WSP) ... 17

Table 15 National-Level Statutes (Wastewater Specific) ... 19

Table 16 Overview of small-scale wastewater treatment technologies for Krabi community. ... 38

Table 17 Details and characteristics of the position where wastewater samples were collected ... 42

Table 18 The physicochemical and biological water quality parameters of samples at locations L0–L27. ... 46

Figures

Page

Figure 1 Internal Tourism in Krabi (2558-2566) ... 2

Figure 2 Wastewater Produced vs. in System, Krabi (2559-2566) ... 6

Figure 3 Necessary Wastewater Treatment Cost vs. Current Cost, Krabi (2566) ... 12

Figure 4 Construction Cost by Treatment System ... 14

Figure 5 O&M Cost by Treatment System ... 15

Figure 6 Land Requirement by Treatment System (just system) ... 16

Figure 7 Gap in Wastewater Produced vs. Capacity, Municipalities, Krabi (2559-2566) ... 17

Figure 8 Construction site of the second Water Quality Management Center of the Ao Nang Subdistrict Administrative Organization ... 21

Figure 9 Polluted canal water observed in Klong Yingsuea and Klong Jark (discharge into Ao Nang Bay), Krabi Province. ... 23

Figure 10 Water quality standards of Thailand, WHO, EU, ASEAN, and US EPA for recreational waters. ... 25

Figure 11 Septic tank with sand filter system ... 26

Figure 12 Schematic of septic tank with sand and gravel filter showing influent, sedimentation, filtration, and effluent pathways (Source: Wang et al., 2021). ... 27

Figure 13 Schematic of simple septic and drainage layout in Chiang Mai, Thailand ... 28

Figure 14 Estimated capital costs of septic tank with sand filter system. ... 28

Figure 15 Integrated septic tank with anaerobic filter ... 29

Figure 16 Schematic of anaerobic filter for low-moderate BOD ... 29

Figure 17 Schematic of anaerobic filter for high volume BOD ... 30

Figure 18 Estimated capital costs of integrated septic tank with anaerobic filter. ... 31

Figure 19 Septic tank with aerobic filter ... 31

Figure 20 Schematic of anaerobic filter for high volume BOD ... 32

Figure 21 Estimated capital costs of septic tank with aerobic filter ... 33

Figure 22 Constructed wetland ... 33

Figure 23 Schematic of a horizontal subsurface flow constructed wetland ... 33

Figure 24 Schematic of (a) horizontal subsurface flow constructed wetland, and (b) vertical flow constructed wetland ... 34

Figure 25 Schematic of a constructed wetland in Rayong province, Thailand ... 35

Figure 26 Estimated capital costs of constructed wetland ... 36

Page

Figure 27 Sampling locations in Klong Yingsuea and Klong Jark, which discharge into Ao Nang Bay, Krabi Province 44

Figure 28 Sampling locations L0 and L13–L22, which discharge into Ao Nang Bay, Krabi Province 50

Figure 29 BOD profile of sampling points at L0–L27, Ao Nang Bay, Krabi Province. 50

Figure 30 COD profile of sampling points at L0–L27, Ao Nang Bay, Krabi Province. 51

Figure 31 DO profile of sampling points at L0–L27, Ao Nang Bay, Krabi Province. 52

Figure 32 Sampling locations L4–L8, L23 and L26–L27, which discharge into Ao Nang Bay, Krabi Province. 52

Wastewater Management and Treatment in Krabi

The trend of urban expansion and economic development, driven by population growth and increasing tourist numbers, has led to greater water demand from tourism-related businesses and an increased volume of wastewater and sewage in Krabi Province. Therefore, an effective wastewater treatment system is essential to accommodate the growing wastewater generated by both the tourism sector and the expanding population. This section presents the current situation and challenges of wastewater management in Krabi Province, reviews technical data and costs associated with small-scale wastewater treatment systems, analyzes water quality test results from selected sample areas, and summarizes the dissemination and support of technical information related to small-scale wastewater treatment technologies. This section is divided into four parts, as detailed below.

1. Wastewater Management and Treatment Challenges in Krabi Province

1.1 Population and Tourism Trends

From 2558 to 2566, the province of Krabi experienced steady population growth (Table 1), parallel with Southern Thailand's broader trends of urbanization and economic development. This growing population, seemingly counter to Thailand's declining population, highlights the gap between centralized provinces like Bangkok and Southern ones.

Table 1 Population of Krabi (2558-2566)

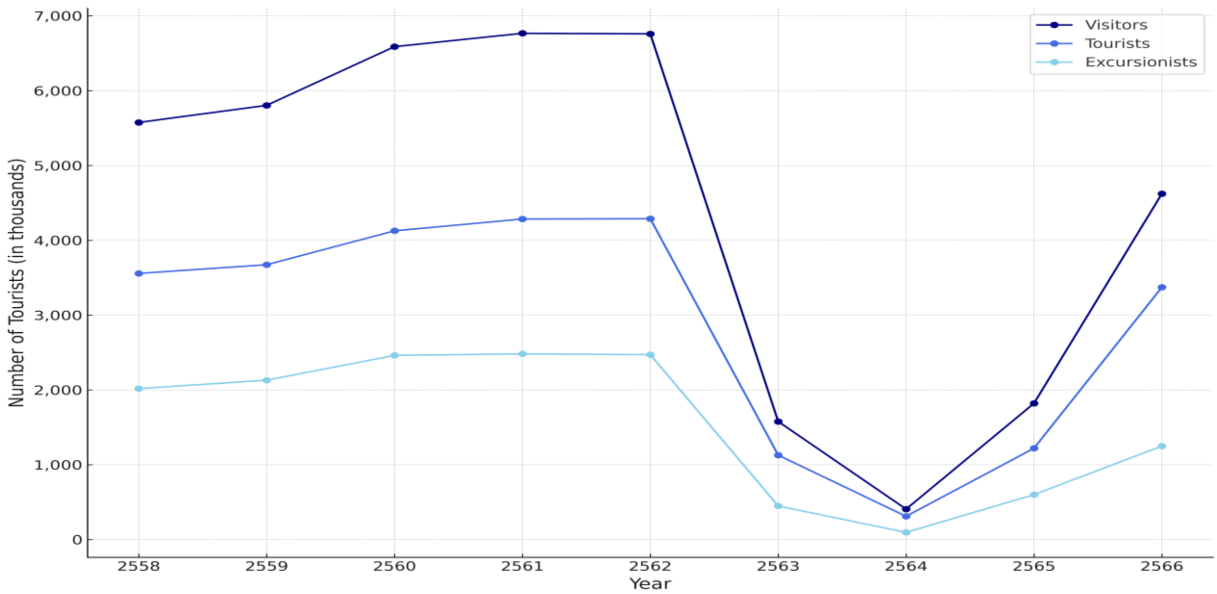
Year	2558	2559	2560	2561	2562	2563	2564	2565	2566
Number of Population	392,380	378,937	382,144	385,426	387,997	389,228	391,241	392,455	394,543

Source: Krabi Provincial Statistical Office (2025)

Krabi has not only become a more attractive living location, however. Over the years, Krabi has become a major tourist destination for both local and foreign visitors, most notably its numerous beaches and coastlines. Krabi shows immense opportunities for the tourism sector, as displayed by the number of visitors over the past decade (Figure 1). Visitors have flocked to Krabi, with its pre-2020 internal tourism showing a generally increasing trend. There was, however, a significant dip in tourism between the years of 2562 to 2564, most likely due to the COVID-19 pandemic, and the subsequent lockdowns and travel restrictions. After 2564, a quick and steady recovery in the number of visitors is seen, as travel handicaps imposed during the COVID-19 era were lifted.

This steadily growing population and number of visitors (World Bank Group, 2024 and Whiteford, L., Koenig, E., & Zarger, R. 2014) has led to a problem for Krabi, more specifically when dealing with wastewater. Both the aforementioned factors cause wastewater within Krabi to increase (as more people means more wastewater), in turn highlighting Krabi's desperate need for more wastewater treatment systems to manage the influx of wastewater brought on by tourism and a growing population.

Figure 1 Internal Tourism in Krabi (2558-2566)



Note: **Visitors* include both Tourists (visitors who stay overnight) and Excursionists (visitors who don't)

Source: Department of Tourism (2025)

1.2 Wastewater Emission

There are various ways to calculate wastewater emission in Krabi. One way is to calculate the product of wastewater produced on average per person and the population of the designated area; the other way is to calculate the amount of wastewater produced from various types of buildings and correspond that with the number of each type of building in Krabi.

1.2.1 Wastewater from Population

To calculate the amount of wastewater the province of Krabi produces using this method, we must multiply the population by the amount of wastewater produced by the average person. The estimate is that one person in the South of Thailand uses around 0.275 cubic meters (prediction from year 2538) (Pollution Control Department, n.d.) of wastewater per day. So, to find the estimated amount of wastewater produced for all the Krabi province, we simply multiply the population of Krabi with 0.275, then by the number of days that year. This gives us the formula (with WK: wastewater produced from Krabi in one year, Pop.: population, or number of people, d: number of days in that given year), and the unit being cubic meters/year;

$$W_K = 0.275 \times Pop. \times d$$

With this new formula, we are now able to calculate the approximate amount of wastewater produced in Krabi in the designated years (Table 2);

Table 2 Amount of Wastewater Produced in Krabi (2559-2566)

Year	Amount (m^3/year)
2559*	38,140,009
2560	38,357,704
2561	38,687,134
2562	38,945,198
2563*	39,175,798
2564	39,270,815
2565	39,392,670
2566	39,602,253

Note: *leap year, onwards calculations for the year 2558 will not be shown due to lack of data

Source: Estimates by the research team

1.2.2 Wastewater from Building Type

To calculate the amount of wastewater the province of Krabi produces using this method, which calculates wastewater based on values from production or actual use, we must first establish how much wastewater each type of building produces (Table 3).

Table 3 Wastewater of Various Building Types in Krabi

Building Type	Measurement	Wastewater (m^3/day - measurement)
Condominium	unit	0.500
Hotel	room	1.000
Dorm	room	0.080
Service Centre	room	0.400
Housing Development	person	0.180
Hospital	bed	0.800
Restaurant	square metre	0.025

Building Type	Measurement	Wastewater (m^3/day - measurement)
Market	square metre	0.070
Mall	square metre	0.005
Office	square metre	0.003

Source: Pollution Control Department (n.d.)

Using this information, to find out wastewater emission, it is imperative to know how much of each type of building is present in Krabi (how many hotels, dorms, hospitals, etc.) and multiply that with the amount produced by one measurement, to find the number each individual building type produces in a day. Then, combining all the wastewater produced by each building type gives us the wastewater amount produced by all buildings in one day. Subsequently, we multiply the product, again, by the number of days in that year.

This gives us the formula (with WK: wastewater produced from Krabi in one year, d: number of days in that given year, C: Condominium, HT: Hotel, D: Dorm, SC: Service Center, HD: Housing Development, HL: Hospital, R: Restaurant, MT: Market, ML: Mall, O: Office), and the unit being cubic meters/year;

$$W_K = d(0.5C + HT + 0.08D + 0.4SC + 0.18HD$$
$$+ 0.8HL + 0.025R + 0.07MT + 0.005ML + 0.003O)$$

However, due to lack of information concerning the amount of each type of building in Krabi, we cannot compute the emission of wastewater using this method. Though, with the actual amounts of building types in Krabi, this would be the preferred method, as it would provide a more accurate amount.

1.3 Wastewater Treatment

1.3.1 Wastewater Entering System

One way of better understanding the wastewater treatment system in Krabi, is to look at the statistics of the amount of wastewater entering the system. The system-wastewater amount may not tell us the exact wastewater treatment capacity of Krabi, but it may be a useful indicator of the system's operational capacity and efficiency. The amount of water entering the system tells us the actual treated amount, rather than the capacity. By comparing the volume of wastewater treated to the estimated total wastewater produced in the area, we can identify gaps in collection and treatment coverage, as well as potential issues with illegal discharge or system overload.

To calculate the amount of wastewater entering the system in Krabi in a year, we can simply multiply the rate that wastewater entered the system in one day (Krabi Wastewater Management Authority, 2025) by the number of days in any given year. With this new formula, we are now able to calculate the amount of wastewater that entered the system in Krabi in the designated years. The system-wastewater amounts, in cubic meters per year, in the designated years (2559-2566) show a general growth trend, with the wastewater amount making a significant net increase (Table 4).

Table 4 Wastewater Entering the System in Krabi (2559-2566)

Year	Amount (m^3/year)
2559*	2,232,600
2560	2,518,500
2561	2,518,500
2562	2,518,500
2563*	2,525,400
2564	2,716,855
2565	2,611,439
2566	2,514,284

Note: *leap year

*Note: the amount of wastewater from Krabi Municipality and Koh Phi Phi

Source: Wastewater Management Authority, Krabi Office

In all, wastewater entering the system in Krabi represents only around 6.5% of all wastewater produced in Krabi each year. The significant gap between the amount of wastewater entering the system as per to the amount of wastewater produced in the province of Krabi in a year (Table 5) (Figure 2) signifies significant instances of illegal or inappropriate wastewater disposal, such as discharge into oceans, rivers, streams, canals, or other bodies of water in nature. Because of this, it is recommended that Krabi increase its wastewater treatment systems and facilities, tighten or better enforce laws regarding wastewater discharge, or hand out harsher punishments for offenders.

Table 5 Gap in Wastewater Produced vs. in System, Krabi (2559-2566)

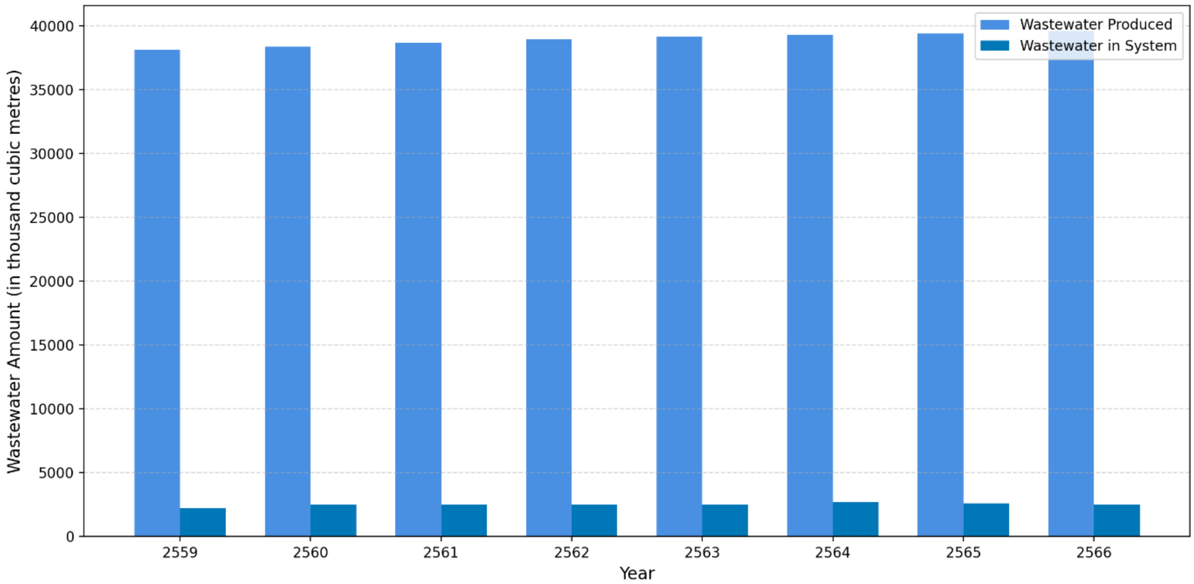
Year	Produced	System	Gap (m^3/year)	Percentage
2559*	38,140,009	2,232,600	35,907,409	5.85
2560	38,357,704	2,518,500	35,839,204	6.57
2561	38,687,134	2,518,500	36,168,634	6.51

Year	Produced	System	Gap (m^3/year)	Percentage
2562	38,945,198	2,518,500	36,426,698	6.47
2563*	39,175,798	2,525,400	36,650,398	6.45
2564	39,270,815	2,716,855	36,553,959	6.92
2565	39,392,670	2,611,439	36,781,230	6.63
2566	39,602,253	2,514,284	37,087,969	6.35

Note: *leap year

Source: Estimates by the research team

Figure 2 Wastewater Produced vs. in System, Krabi (2559-2566)



Source: Estimates by the research team and Wastewater Management Authority, Krabi Office

1.3.2 Wastewater Treatment System Capacity

The capacity of Krabi's current wastewater treatment system is separated into centralized and decentralized wastewater treatment types. Centralized systems in Krabi (Kanchanapiya, P., & Tantisattayakul, T., 2022) include an Aerated Lagoon, which has a treatment capacity of 12,000 cubic meters per day, two combined systems, Activated Sludge (AS) and Constructed Wetlands (CW), which have a capacity of 400, and a newly constructed electric system, which has a capacity of 1,200 (Table 6).

Table 6 Wastewater Treatment System Capacity in Krabi *

System Type	Capacity (m³/year [365 days])	Capacity (m³/year [366 days])
Aerated Lagoon	4,380,000	4,392,000
Activated Sludge + Constructed Wetlands	146,000	146,400
Electric[1]	438,000	450,000
Total	4,964,000	4,988,400

Source: Wastewater Management Authority, Krabi Office (2025) and 1 refer to Annie. (2023)

This is excluding de-centralized wastewater treatment systems, such as septic tanks, which are more abundantly used in non-city or non-municipality areas. Overall, wastewater system capacity in Krabi can handle up to only around 13% of total wastewater produced (Table 7), further highlighting the gap and need of better wastewater treatment.

Table 7 Gap in Wastewater Produced vs. Capacity, Krabi (2559-2566)

Year	Produced	Capacity	Gap (m³/year)	Percentage
2559*	38,140,009	4,988,400	33,601,609	13.08
2560	38,357,704	4,964,000	33,831,704	12.94
2561	38,687,134	4,964,000	34,161,134	12.83
2562	38,945,198	4,964,000	34,419,198	12.75
2563*	39,175,798	4,988,400	34,637,398	12.73
2564	39,270,815	4,964,000	34,744,815	12.64
2565	39,392,670	4,964,000	34,866,670	12.60
2566	39,602,253	4,964,000	34,638,253	12.53

Note: *leap year

*The total capacity for years prior to 2566 excludes the Electric System, as it was built in 2566

Source: Estimates by the research team

Furthermore, the gaps between System Capacity, Wastewater in System, and Wastewater Produced highlights that a very small amount of wastewater actually enters the treatment system in Krabi, and the system is significantly underwhelmed by the amount coming in, as the wastewater in system currently only makes up around half of the system capacity.

1.3.3 Wastewater Treatment Option

Options for sustainable water management and enhancing water resource development capabilities, in the area of wastewater management, include the main approach of wastewater treatment using physical and biological methods, along with chemistry. Water recycling is the process of treating or improving the quality of wastewater generated from various activities, especially industrial production processes, for reuse or repurposing in a quality manner that meets needs. Desalination, on the other hand, is a method to address water scarcity, reduce the cost of raw water production, and ensure long-term water security. Details are as follows:

Wastewater recycling and Reuse

The amount of wastewater in Krabi province is increasing due to the growing demand for water from households, industries, services, and tourism. Improper wastewater management could negatively impact natural resources and the environment. However, some used water enters a preliminary treatment system, while the remainder is collected in a centralized wastewater treatment system. The treated wastewater is then recycled or reused to maximize resource efficiency. Treated wastewater can be reused for various activities, such as car washing, floor cleaning, plant watering, toilet flushing, and agricultural irrigation, as well as in industrial and agro-industrial processes. Reusing wastewater reduces the volume of discharge into natural water sources, decreases dependence on freshwater supplies, lowers raw water procurement costs, and supports sustainable and cost-effective water resource management.

Wastewater recycling and reuse involves several main steps and technologies: 1) pre-treatment/primary: collection and primary wastewater treatment or physical treatment , which involves filtering out large debris, food scraps , gravel , and sand using screens or sediment traps before further treatment; 2) Biological treatment: the dissolved oxygen microorganisms need to decompose organic matter (Biochemical Oxygen Demand: BOD), such as through activated sludge (AS) systems, which are for municipal and industrial wastewater. 3) Tertiary/ Advanced Treatment involves removing small contaminants, chemicals, and pathogens to meet recycled water standards. To convert wastewater back into clean water that is close to tap water, there are popular methods such as (3.1) Membrane Bioreactor (MBR) systems combine biological treatment and membrane filtration, resulting in clear water with lower BOD values and requiring less space. (3.2) Reverse Osmosis (RO)/Ultrafiltration (UF) systems use high-precision membrane filtration to remove small particles for wastewater reuse. (3.3) Disinfection systems use UV light or chlorine to remove dissolved residues in water, such as UV Ultraviolet, etc. and 4) Treated wastewater can be reused in two ways: on-site recycling, which involves recycling wastewater from a single source (e.g., industrial process wastewater treatment), and off-site recycling, which involves treating wastewater from multiple sources, such as using Reverse Osmosis (RO) or Ultrafiltration (UF) systems to reuse wastewater from the final treatment plant.

Wastewater recycling involves multiple steps and processes, with treatment costs depending on the selected technology. Examples of treatment systems include ultrafiltration (0.1 micron filters), membrane bioreactors, reverse osmosis, deionization systems, sedimentation systems, carbon filter tanks, and water circulation systems for removing suspended solids. Equipment maintenance costs are also an important consideration. Effective water recycling, including appropriate reuse options, is essential. When wastewater with low contamination levels can be treated and reused directly, costs are reduced and the burden on centralized treatment systems is minimized. This approach also expands opportunities for utilizing treated water."

Seawater desalination system (Desalination)

The process of converting seawater into fresh water is known as desalination. A widely used technology is Sea Water Reverse Osmosis (SWRO), which applies high pressure to force seawater through a membrane, removing salt and dissolved substances. The desalination process begins with pumping seawater, followed by pretreatment to remove turbidity and suspended solids using an ultrafiltration (UF) membrane system. The water is then processed through an SWRO membrane to remove dissolved salts and produce fresh water. This process relies on advanced technology. Typically, one cubic meter (1,000 liters) of seawater yields about 400 liters of fresh water. The remaining 600 liters become highly concentrated brine, with nearly twice the normal salt concentration, which is discharged back into the sea

Desalination is particularly suitable for areas with limited freshwater resources, including coastal regions and large-scale industrial facilities. In the future, the use of seawater desalination is expected to increase, especially in island areas such as Koh Phi Phi in Krabi Province, where freshwater shortages during the dry season, poor groundwater quality, and the high cost of transporting water from the mainland are key challenges

A comparison of two technology options shows that, as of 2025, desalination (the production of freshwater from seawater) is generally more expensive than wastewater reuse and recycling. Seawater Reverse Osmosis (SWRO), the most commonly used desalination technology, has several limitations, including high energy consumption and a limited membrane lifespan. The main cost components include electricity, piping, and reverse osmosis (RO) membrane maintenance, with total costs estimated at approximately 40–50 baht per cubic meter. The final selling price may be higher when water is supplied to households due to additional distribution costs. In contrast, wastewater recycling is less costly and more sustainable (Aquatic Resources Research Institute, Chulalongkorn University, n.d.)

1.4 Wastewater Treatment Cost

To estimate the total cost of Krabi's needed wastewater treatment, we must first separate Krabi into urban and rural areas, since they each require different systems of wastewater treatment; urban areas require centralized systems, while rural areas use decentralized ones. And, as the prices are different, we must first, to estimate the quantity of wastewater treatment required, and therefore its cost, calculate the amount of waste produced in each type of population.

1.4.1 Wastewater Production by Population Type (Municipalities vs. Rural)

The population statistics for Krabi show that around 87,602 of 392,455 in the year 2565 in Krabi lived in municipalities, which is around 22% (Krabi Provincial Statistical Office, n.d.). Using this figure, we can estimate wastewater produced by urban, or municipal, areas in any given year, and vice versa, for wastewater produced by rural, or non-municipal areas. We can do this by multiplying the municipal and rural populations (Table 8) by our standard estimate of 0.275, to find the amount of wastewater produced in each type of population in each year (Table 9).

Table 8 Population of Krabi (Municipalities vs. Rural) (2559-2566)

Year	Municipalities	Rural
2559	83,366	295,570
2560	84,071	298,072
2561	84,793	300,632
2562	85,359	302,637
2563	85,630	303,597
2564	86,073	305,167
2565	86,340	306,114
2566	86,799	307,743

Source: Krabi Provincial Statistical Report

Table 9 Amount of Wastewater Produced in Krabi (Municipalities vs. Rural) (2559-2566)

Year	Municipalities (in m^3/year)	Rural (in m^3/year)
2559*	8,390,801	29,749,207
2560	8,438,694	29,919,009
2561	8,511,169	30,175,965
2562	8,567,943	30,377,255
2563*	8,618,675	30,557,122

Year	Municipalities (in m^3/year)	Rural (in m^3/year)
2564	8,639,579	30,631,235
2565	8,666,387	30,726,283
2566	8,712,495	30,889,757

Note: *leap year

Source: Estimates by the research team

Wastewater Treatment Cost by Population Type (Municipalities vs. Rural)

Then, to calculate the cost of total cost of wastewater treatment in the population types during the dedicated years, we simply multiply the wastewater produced by the average cost of each system (centralized vs. Decentralized), in m^3/year.

The construction and O&M costs of centralized treatment, according to the report is 2.20 and 2.21 (Prateep Na Talang, R., Sirivithayapakorn, S., & Polruang, S., 2022), but in calculations we'll use (conservative estimate) 2.2 baht per m^3, and the costs of decentralized treatment is 4.28 and 7.55:(conservative estimate) 4.28 baht per m^3. Using these figures, we can multiply the cost of per m^3 wastewater treatment by wastewater produced in each type of population to find the cost of treating wastewater in centralized and decentralized areas in Krabi, in baht/year (Table 10).

Table 10 Cost of Wastewater Treatment in Krabi (Municipalities vs. Rural) (2559-2566)

Year	Municipalities (baht/year)	Rural (baht/year)	Total
2559*	18,459,764	127,326,606	145,786,370
2560	18,565,128	128,053,359	146,618,487
2561	18,724,573	129,153,130	147,877,703
2562	18,849,476	130,014,651	148,864,128
2563*	18,961,086	130,784,484	149,745,571
2564	19,007,074	131,101,690	150,108,764
2565	19,066,052	131,508,491	150,574,544
2566	19,167,490	132,208,163	151,375,654

Note: *leap year

Source: Estimates by the research team

1.4.2 Total Necessary Wastewater Treatment Cost by Subtraction

However, because Krabi has current existing systems, to find the cost of *necessary* (not total cost of) wastewater treatment a given year, we must subtract the cost of existing wastewater treatment systems from the total cost. Because of lack of information and the small nature of these systems, the cost of decentralized wastewater systems will not be calculated.

The cost of existing systems is simply calculated by multiplying the system capacity with 2.2, as all systems studied in this report are centralized. As of 2566 (the latest year this report studies), there are three centralized systems in Krabi, all totaling 10,920,800 baht/year, assuming maintenance costs for existing systems is zero.

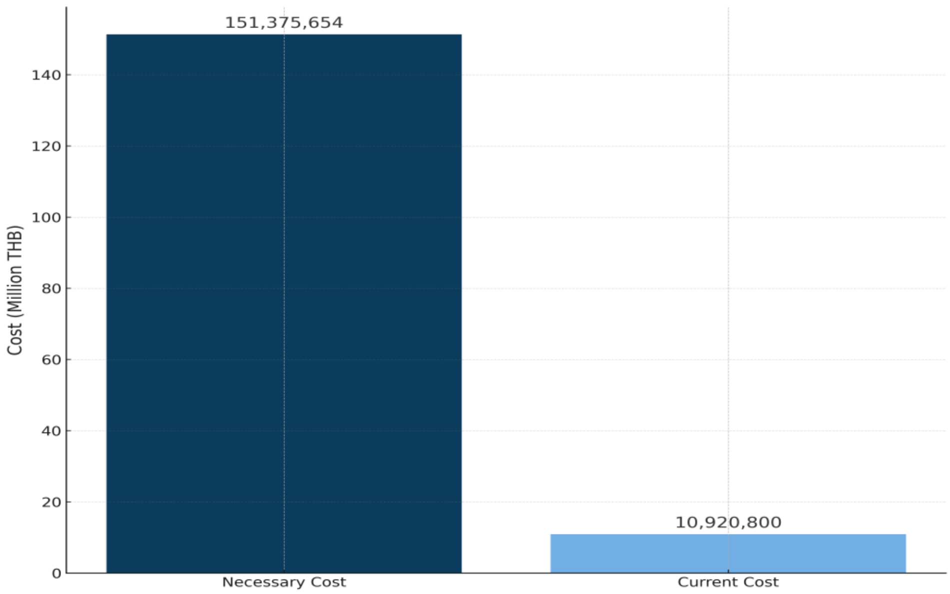
This gives us the formula for the cost of further necessary wastewater treatment (with W_C: Wastewater Treatment Cost, *Wcen*: Wastewater produced in Centralized spaces (Municipalities), C_E: Cost of Existing Wastewater Treatment Systems, *Wdecen*: Wastewater produced in Decentralized Spaces (rural), and the unit being baht/year);

$$W_c = ((2.2 \times W_{cen}) - C_E) + (4.28 \times W_{decen})$$

In this study, for the sake of convenience and lack of current data, we will use the year 2566's statistics and figures to estimate the cost of further necessary wastewater treatment systems *today*. Using 2566, we get a total cost of further necessary wastewater treatment of 140,454,848.96 baht.

This gigantic cost, the baht amount necessary to treat the amount of wastewater produced in Krabi, is a direct result of the overflow of water out of the system, and the massive amounts of wastewater produced, and is significantly bigger than the cost of current, existing systems (Figure 3). The problem of wastewater treatment in Krabi, if wanted to be dealt with, would require massive amounts of money, care, and determination.

Figure 3 Necessary Wastewater Treatment Cost vs. Current Cost, Krabi (2566)



Source: Estimates by the research team

1.4.3 Total Necessary Wastewater Treatment Cost by Population

Another way to calculate the necessary wastewater treatment cost is just to simply multiply the gap between wastewater produced and wastewater capacity by their respective rates. (Table 11)

Table 11 Cost of Necessary Wastewater Treatment in Krabi (Municipalities vs. Rural) (2559-2566)

Year	Municipalities (m^3/year)	Necessary Cost (Municipal.)	Rural (m^3/year)	Necessary Cost (Rural)
2559*	8,390,801.991	18,459,764	29,749,207.059	127,326,606
2560	8,438,694.880	18,565,128	29,919,009.12	128,053,359
2561	8,511,169.645	18,724,573	30,175,965.105	129,153,130
2562	8,567,943.753	18,849,476	30,377,255.122	130,014,651
2563*	8,618,675.604	18,961,086	30,557,122.596	130,784,484
2564	8,639,579.383	19,007,074	30,631,235.992	131,101,690
2565	8,666,387.538	19,066,052	30,726,283.088	131,508,491
2566	8,712,495.798	19,167,490	30,889,757.828	132,208,163

Source: Estimates by the research team

1.5 Wastewater Treatment Needed Facility Requirement

It is clear that the problem of wastewater production, and subsequently the arguably bigger issue of lack of wastewater treatment is detrimental to the natural resources and the environment of Krabi. Without government or civilian intervention, Krabi is on track to become overwhelmed, more than it already is, soon with problems of wastewater. Policy will help dictate the future of Krabi's sustainability, not only as a tourist spot, but as a Thai province. One of the most common proposed methods to better deal with wastewater is to increase capacity by adding systems.

1.5.1 Wastewater Treatment Systems for Municipalities

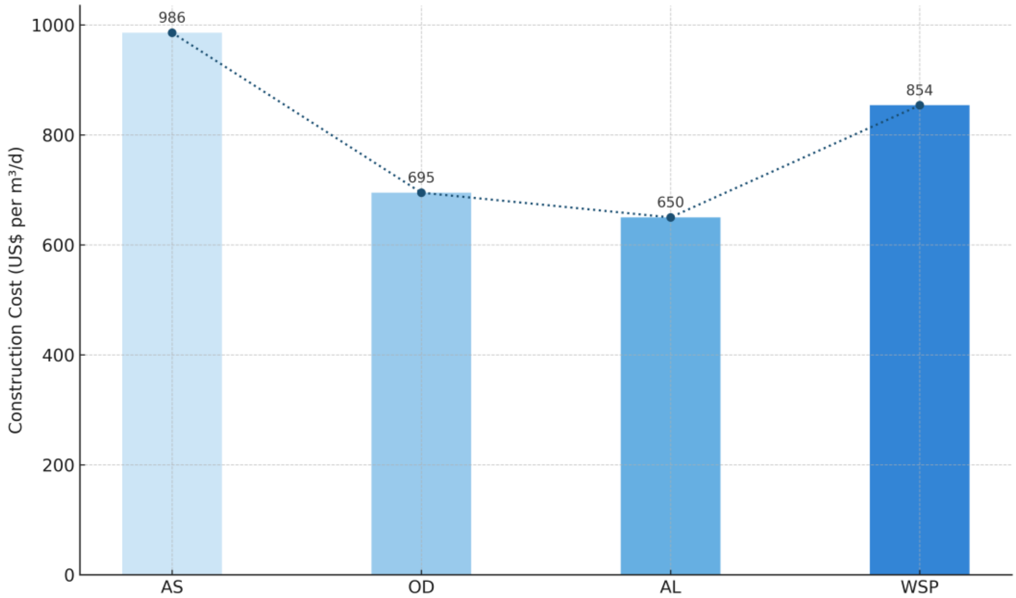
One way of dealing with Krabi's wastewater problem is increasing the number and quantity of centralized wastewater treatment systems in municipalities.

It is important, first, to recognize that different types of centralized wastewater treatment systems vary in cost, size, and efficiency, all major factors that should be under consideration when deciding which type of treatment should be implemented in Krabi. Cost, for example, of each system fluctuates based on construction costs and operation and maintenance (O&M) costs (Singhirunnusorn, W., & Stenstrom, M. K., 2010). The four main types of wastewater treatment systems, Activated Sludge (AS), Oxidation Ditches (OD), Aerated Lagoons (AL), and Waste Stabilization Ponds (WSP) all have varying factors that influence its cost.

The AS system has the highest construction cost and the lowest O&M cost. The WSP system has the second highest construction cost and the second lowest O&M cost. The OD system has the second lowest construction cost and the highest O&M cost, while the AL system has the lowest construction cost and the second largest O&M cost (Figure 4, Figure 5).

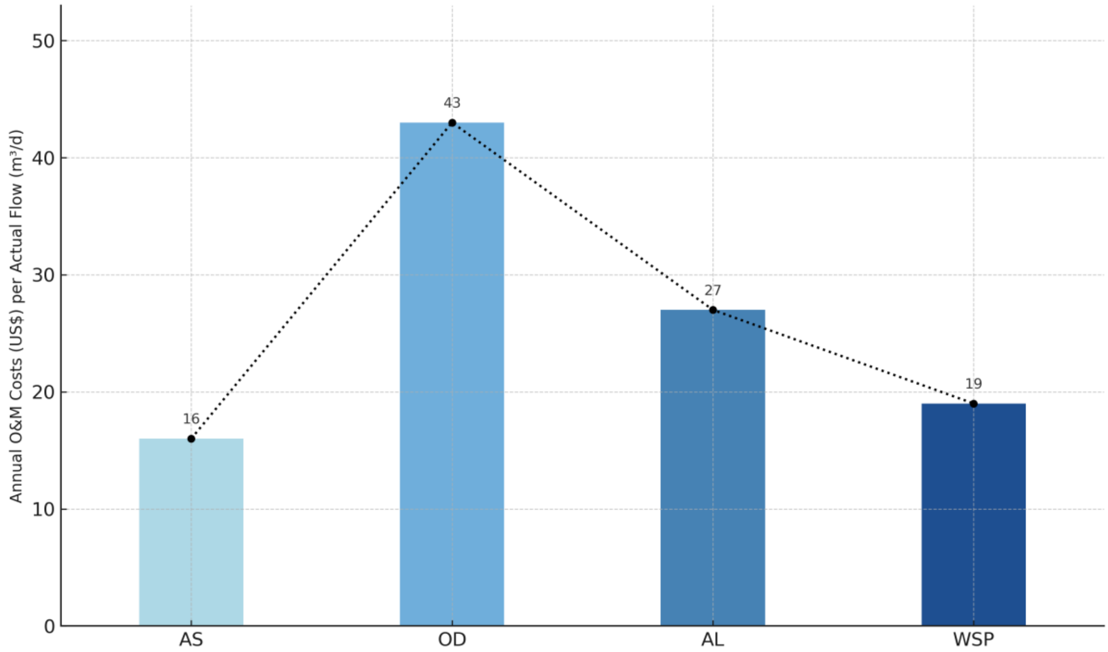
Combined and scaled (Table 12), the AS system costs the most, followed by the WSP, OD, and AL systems, respectively. So, accordingly, when deciding which avenue Krabi should take when attempting to resolve its wastewater treatment issue in centralized or municipal populations, it is important to consider price.

Figure 4 Construction Cost by Treatment System



Source: Singhirunnusorn, W., & Stenstrom, M. K., (2010)

Figure 5 O&M Cost by Treatment System



Source: Singhirunnusorn, W., & Stenstrom, M. K., (2010)

Table 12 Total Cost of Wastewater Treatment Systems (AS vs. OD vs. AL vs. WSP)

System	Total Cost (Construction + O&M cost)	Rank
Aerated Lagoons (AL)	677	1
Oxidation Ditches (OD)	738	2
Waste Stabilization Ponds (WSP)	873	3
Activated Sludge (AS)	1,002	4

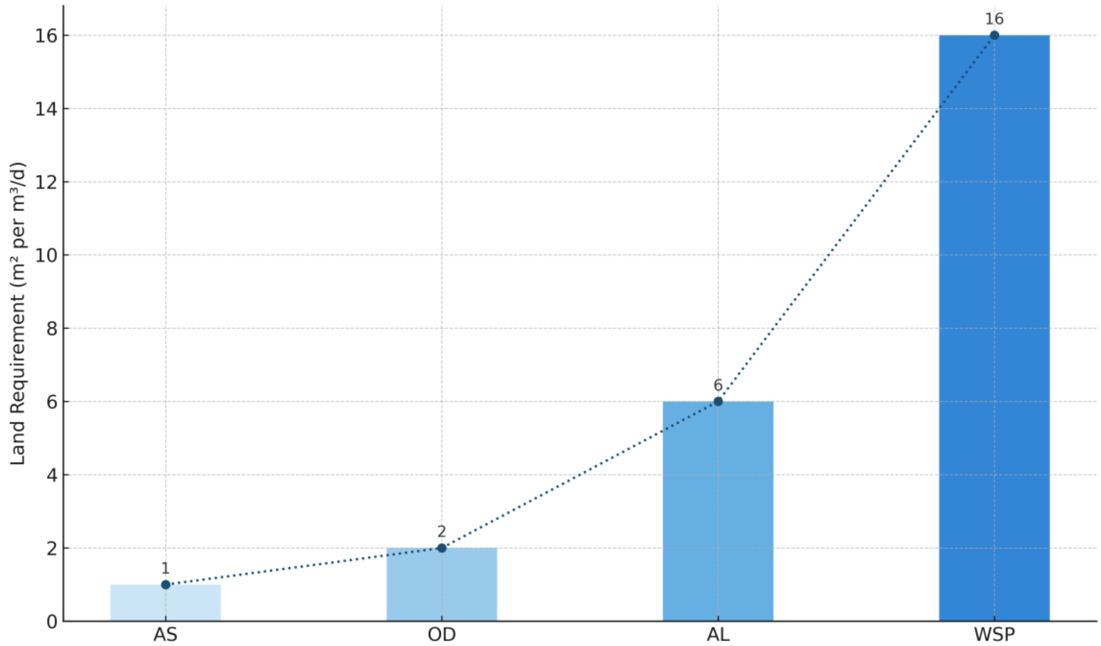
*Rankings are Author Rationale

Source: Singhirunnusorn, W., & Stenstrom, M. K., (2010)

Other than price, Krabi will also have to consider the size of the wastewater treatment systems. A bigger land requirement for certain systems would be detrimental for Krabi's municipalities, especially because Krabi is one of Thailand's smallest provinces. In terms of land requirement, the aforementioned systems rank as follows: WSP, with the highest land requirement, followed by AL, OD, and AS (Figure 6).

Lastly, Krabi will have to consider the efficiency of each type of system, the quality of its treatment will influence decision making by Krabi officials. Wastewater pollution is measured by two indicators: Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS). The percentage removal of both types of pollution determines a treatment system's efficiency (Table 13).

Figure 6 Land Requirement by Treatment System (just system)



Source: Singhirunnusorn, W., & Stenstrom, M. K., (2010)

Table 13 Efficiency of Wastewater Treatment Systems (AS vs. OD vs. AL vs. WSP)

System	TSS Removal (%)	BOD Removal (%)
Aerated Lagoons (AL)[1]	80-90	50-95
Oxidation Ditches (OD) [2]	94.2	90.5
Waste Stabilization Ponds (WSP) [3]	30	82
Activated Sludge (AS) [4]	85-98	85-99

Source: [1] Shahryar Jafarinejad. (2017),

[2] Alramthi, S. M., Ali, G. H., Elthagafi, A. M., Eldosari, S. H., Zhu, B.-K., & Safaa, H. M. (2022),

[3] Adu-Ofori, K., Amfo-Otu, R., & Hodgson, I. (2016)

[4] Nippon Dynawave Packaging Company (2016)

Krabi will have to consider all three factors, land, cost, and efficiency, when deciding the quantity and amount of new wastewater treatment (Table 14). However, it is clear the big gap between wastewater produced and capacity of treatment in Krabi municipalities (Figure 7) warrants the construction of new systems.

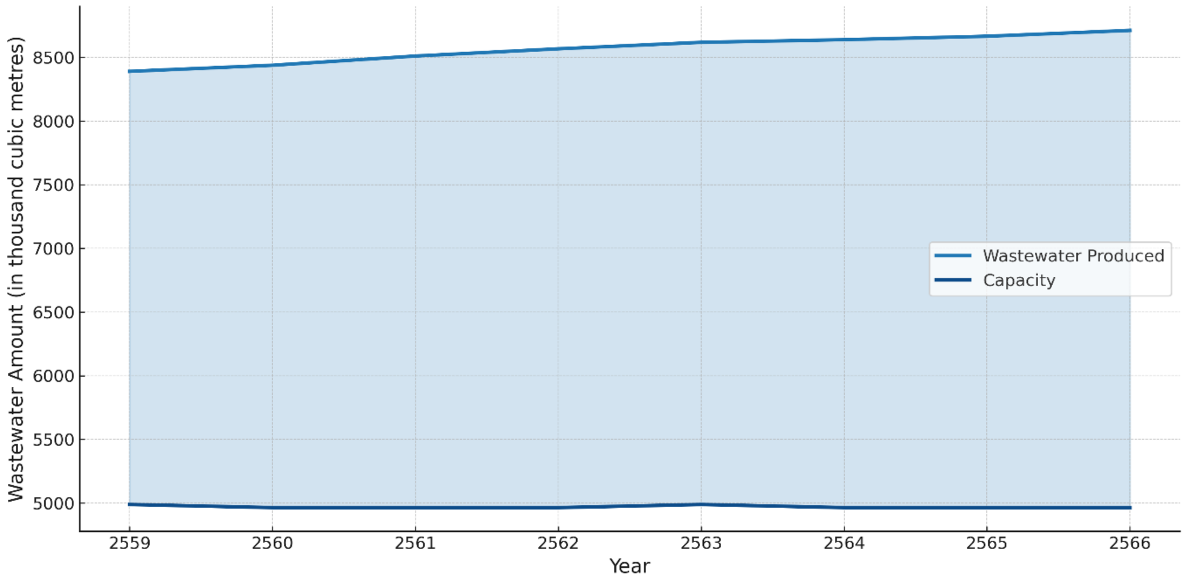
Table 14 Total Cost of Wastewater Treatment Systems (AS vs. OD vs. AL vs. WSP)

System	Cost Rank	Land Req.	Efficiency
Aerated Lagoons (AL)	1	3	3
Oxidation Ditches (OD)	2	2	1
Waste Stabilisation Ponds (WSP)	3	4	4
Activated Sludge (AS)	4	1	2

*Rankings are Author Rationale

Source: Singhirunnusorn, W., & Stenstrom, M. K., (2010)

Figure 7 Gap in Wastewater Produced vs. Capacity, Municipalities, Krabi (2559-2566)



Source: Estimates by the research team

1.5.2 Wastewater Treatment Systems for Rural Areas

Besides increasing the number of centralized wastewater treatment systems in municipalities, Krabi can also increase the quantity and quality of decentralized systems in rural areas. Typically, municipal areas are the focus of wastewater treatment. But, considering Krabi's gap between wastewater produced from municipalities vs. rural areas (rural areas produced 3.5 times more wastewater than municipalities), rural areas are just as, if not more, important in terms of treatment.

In rural areas, especially tropical ones, septic tanks make up most forms of wastewater treatment in rural areas. However, septic tanks, though prominent and prevalent, are solely basic systems for primary treatment and require post-treatment. Another simple system is Constructed Wetlands (Boguniewicz-Zablocka, J., & Capodaglio, A. G., 2017), which are low cost, simple to design, and efficient in treatment. Other systems like Membrane Bioreactors (MBRs) are effective in treatment but costly and require immense maintenance & energy use.

Wastewater treatment system improvement in rural areas faces many difficulties, the most important of these being: financial, management, and difficulties concerning awareness (Deng, Y., & Wheatley, A., 2016). Small systems in rural areas often lack government funding (significantly less than centralized systems), facilities are often left without maintenance, and the rural population often lack knowledge about correct handling of wastewater.

Recommended solutions include increasing government oversight, raising awareness in local communities, and improving training and management systems. Krabi must also consider local context and subsequently match suitable technology, simultaneously considering land requirement, cost, and efficiency (Boguniewicz-Zablocka, J., Klosok-Bazan, I., Capodaglio, A. G., & Ploskonka, J., 2018). For rural areas, specifically, the consideration of these factors will guide the construction of new rural treatment systems, helping bridge the gap in wastewater produced and current treatment capacity in rural areas, which is tens of millions of cubic meters.

1.6 Wastewater Treatment: Policy and Enforcement

The solutions mentioned deal with the aftermath of wastewater production. However, several policies can be suggested to improve the treatment capacity of wastewater treatment systems in Krabi, which deal with the problem at its root.

1.6.1 Current Policy and Laws

Several national-level statutes currently exist in the realm of wastewater treatment in Thailand. The laws range from general and widely covering to wastewater specific. The Enhancement and Conservation of National Environmental Quality Act (B.E. 2535/1992) (NEQA), for example, details a general overview of managing resources, preserving the environment, and controlling pollution. More specifically to wastewater, the sets discharge standards, sets legal obligations and penalties, and supports local enforcement and institutions. There are various other national-level statutes already in place for wastewater production and treatment (Table 15).

Under these laws, the Ministry of Natural Resources and Environment (MNRE), through the Pollution Control Department (PCD) and Pollution Control Board, sets detailed standards and notifications for wastewater (setting discharge limits, defining monitoring requirements). National Laws, as is, seem tough and strict on wastewater discharge and treatment.

Krabi-level laws also tell us a lot about the problem in the current wastewater treatment system. Environmental Protection zones have been declared in Krabi, and in 2022 the MNRE explicitly charged Krabi Provincial Natural Resources and Environment Office with supervising and enforcing the measures. Local governments (Krabi City Municipality, Ao Nang Subdistrict Administrative Organization (SAO), etc.) implement the aforementioned acts within their areas, issuing ordinances and local permits for septic systems or improvements and construction of sewer systems.

The law, for the most part, is not the root of the major problem in Krabi's mishandling of wastewater, further pointing to the quantity of systems as the main problem.

Table 15 National-Level Statutes (Wastewater Specific)

Law	General Description	Wastewater Specific
NEQA (1992)	– Pollution control – Environmental impact assessments – Enhancement of national environmental quality	– Set discharge standards – Set legal obligations and penalties – Support local institutions and enforcement
Factories Act (1992)	– Regulations for factory location, environment, building design, machinery, worker safety, and waste management	– Prohibition of discharge without treatment – Sets standard for dischargeable wastewater
Public Health Act (1992)	– Regulates public health: ○ Sanitation ○ Waste management ○ Food safety ○ Disease control	– Licenses for businesses involved in collecting, transporting, or disposing of sewage and waste – Government regulation
The Cleanliness Act (1992)	– Prohibits actions: ○ Damaging public property ○ Littering and obstructing public areas	– Forbids the emission of waste or other materials on roads, waterways, or other public spaces.
Navigation in Thai Waters Act (1913)	– Rules and regulations for various aspects of maritime activity: ○ Vessel operations ○ Licensing and safety	– Regulates the dumping of refuse and other waste materials into waterways and prohibits actions that could pollute them
Water Resources Act (2018)	– Aims to create a unified and efficient system for managing all water resources	– Prohibits actions that cause pollution, danger, or damage to water resources

Source: Collected by Research team

1.6.2 Enforcement

If the law is not the problem, it is reasonable to assume that the main problem lies in enforcement. Enforcement in Krabi combines inspections, fines and public projects. Provincial and district officials, led by the Governor's office or the Provincial NRE Office, inspect hotels, restaurants and communities for illegal discharges.

For example, in 2019 authorities punished two Ao Nang restaurants (Thailandia and Taj Palace) for dumping untreated wastewater into a canal leading to Ao Nang Beach. The deputy governor announced that Krabi will inspect all businesses along the Chak Canal and punish all who release untreated wastewater, along with fining each violator ฿10,000 under the country's cleanliness laws.

However, enforcement appears to be rare, as it is less reported on by Krabi provincial offices (Krabi Provincial Office of Natural Resources and Environment, n.d.). To lower Krabi's wastewater production and dumping, the law needs to be more strictly and robustly enforced.

1.6.3 Funding

Another common problem with policy and enforcement is funding. Though Krabi operates, in accordance with national law, a polluter pays principle, government funding often only comes for big treatment systems, along with O&M costs. Most of the funding comes from the Wastewater Management Authority (WMA) under the Interior Ministry (Krabi Provincial Office of Natural Resources and Environment, n.d.). Sometimes international partners such as the German GIZ works with the WMA on wastewater initiatives (GIZ Thailand, 2019).

However, funding, especially for rural areas, is one of the biggest problems in wastewater treatment. Funding for small systems is virtually non-existent, as systems most common in the areas do not require monthly fees or high operational costs (septic tanks). However, due to a lack of systems, in quantity, villagers often dispose of their wastewater into natural water sources. If funding for rural wastewater treatment increases, it is likely that the quantity of illegal dumping will subsequently decrease.

1.6.4 The future operation of Krabi's wastewater treatment system

Krabi Province addresses community wastewater issues through the sustainable management of community wastewater treatment systems. Currently, there are two integrated wastewater treatment systems: the Krabi Municipality wastewater treatment system, which covers an area of approximately 1.51 square kilometers (9.89% of the total municipal area), and the Ao Nang Subdistrict Administrative Organization's wastewater treatment system, also known as the Phi Phi Island Water Quality Management Center, located in Ao Nang Subdistrict, Mueang District, Krabi Province. This system has the capacity to treat approximately 1,200 cubic meters of wastewater per day and includes a wastewater pumping station, a treatment system, and water quality monitoring through the collection of treated wastewater samples for laboratory analysis. The treated water is then reused through a reverse osmosis (RO) system for various projects.

To further address wastewater management needs, there is a plan to construct a second wastewater treatment plant under the Ao Nang Subdistrict Administrative Organization. This project aims to manage wastewater more effectively, reduce pollution discharged into public water sources, and maintain environmental conditions in tourist areas within the Ao Nang Subdistrict. The project also aims to allow public use of the area above the wastewater treatment facility for activities such as recreation and exercise, thereby expanding the wastewater treatment service area in Village No. 2, Ao Nang Subdistrict, Mueang Krabi District, Krabi Province. Due to increasing economic growth in the area, wastewater volumes have risen, creating a need for additional treatment capacity. Most wastewater in the Ao Nang Subdistrict Administrative Organization area originates from residential communities and commercial establishments such as restaurants, service businesses, and markets, and is often discharged into public water sources without proper treatment. This situation negatively affects quality of life, public health, and the ecosystem, and may harm biodiversity.

The second wastewater treatment plant is currently in the process of finalizing a joint agreement between the Ao Nang Subdistrict Administrative Organization and the Wastewater Management Organization (WMO) for the management and operation of the community's integrated wastewater system. The project involves the construction of the Ao Nang Subdistrict Administrative Organization's second Water Quality Management Center (Figure 8) on an area of 8,106 square meters. The facility will be an activated sludge aeration–type wastewater treatment plant with media, capable of treating 2,000 cubic meters of wastewater per day. The structure will be a reinforced concrete building, with the wastewater treatment system located underground, along with an office building for operational control. The primary objective of the project is to reduce pollutant loads in wastewater before discharge into public water sources. In addition, the area above the wastewater treatment system will be available for public recreational activities such as relaxation and exercise (Wastewater Management Organization, 2025).

Figure 8 Construction site of the second Water Quality Management Center of the Ao Nang Subdistrict Administrative Organization

Source: Wastewater Management Organization (2025)

1.7 Conclusion

In all, the gap between wastewater produced in Krabi and wastewater in system and wastewater treatment capacity highlights an inherent need for Krabi to improve systematic opposition, preventing wastewater produced, whether by policy or laws and dealing with wastewater in both municipal and rural areas, through the construction of new systems, improvement to current capacity. The main recommended solution is to improve the wastewater treatment capacity of Krabi in both municipal and rural areas, which of course, would require more funding. Furthermore, the law needs to be more frequently enforced and check-ups more common. In all, through increasing capacity and enforcing policy, Krabi may bridge the gap between its produced wastewater and its treatment capacity.

2. Small-Scale Wastewater Treatment Systems in Krabi

2.1 Introduction

Tourism has played an important role in Thailand's national development for more than three decades. According to the Tourism Authority of Thailand (TAT), the tourism sector contributes over 20% of the national gross domestic product (GDP) (TTR Weekly, 2025). The southern provinces, particularly those along the Andaman coast, are globally recognized for their natural beauty, including limestone cliffs, coral reefs, mangrove forests, and white sandy beaches. Among them, Krabi Province has become a major tourism destination, with popular attractions such as Ao Nang Beach, Railay, and the Phi Phi Islands.

In recent years, the trend in Thailand's tourism has shifted toward eco-tourism and community-based tourism, which promote environmental awareness and local participation. Ao Nang Beach has emerged as a central hub for both domestic and international visitors. The expansion of small-scale tourism facilities, including homestays, boutique hotels, local restaurants, and small laundry services, has generated substantial economic benefits for local communities. However, the rapid growth of these businesses has also increased pressure on local infrastructure and the natural environment, especially in relation to wastewater management.

Many small enterprises are located outside the municipal boundaries, where there is no connection to centralized wastewater collection and treatment systems. Consequently, untreated or partially treated wastewater is often discharged directly into nearby canals such as Klong Yingsuea and Klong Jark, which ultimately flow into Ao Nang Bay (Figure 9). This situation threatens water quality, aquatic ecosystems, and the long-term sustainability of the tourism sector in Krabi Province.

The discharge of untreated wastewater presents serious environmental risks. Elevated biochemical oxygen demand (BOD) and chemical oxygen demand (COD) reduce dissolved oxygen (DO) concentrations, stressing aquatic organisms. High nutrient concentrations, particularly nitrogen and phosphorus, promote eutrophication and algal blooms, while microbial contamination from Escherichia coli (E. coli) and coliform bacteria poses health risks to swimmers and seafood consumers. Additionally, chemical pollutants such as detergents, surfactants, and oils alter water chemistry and harm marine life. These pollutants have been widely identified as key factors contributing to the degradation of coastal water quality in Thailand (Pollution Control Department, 2017a; Department of Marine and Coastal Resources, 2020).

Figure 9 Polluted canal water observed in Klong Yingsuea and Klong Jark (discharge into Ao Nang Bay), Krabi Province.

Source: TDRI (2025)

The sources of these pollutants in peri-urban Krabi are diverse. Wastewater from homestays and hotels typically contains organic matter, suspended solids, and pathogens, similar to domestic sewage. Restaurants additionally contain oils, grease, and food residues, while laundry shops discharge detergents and microplastics. Together, these discharges create a complex mixture of contaminants that degrade canal and marine water quality. The resulting pollution not only affects ecosystems such as coral reefs and seagrass beds but also damages the area's image as a clean, eco-friendly tourism destination.

Unlike urban centers such as Bangkok or Phuket, where municipal wastewater treatment plants are available, peri-urban and rural communities in Krabi lack centralized infrastructure. Extending sewer networks and treatment facilities to these areas would require large capital investment and face technical challenges due to the dispersed settlement pattern and seasonal variations in wastewater flow. During the high tourist season, wastewater generation increases sharply, while during low seasons, flow rates drop significantly. These fluctuations complicate the operation of large-scale centralized wastewater treatment systems.

Therefore, the most practical approach is to promote small-scale and decentralized wastewater treatment systems that are designed to suit local conditions and enterprise capacities. To be effective, such systems should demonstrate reliable performance in reducing organic load, pathogens, and suspended solids to acceptable standard concentrations. They must also be economically feasible, with low installation and operating costs suitable for small business owners. Operational simplicity is essential, allowing local users to manage and maintain systems without specialized technical knowledge. Adaptability is also required to accommodate different site conditions, from single homestays to clustered community enterprises. Finally, environmental sustainability should be a guiding principle, emphasizing systems that minimize energy use, integrate with the local landscape, and align with the principles of eco-tourism that define Krabi's development vision.

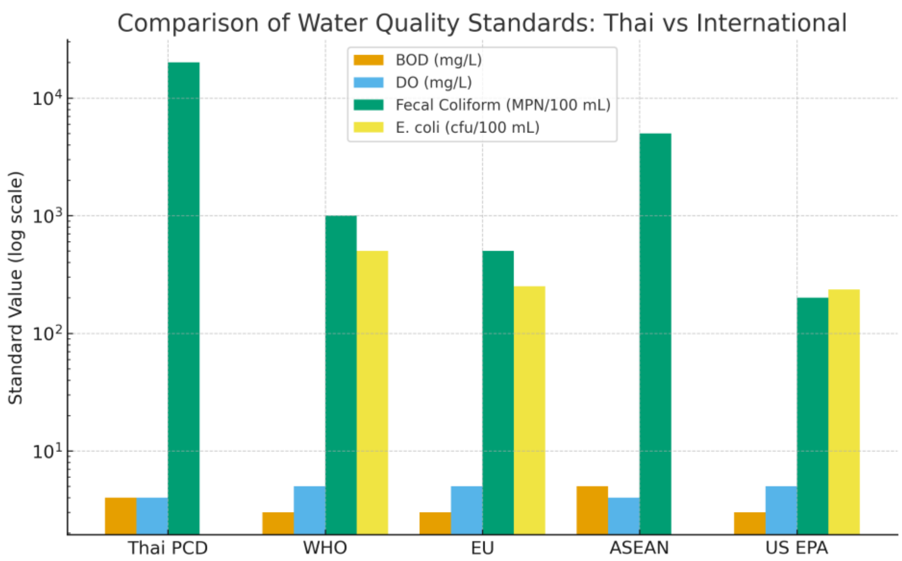
This report, therefore, aimed to evaluate the technical and economic feasibility of small-scale wastewater treatment systems suitable for Krabi's local enterprises. The findings are intended to support decision-makers, local authorities, and small business operators in implementing appropriate wastewater solutions that protect environmental quality while maintaining Krabi's position as a leading sustainable tourism destination.

2.2 Water Quality Standards

Water quality standards serve as essential benchmarks for guiding wastewater management practices and for protecting aquatic ecosystems, public health, and tourism resources. In Thailand, the Pollution Control Department (PCD) classifies surface waters into five classes, ranging from Class 1 (the highest quality, suitable for drinking water supply after conventional treatment) to Class 5 (suitable only for navigation). For canal waters, the surface water quality standards of Thailand require biochemical oxygen demand (BOD) ≤ 4 mg/L, dissolved oxygen (DO) ≥ 2 mg/L, and total coliform bacteria (TCB) and fecal coliform bacteria (CFB) fecal coliform bacteria both ≤ 20,000 MPN/100 mL (Pollution Control Department, 2017)

International guidelines, however, often impose stricter microbial criteria. The World Health Organization (WHO, 2021), the European Union (EU, 2006), and the United States Environmental Protection Agency (US EPA, 2022) recommend using E. coli as an indicator parameter, with threshold values ranging between 200 and 500 CFU/100 mL for safe recreational water. These standards reflect a global trend toward adopting microbial indicators that are more reliable and relevant to human health risks. In comparison, Thailand's water quality standards rely on total coliform bacteria (TCB) and fecal coliform bacteria (CFB) and the higher allowable thresholds suggests a gap in microbial protection for high-value recreational beaches such as Ao Nang.(Figure 10)

Figure 10 Water quality standards of Thailand, WHO, EU, ASEAN, and US EPA for recreational waters.



Source: WHO (2021)

2.3 Wastewater Treatment Technologies for Small-scale Decentralized Wastewater Treatment System

Centralized sewerage systems with large-scale wastewater treatment plants have significantly improved environmental quality and public health in urban areas. However, their construction, operation, and maintenance involve high capital and running costs, making them impractical for many smaller municipalities and peri-urban communities, particularly in the southern provinces of Thailand, where tourism development has expanded rapidly. In such areas, decentralized wastewater treatment systems represent a viable and sustainable alternative.

This section presents a technical and economic comparison of small-scale decentralized wastewater treatment technologies applicable to homestays, restaurants, small hotels, and laundry facilities in Krabi Province, Thailand. Decentralized systems are suitable for areas where existing on-site treatment is insufficient or where conventional centralized systems are not feasible due to geographic, economic, or infrastructure constraints. Decentralized wastewater treatment technologies offer a range of options, from simple natural treatment methods to advanced mechanical and biological systems. Their adoption should be carefully assessed by considering technical performance, economic feasibility, social acceptability, and environmental sustainability. A balanced approach helps ensure that the selected system can effectively reduce pollution while being affordable and manageable for local enterprises and communities.

For this study, four technology options were evaluated:

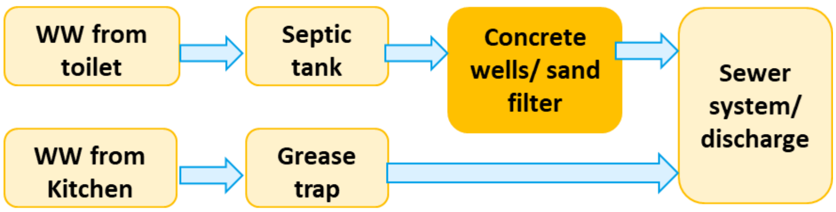
1. Septic tank with sand filter
2. Integrated septic tank with anaerobic filter
3. Septic tank with aerobic filter
4. Constructed wetland

Each technology was assessed based on its treatment efficiency, cost of installation and operation, maintenance requirements, and suitability for local applications in Krabi's tourism-related enterprises for 10-15 tourists/homestay. The comparative analysis aims to provide practical recommendations for selecting appropriate small-scale wastewater treatment technologies that align with both environmental objectives and community capacity.

2.3.1 Septic Tank with Sand Filter

The septic tank with sand filter system is among the most commonly applied small-scale wastewater treatment options in Thailand, particularly in rural and peri-urban areas (Figure 11). It represents a low-cost, low-technology approach that combines primary sedimentation with secondary filtration through sand and gravel media. The system is simple to construct and operate, relying on natural physical and biological processes without the need for mechanical equipment or electricity.

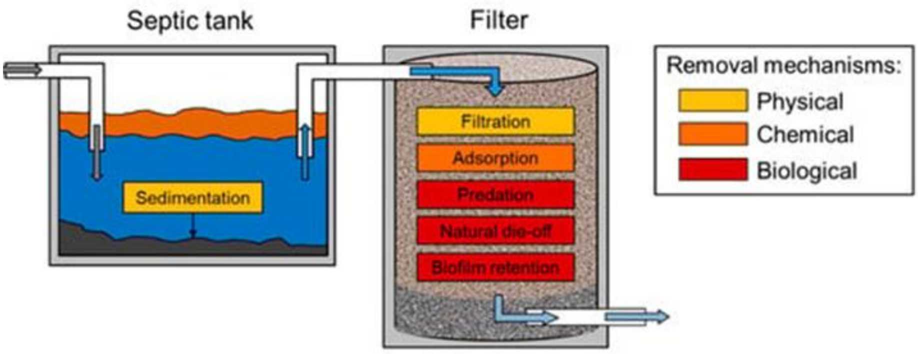
Figure 11 Septic tank with sand filter system



Source: Prepared by the research team

In the first stage, wastewater enters a septic tank, where flow is slowed to allow solids to settle and undergo anaerobic digestion. Floating materials such as grease and scum accumulate at the surface, while heavier solids form sludge at the bottom. Within the tank, anaerobic microorganisms partially degrade organic matter, resulting in moderate reductions of biochemical oxygen demand (BOD) and suspended solids (SS). However, septic tanks alone rarely meet the effluent standards set by the Pollution Control Department (PCD), Thailand, particularly for microbial contamination (fecal coliform bacteria) and nutrient removal. The effluent from the septic tank then passes through a sand filter, which serves as a secondary treatment step. The sand filter typically consists of layered media; coarse gravel at the base, followed by medium gravel and fine sand at the top. As the effluent percolates through these layers, SS are physically trapped, and biofilms forming on the sand grains further degrade organic matter and pathogens. This combination of filtration and biological polishing improves effluent clarity and enhances pathogen reduction through natural die-off and adsorption processes (Figure 12).

Figure 12 Schematic of septic tank with sand and gravel filter showing influent, sedimentation, filtration, and effluent pathways (Source: Wang et al., 2021).

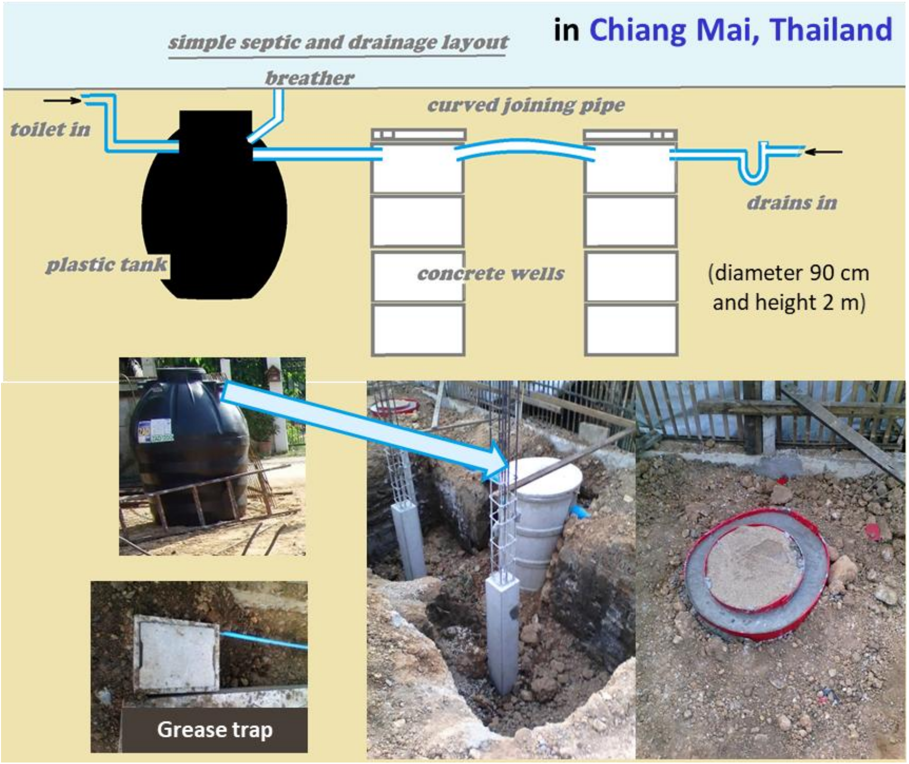


Source: Wang et al (2021)

Field applications in provinces such as Chiang Mai (Figure 13), Surat Thani, and Krabi demonstrate that septic tank and sand filter systems can achieve 40-60% BOD removal, 30-50% total suspended solids (TSS) removal, and minor reductions in fecal coliform bacteria (typically less than 90% removal). Consequently, effluent concentrations often exceed 10,000 MPN/100 mL, making the system unsuitable for discharge into environmentally sensitive water bodies such as Klong Yingsuea and Klong Jark, which drain into Ao Nang Bay, without additional treatment.

The key advantage of this system lies in its affordability and simplicity. Estimated capital costs in Krabi range from 41,000 to 60,000 THB per unit (Figure 14), depending on capacity and local material availability. Operational costs are minimal, limited mainly to periodic desludging of the septic tank every two to three years and occasional cleaning or replacement of sand filter media. The system can be constructed using locally available materials and operated without specialized technical expertise, making it a practical choice for small homestays, rural restaurants, or community centers. However, its main limitations include modest treatment efficiency, land requirements for filter beds, and limited hydraulic capacity during peak tourist periods. For densely developed or environmentally sensitive zones, such as Ao Nang's tourism clusters, this system alone is inadequate. In such cases, the septic tank with sand filter should be integrated with an additional polishing step, such as chlorination, ultraviolet disinfection, or a small constructed wetland, to ensure compliance with discharge standards and protection of coastal water quality.

Figure 13 Schematic of simple septic and drainage layout in Chiang Mai, Thailand



Source: Len HEND. (n.a.)

Figure 14 Estimated capital costs of septic tank with sand filter system.

Option 1: Septic tank + Coarse sand filter (for 10-15 people/homestay)

Item	Estimated cost (THB)
Grease tap (80 – 100 L)	3,000 – 5,000
Septic Tank (2,000 – 3,000 L)	8,000 – 15,000
Concrete construction (wells, base)	15,000 – 20,000
Small sand filter material (1.5×1.5 m)	5,000 – 7,000
Piping and fittings	5,000
Labor cost	5,000 – 8,000
Total estimated cost	41,000 – 60,000 THB

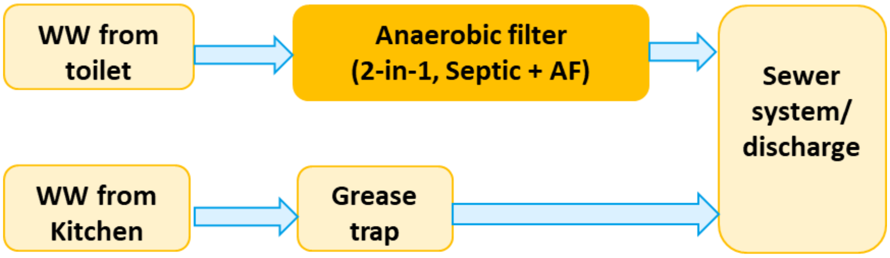
Source: Compiled by Research team

2.3.2 Integrated Septic Tank with Anaerobic Filter

The integrated septic tank with anaerobic filter is a compact, prefabricated wastewater treatment system that enhances the performance of a conventional septic tank by incorporating a biological filtration stage (Figure 15). In this configuration, the septic tank and anaerobic filter are combined into a single modular unit, typically constructed from reinforced concrete or high-density polyethylene (HDPE). Its simple operation makes it well-suited for homestays, restaurants, and small businesses in peri-urban areas where land availability is limited.

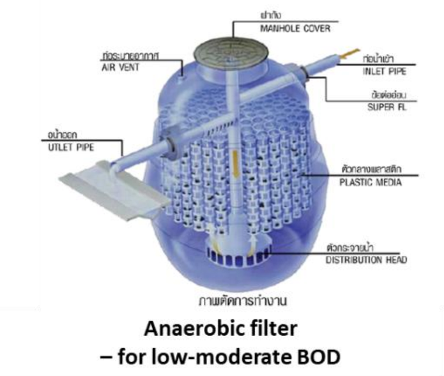
In the first compartment, the unit functions as a traditional septic tank, allowing wastewater to slow down so that heavier solids settle and undergo anaerobic digestion. The effluent then flows into the anaerobic filter chamber, which is packed with inert media such as plastic rings, gravel, or honeycomb blocks (Figure 16 and Figure 17). These materials provide surfaces for biofilm growth, allowing anaerobic microorganisms to further degrade soluble and colloidal organic matter as the wastewater passes through. This additional biological stage enhances organic removal and stabilizes the overall treatment process.

Figure 15 Integrated septic tank with anaerobic filter



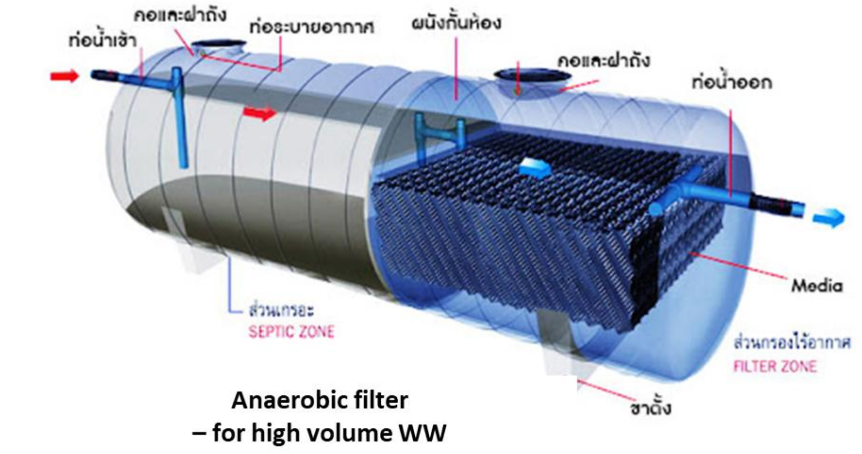
Source: Compiled by Research team

Figure 16 Schematic of anaerobic filter for low-moderate BOD



Source: Pattanan Nakpinit, Municipal wastewater design (2021)

Figure 17 Schematic of anaerobic filter for high volume BOD



Source: Perfect Solution Water. (2020)

In terms of performance, the integrated septic tank with anaerobic filter typically achieves BOD removal of 60-70%, TSS reduction of 50-70%, and moderate pathogen removal, reducing fecal coliform bacteria by about 90-99%. While microbial removal remains limited, the system performs significantly better than a septic tank alone. It is also more resistant to hydraulic and organic shock loads, which is an important advantage for small-scale tourism facilities that experience fluctuating occupancy or seasonal variations in wastewater flow, as commonly observed in Krabi's coastal communities.

From an economic viewpoint, installation costs range from 28,000 to 48,000 THB per unit (Figure 18), depending on tank volume and material specifications. Operational costs are very low since the system requires no electricity and minimal supervision. Routine maintenance primarily involves desludging every 1.5-2 years and occasional rinsing of the filter media to prevent clogging and maintain permeability. The advantages of this system include its compact design, low capital and operational costs, and ease of maintenance, making it highly compatible with homestay and small business operations in Krabi. However, the effluent quality may still not meet Pollution Control Department (PCD) discharge standards for microbial indicators if released directly into surface water. Therefore, this system is most effective when combined with a secondary natural polishing process, such as a constructed wetland, disinfection pond, or subsurface infiltration bed, to further reduce pathogen levels before final discharge.

Figure 18 Estimated capital costs of integrated septic tank with anaerobic filter.

Option 2: Anaerobic filter (for 10-15 people/homestay)

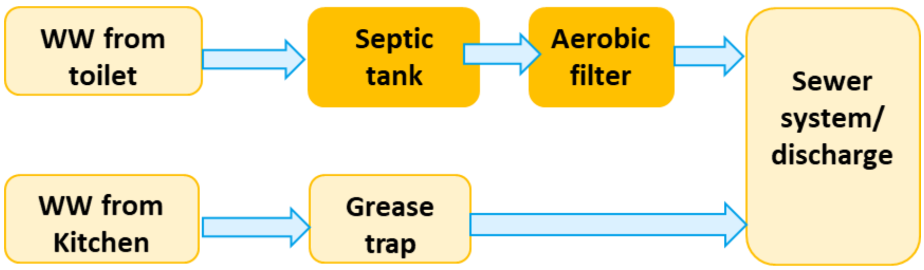
Item	Estimated cost (THB)
Grease tap (80 – 100 L)	3,000 – 5,000
2-in-1 anaerobic filter (2.5 – 3 m^3)	12,000 – 20,000
Filter media (for 1 – 1.5 m^3)	3,000 – 5,000
Piping, fittings, etc.	5,000 – 10,000
Labor cost	5,000 – 8,000
Total estimated cost	28,000 – 48,000 THB

Source: Compiled by Research team

2.3.3 Septic Tank with Aerobic Filter

The septic tank with aerobic filter represents a hybrid treatment configuration that combines primary anaerobic digestion with secondary aerobic biological polishing to achieve higher effluent quality (Figure 19). Wastewater first enters the septic tank, where solids settle and undergo anaerobic decomposition. The clarified effluent then flows into an aerobic treatment chamber, which contains either fixed-film media or suspended-growth biomass, supported by continuous aeration.

Figure 19 Septic tank with aerobic filter



Source: Compiled by Research team

Within the aerobic chamber (Figure 20), the media (such as plastic honeycomb modules, gravel, or synthetic fiber mats) provide surfaces for the attachment of aerobic microbial biofilms. These microorganisms oxidize soluble organic matter in the presence of oxygen supplied by diffused air systems or mechanical aerators. This stage significantly enhances the removal of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and pathogens, resulting in clearer effluent with lower odor and organic load compared to anaerobic systems alone.

In terms of treatment performance, this system typically achieves 80-90% BOD removal and 70-90% total suspended solids (TSS) reduction. Pathogen removal is also improved, when properly operated, the system can remove 99.0-99.9% of fecal coliform bacteria, providing substantially cleaner effluent compared to anaerobic systems. While nutrient removal remains limited, it can be partially improved by extending aeration time or using biofilm carriers that promote nitrification. For discharges into sensitive water bodies such as Klong Yingsuea and Klong Jark, an additional disinfection or polishing step may still be required to meet Pollution Control Department (PCD) standards.

Figure 20 Schematic of anaerobic filter for high volume BOD

Sources: Norkaew et al. (2023) and Pattanan Nakpinit, Municipal wastewater design (2021)

From an economic perspective (Figure 21), installation costs for small-scale systems in Krabi range from 41,000-68,000 THB per unit, depending on tank size and aeration equipment type. Operating costs are higher than those of anaerobic systems due to continuous electricity consumption for air pumps or blowers and the need for regular maintenance of aeration devices. Sludge removal is generally required every 1-2 years to maintain system efficiency.

The main advantages of the septic tank with aerobic filter system include its high treatment efficiency and its ability to consistently produce high water quality effluent. This makes it a suitable option for small- to medium-sized homestays, boutique hotels, or restaurants situated near environmentally sensitive coastal areas such as Ao Nang Beach. The system is particularly advantageous in contexts where strict discharge regulations are enforced. However, several limitations should be noted. The system's reliance on electricity increases both operating costs and vulnerability to power interruptions, which are occasionally experienced in rural parts of Krabi. Moreover, the aeration equipment requires regular inspection and maintenance, and local operators need basic technical training for routine operation. For very small enterprises or individual households, these operational requirements may be challenging without external technical support.

Figure 21 Estimated capital costs of septic tank with aerobic filter

Option 3: Septic tank + Aerobic filter (for 10-15 people/homestay)

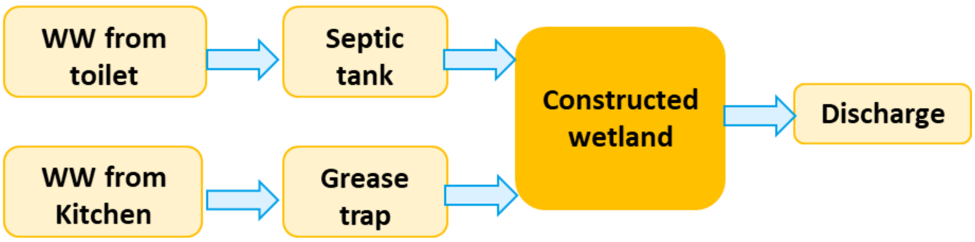
Item	Estimated cost (THB)
Grease tap (80 – 100 L)	3,000 – 5,000
Septic Tank (2,000 – 3,000 L)	8,000 – 15,000
Aerobic filter (tank, aeration system, and filter media)	15,000 – 23,000
Filter media (1 – 1.5 m^3)	3,000 – 5,000
Aeration system (blower, piping, etc.)	5,000 – 10,000
Labor cost	7,000 – 10,000
Total estimated cost	41,000 – 68,000 THB

Source: Compiled by Research team

2.3.4 Constructed Wetland

The constructed wetland is a nature-based wastewater treatment system that replicates the self-purifying processes found in natural wetlands (Figure 22). It consists of shallow, engineered basins filled with layers of gravel, sand, and soil, planted with selected aquatic macrophytes such as cattails (*Typha spp.*), reeds (*Phragmites spp.*), or vetiver grass (*Vetiveria zizanioides*). Wastewater is introduced into the basin and treated as it flows horizontally or vertically through the porous substrate, undergoing a combination of physical, chemical, and biological processes that remove pollutants.

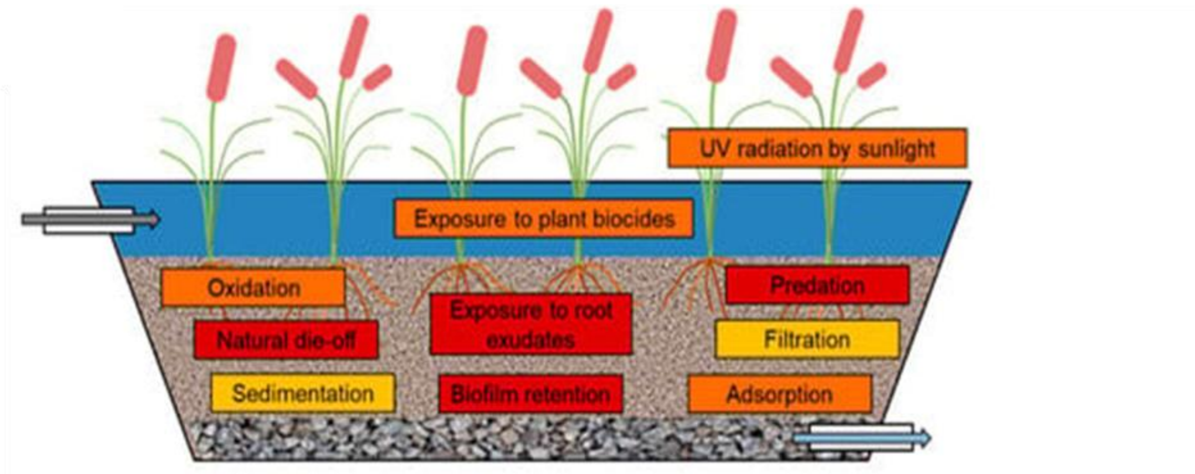
Figure 22 Constructed wetland



Source: Compiled by Research team

Treatment in the constructed wetland occurs through multiple mechanisms (Figure 23). Physical processes such as sedimentation and filtration remove suspended solids, while chemical processes including adsorption and precipitation reduce nutrients and heavy metals. Biological processes play a dominant role; microorganisms in the substrate and plant root zone (rhizosphere) degrade organic matter, while the plants themselves uptake nutrients and facilitate oxygen transfer to localized aerobic zones. This micro-aeration enhances microbial activity, improving both organic and pathogen removal efficiency.

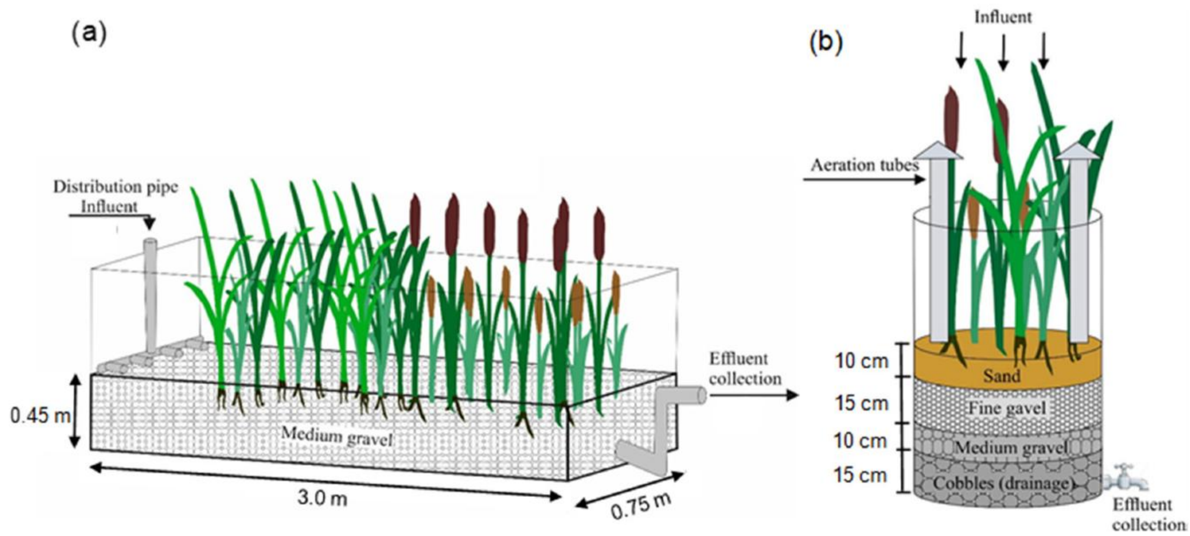
Figure 23 Schematic of a horizontal subsurface flow constructed wetland



Source: Wang et al., 2021

In terms of performance, the constructed wetlands typically achieve 70-90% BOD removal, 60-80% total suspended solids (TSS) removal, and about 90.0-99.9% reductions in pathogens, depending on design configuration, hydraulic retention time, and loading rate. Nutrient removal, particularly for nitrogen and phosphorus, varies by system type. Horizontal subsurface flow wetlands provide moderate nitrogen removal through denitrification, while vertical flow wetlands offer better ammonia oxidation due to intermittent aeration (Figure 24). In Thailand, the constructed wetlands have been successfully implemented in rural communities and eco-tourism areas, for example, in Rayong (Figure 25), Chiang Rai, Surat Thani, and Phuket, owing to their low-energy demand and visual compatibility with natural landscapes.

Figure 24 Schematic of (a) horizontal subsurface flow constructed wetland, and (b) vertical flow constructed wetland



Source: Gikas et al., 2021

Figure 25 Schematic of a constructed wetland in Rayong province, Thailand

Source: ENVI 101 Geotechnical specialist (n.a.)

From an economic perspective (Figure 26), the constructed wetlands are among the most cost-effective decentralized options when sufficient land is available. Construction costs are estimated at 27,000-44,000 THB per unit, for systems designed to treat 1-2 m^3/day, suitable for small homestay clusters or restaurant operations. Operational costs are minimal since no electricity is required, and maintenance is limited to periodic vegetation harvesting and sludge removal every 5-10 years. Compared with mechanical or aerated systems, the constructed wetlands have the lowest lifecycle cost and are well aligned with the resource limitations of small enterprises.

The advantages of constructed wetlands extend beyond wastewater treatment. They offer ecological integration, low energy use, and valuable co-benefits such as habitat creation, carbon sequestration, and aesthetic landscaping; features that complement Krabi's eco-tourism identity and enhance the environmental image of local enterprises. However, several limitations must be considered. Constructed wetlands require land areas of approximately 10-15 m^2 per household, which may be difficult to secure in high-density tourist areas near Ao Nang Beach. Their performance can vary seasonally, with reduced efficiency during heavy rainfall or flooding, when hydraulic overloading dilutes treatment capacity. Furthermore, although effluent quality from the constructed wetlands generally meets national standards for organic parameters, microbial concentrations may remain above the Thailand's surface water quality standards for direct discharge into sensitive marine environments unless supplemented by a tertiary disinfection step or additional polishing unit.

Figure 26 Estimated capital costs of constructed wetland

Option 4: Constructed wetland (natural wastewater treatment)
(For 1 homestay with 10-15 people)

Item	Estimated cost range (THB)
Grease tap (for 1 homestay with 10-15 people)	3,000 – 5,000
Septic Tanks (2,000 – 3,000 L)	8,000 – 15,000
Excavation + liner (for 10 – 15 m^3 wetland bed)	4,000 – 6,000
Sand + gravel (for 3 – 4 m^3)	4,000 – 5,000
Wetland plants (50 – 100 plants)	1,000 – 2,000
Piping (inlet/outlet)	2,000 – 3,000
Labor cost	5,000 – 8,000
Total estimated cost	27,000 – 44,000 THB

Source: Compiled by Research team

2.4 Comparative Analysis of Small-Scale Wastewater Treatment Options

2.4.1 Technical Performance

Table 16 shows overview of small-scale wastewater treatment technologies for Krabi community. The four treatment systems are different in their treatment mechanisms and pollutant removal efficiencies.

1) The septic tank with sand filter is a simple two-stage process that combines sedimentation and filtration. It typically achieves 40-60% biochemical oxygen demand (BOD) removal, 30-50% total suspended solids (TSS) reduction, and limited pathogen removal. Although this performance is modest, it can be acceptable in low-density areas where effluent is dispersed into soil or reused for irrigation after natural polishing.

2) The integrated septic tank with anaerobic filter provides improved treatment through biofilm-based anaerobic degradation. This design enhances organic matter removal, achieving 60-70% BOD reduction and 50-70% TSS removal. Pathogen reduction is moderate (90-99% removal). The compact modular design and stable performance under fluctuating loading conditions make this system suitable for small homestays and restaurants with limited space.

3) The septic tank with aerobic filter further improves treatment efficiency by introducing oxygen into the biological process. With continuous aeration, aerobic microorganisms degrade soluble organic matter more effectively, achieving 80-90% BOD removal, 70-90% TSS reduction, and pathogen removal up to 99.0-99.9% under well-maintained conditions. However, the system's reliance on electricity and regular maintenance may limit its application in areas with unreliable power supply.

4) The constructed wetland represents a nature-based approach, using plants, gravel media, and microbial activity to remove pollutants. The constructed wetlands typically achieve 70-90% BOD removal, 60-80% TSS reduction, while pathogen reduction depending on design and loading. In addition, The constructed wetlands provide partial nutrient removal and aesthetic value, aligning with Krabi's eco-tourism identity.

2.4.2 Economic Considerations

Economic evaluation indicates that constructed wetlands and integrated septic tanks with anaerobic filters are the most cost-effective options, with installation costs ranging from 27,000-48,000 THB per unit and minimal operational expenses. The septic tank with sand filter also offers an affordable solution, costing approximately 41,000-60,000 THB per unit with only periodic maintenance required every 2-3 years. The septic tank with aerobic filter, while achieving higher effluent quality, requires higher investment (41,000-68,000 THB) and ongoing electricity costs for aeration. Maintenance demands are also greater, including inspection and cleaning of aeration devices. For small-scale homestays and local restaurants, these recurring costs may pose financial challenges. Overall, systems with passive or low-energy operation, such as sand filters, anaerobic filters, and wetlands, are more compatible with Krabi's small business operators who prioritize low capital and operational expenditure.

2.4.3 Operational Feasibility

Operational simplicity is a major advantage of the septic tank with sand filter and the constructed wetland systems. These technologies require minimal operator intervention, relying primarily on gravity flow and natural biological activity. Routine tasks are limited to desludging the septic tank every few years, and for the constructed wetlands, occasional vegetation harvesting to maintain hydraulic flow. The integrated septic tank with anaerobic filter also requires little technical skill, with maintenance limited to periodic desludging and filter inspection. In contrast, the aerobic filter demands more active management. Continuous aeration must be maintained, and mechanical components such as air blowers or diffusers require regular service. This increases both operational attention and the potential for system downtime if the equipment fails. For communities and businesses with limited technical capacity, low-maintenance systems such as sand filters and constructed wetlands are the most reliable solutions.

Table 16 Overview of small-scale wastewater treatment technologies for Krabi community.

Technology	Installation Cost (THB)	BOD Removal Efficiency	Area required/ household (m^2)	Energy Requirement	Maintenance	Advantages	Disadvantages	Suitability
Septic Tank and Sand Filter	41,000-60,000	40-60%	2-5	None	Very low (de-sludge every 2-3 yrs)	Simple and cheap	Not efficient for high BOD	Small homestays in rural areas
Integrated Septic and Anaerobic Filter	28,000-48,000	60-70%	1	None	Low (de-sludge every 1.5-2 yrs, and media rinse)	Compact and simple installation	Limited BOD removal and require sludge removal	Compact homestays, small restaurants
Septic Tank and Aerobic Filter	41,000-68,000	80-90%	2-3	Continuous electricity	Moderate (electricity, aerator maintenance)	High efficiency and better effluent	Require electricity cost, pump maintenance and sludge removal	Boutique hotels, small restaurants
Constructed Wetland	27,000-44,000	70-90%	10-15	None	Very low (vegetation harvest, sludge 5-10 yrs)	Eco-friendly and long life	Require space and startup time	Communities, eco-villages, and homestay

Source: Compiled by the research team

2.4.4 Land and Energy Requirements

Land and energy availability are key design constraints for decentralized systems in Krabi. The constructed wetland requires a relatively large area approximately 10-15 m^2 per household equivalent, which may not be feasible for properties located near Ao Nang Beach or in dense commercial zones. However, it is an entirely passive system with no electricity requirement, providing a sustainable option for sites with available land. The septic tank with sand filter and integrated anaerobic filter is compact and energy-free, suitable for constrained sites. The aerobic filter is compact and requires continuous electricity for aeration, increasing both cost and operational dependency. Overall, low-energy systems are preferred in areas with unreliable power supply or where long-term cost savings are priorities. Constructed wetlands and anaerobic filters represent the best balance between land use, simplicity, and energy independence.

2.5 Recommendations for Krabi Province

Based on the comparative analysis of decentralized wastewater treatment technologies, the following recommendations are proposed for improving wastewater management in Ao Nang and surrounding areas of Krabi Province. The recommendations consider the technical performance, economic feasibility, land requirements, and operational capacity of local enterprises and communities.

1) **For small homestays (10-15 Guests)** – The integrated septic tank with anaerobic filter is recommended as the most practical and cost-effective solution. This system provides reliable treatment efficiency, compact design, and minimal operational requirements. Where land is available, it is strongly recommended to combine the anaerobic filter with a small constructed wetland as a secondary polishing stage. The constructed wetland will enhance pathogen and nutrient removal before final discharge or reuse, ensuring that effluent quality meets local environmental standards.

2) **For small to medium-sized restaurants and boutique hotels** – These types of businesses generate higher organic loads from kitchen wastewater, dishwashing, and general cleaning activities. The septic tank with aerobic filter is recommended as the most suitable treatment option. This system provides high removal efficiency for organic matter and suspended solids, typically achieving 80-90% BOD reduction, and produces clear effluent suitable for discharge to nearby canals with minimal environmental impact. This option is particularly appropriate where the electricity supply is stable, allowing continuous aeration for year-round operation. However, it is important that system operators receive basic training in aeration equipment maintenance and regular sludge management to ensure consistent treatment performance. Where land is available, a constructed wetland or small disinfection pond can be added downstream as a polishing step to further improve effluent quality before final discharge.

3) **Community clusters or areas with available land** - For small communities, groups of homestays, or peri-urban villages with shared wastewater flows, constructed wetlands are highly recommended. These systems are well-suited to Krabi's environmental conditions, requiring low maintenance and no electricity while providing excellent treatment and landscape integration. Constructed wetlands also serve as green infrastructure, supporting biodiversity, improving aesthetics, and reinforcing Krabi's image as an eco-friendly tourism destination. They are particularly valuable for areas near Klong Yingsuea and Klong Jark, where collective systems could reduce untreated discharges into coastal waters.

3. Water quality analysis in Ao Nang Subdistrict, Krabi

3.1 Introduction

Tourism-driven coastal areas often face increasing pressure on environmental infrastructure, particularly wastewater management systems. In Thailand, provinces along the Andaman coast, including Krabi, have experienced rapid growth in tourism-related activities over the past two decades. Ao Nang, as a major tourism hub, has undergone significant expansion in accommodation, food services, and supporting businesses such as laundry operations. While this development has contributed to local economic growth, it has also increased the volume and complexity of wastewater generated within the area. In many peri-urban and tourism-intensive zones, wastewater management systems have not expanded at the same pace as development. As a result, wastewater is often managed through a combination of on-site treatment systems, partial collection networks, and natural drainage pathways. These systems may vary in performance depending on design, maintenance, and seasonal loading conditions. During peak tourism periods, the volume of wastewater can increase substantially, placing additional stress on existing infrastructure. In general, coastal tourism areas have shown that water quality deterioration is often associated with a combination of organic pollution, nutrient enrichment, and microbial contamination. These conditions can affect aquatic ecosystems, reduce water quality for recreational use, and influence the overall environmental sustainability of tourism destinations.

In the context of Ao Nang, canals and drainage systems play an important role as receiving bodies for surface runoff and wastewater discharge. These canals eventually connect to coastal waters, making them critical pathways influencing nearshore water quality. Understanding the characteristics of wastewater in these systems is therefore essential for identifying pollution patterns and supporting appropriate management strategies. The present study aimed to (1) assess water quality at multiple monitoring locations across Ao Nang, (2) identify spatial patterns and potential pollution hotspots, and (3) interpret pollutant characteristics to better understand possible contributing sources under local conditions. The findings are intended to support evidence-based planning and wastewater management in coastal tourism areas.

3.2 Sampling Locations and Study Design

Wastewater samples were collected from 28 monitoring locations (L0–L27) across Ao Nang, Krabi Province, located along the Andaman coast of southern Thailand. The study area is characterized by mixed land use, with a range of tourism-related activities, including accommodation, food services, and supporting facilities. Two main canal systems, Klong Yingsuea and Klong Jark, function as primary drainage pathways, conveying surface runoff and various water inputs from inland areas toward Ao Nang Bay. The specific locations in shown in Table 17.

Sampling was conducted over a three-day period from 27 to 29 October 2025, representing water quality conditions at the time of observation. The sampling network was designed to capture variation across different parts of the drainage system, including upstream canal sections, urban drainage areas, and coastal discharge points. Sampling locations included natural canals, roadside drains, and outfalls, representing a range of hydraulic conditions and potential influences from surrounding land use. An upstream–downstream approach was applied along the main waterways to examine changes in water quality along the flow path prior to discharge into coastal waters. This approach allows spatial patterns to be observed, including areas where pollutant concentrations may increase, decrease, or remain relatively stable. Observed variations may reflect the combined effects of flow conditions, mixing processes, and inputs from surrounding areas. Additional sampling points were located at drainage junctions and areas receiving inputs from multiple pathways to better represent cumulative conditions within the system. For interpretation purposes, the study area was grouped into three zones: (i) canal systems within urban and tourism-influenced areas, (ii) mixed drainage zones receiving combined inputs, and (iii) downstream and coastal discharge areas influenced by tidal exchange and saline intrusion.

Table 17 Details and characteristics of the position where wastewater samples were collected

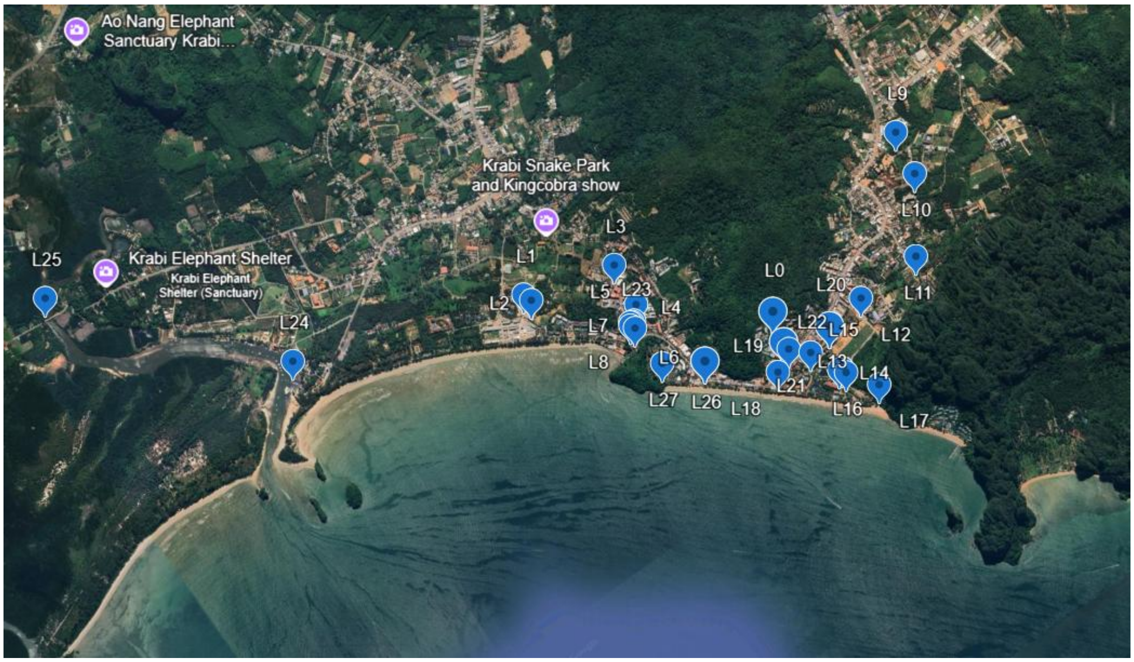
Position	Label	Klong Chak (Ao nang)	Klong Yink Suea	Nop parat Thara pier	Laundry	Res-taurant	Hotel (water treat ment)	Night Market	Mountain Source	Toilet	Tree/ Shrub	Pier	Drainage	Solid Waste	Total
L0	Kaem Ling pond (Tipa Hotel)	1	0	0	0	0	0	0	1	0	0	0	0	0	2
L1	Drainage (behind Landmark night market)	0	1	0	0	1	1	1	0	1	0	0	0	0	5
L2	Sink (behind Landmark night market)	0	1	0	0	1	1	1	0	1	0	0	0	0	5
L3	Front of Deevana Hotel	0	1	0	1	0	0	0	1	0	0	0	0	1	4
L4	Front of Spa	0	1	0	0	0	1	0	0	0	1	0	0	1	4
L5	Center of Klong Yink Suea	0	1	0	0	0	0	0	0	0	1	0	1	0	3
L6	Drainage on pavilion side	0	1	0	1	0	0	0	0	0	1	0	1	0	4
L7	Drainage on 7-11 side	0	1	0	0	0	1	0	0	0	1	0	1	0	4
L8	Drainage on Wangsai side	0	1	0	0	1	0	0	0	0	1	1	1	1	6
L9	The canal behind the laundry factory	1	0	0	1	0	0	0	0	0	1	0	0	1	4
L10	Y-junction next to Centara Phu Pano Hotel	1	0	0	0	0	1	0	0	0	1	0	0	0	3
L11	Front of Sainai Hotel	1	0	0	0	0	1	0	0	0	1	0	0	0	3
L12	The canal opposite Seaseeker Hotel	1	0	0	0	1	1	1	0	0	1	0	0	0	5
L13	Drainage (behind of Bluesotel Hotel)	1	0	0	0	0	1	1	0	0	0	0	1	0	4
L14	Under Centara Aonang Hotel	1	0	0	0	0	1	0	0	0	1	0	1	0	4
L15	Drainage (Next to Centera Aonang Hotel)	1	0	0	0	0	1	0	0	0	1	0	1	0	4

L16	Next to the toliet (Aonang 15)	1	0	0	0	0	0	0	0	1	1	0	0	1	4
L17	Drainage Discharge	1	0	0	0	1	0	0	0	1	0	0	0	0	3
L18	Drainage on Phra Nang Curve	1	0	0	0	0	1	0	0	1	0	0	1	0	4
L19	Wastewater treatment tank (Police station)	1	0	0	0	0	0	0	0	1	0	0	1	0	3
L20	Front of Peach laguna Hotel	1	0	0	0	0	1	0	0	0	1	0	0	0	3
L21	Front of Aonange Villa	1	0	0	0	0	1	0	0	0	0	0	1	0	3
L22	Y-junction in Aonang Villa	1	0	0	0	0	1	0	0	1	1	0	0	0	4
L23	Klong Yink Suea pier	0	1	0	0	0	0	0	0	0	1	1	1	0	4
L24	Nopparat Thara pier	0	0	1	0	0	0	0	0	0	0	1	0	0	2
L25	Klong Son	0	0	1	0	1	0	0	0	0	0	0	0	0	2
L26	Drainage on Reeve	0	1	0	0	1	1	0	0	0	0	0	1	0	4
L27	Wastewater treatment pond (Krabi Resort)	0	1	0	0	0	1	0	0	0	1	0	1	0	4
	Total	15	11	2	3	7	16	4	2	7	16	3	13	5	

Source: Prepared by the research team

As shown in Figure 27, the sampling points are distributed along the canal network from inland areas toward the coast, with several locations situated near discharge points into Ao Nang Bay. This configuration provides a basis for examining how water quality varies along with the drainage system and how inland conditions may be reflected in coastal receiving waters. All interpretations presented in this study are based on observed water quality data collected during the sampling period and are intended to represent general conditions at the time of sampling.

Figure 27 Sampling locations in Klong Yingsuea and Klong Jark, which discharge into Ao Nang Bay, Krabi Province



Source: Prepared by Research team

3.3 Analytical Methods

Water samples collected from the 28 monitoring locations were analyzed for key physical, chemical, and microbiological parameters relevant to wastewater characterization and surface water quality assessment. The parameters included pH, electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia nitrogen (NH_4^+-N), phosphate (PO_4^{3-}-P), fecal coliform bacteria (FCB), and oil and grease.

Field measurements for pH, EC, and DO were conducted on-site using a portable water quality meter (Ponpe 510 PD, China) to minimize changes during sample handling. Water samples were collected in clean plastic bottles and stored at 4 °C prior to analysis. BOD, NH_4^+-N and PO_4^{3-}-P were analyzed in the laboratory following the Standard Methods for the Examination of Water and Wastewater (APHA, 2023). COD, FCB and oil and grease were analyzed by the Environmental Laboratory and International Standards Department, Mahidol University. The BOD and COD were analyzed to assess the concentrations of organic pollution, while NH_4^+-N and PO_4^{3-}-P were determined to evaluate nutrient concentrations associated with wastewater inputs. FCB were analyzed as an indicator of microbial contamination, and oil and grease were measured to assess the presence of hydrocarbon-related substances.

Quality control measures, including instrument calibration and standard checks, were applied to ensure data reliability. All samples were analyzed in triplicate. It should be noted that the analytical results represent conditions during the sampling period (27–29 October 2025), and may vary due to temporal changes, hydrological conditions, and environmental factors.

3.4 Results and Analysis

3.4.1 Overview of Water Quality Conditions

Table 18 presents the physicochemical and microbiological characteristics of water samples collected from 28 monitoring locations (L0–L27) in the study area. The results show considerable spatial variation, with clear indications of organic pollution, nutrient enrichment, and microbial contamination at several locations. Overall, water quality conditions vary along the drainage network, with generally more degraded conditions observed in downstream and coastal discharge zones.

Temperature ranged from approximately 26.5 to 30.7 °C, while pH values were within a neutral to slightly alkaline range (7.1–8.5), which is typical for tropical surface waters. EC varied widely across the study area, with higher values observed at coastal and estuarine locations. These elevated EC values are consistent with the influence of saline intrusion and tidal mixing, particularly near discharge points connected to the sea.

Table 18 The physicochemical and biological water quality parameters of samples at locations L0–L27.

Position	Detail	temp (°C)	pH	EC (mS/Cm)	DO (mg/L)	BOD (mg/L)	Ammonia-nitrogen (mgN/L)	Ortho phosphate (mgP/L)	COD (mg/L)	Oil and grease (mg/L)	FCB (MPN/100 mL)
L0	Kaem Ling pond (Tipa Hotel)	26.50	8.20	1.45	3.80	66	0.12	1.35	3	4.5	78
L1	Drainage (behind Landmark night market)	30.70	7.36	5.98	7.90	6	0.26	2.39	9	3.8	2,400
L2	Sink (behind Landmark night market)	29.00	7.62	2.77	6.50	42	0.83	2.55	27	3.5	16,000
L3	Front of Deevana Hotel	28.30	8.52	3.51	6.90	57	1.34	2.91	9	4	78,000
L4	Front of Spa	29.50	7.54	1.04	4.70	33	3.08	4.60	62	5.2	1,100,000
L5	Center of Klong Yink Suea	29.70	7.47	6.95	4.50	48	2.74	4.96	125	4	1,700,000
L6	Drainage on pavilion side	28.90	7.38	1.50	4.20	78	3.13	5.66	565	13	92,000
L7	Drainage on 7-11 side	29.20	7.39	8.90	5.00	93	1.58	3.15	110	11	170,000
L8	Drainage on Wangsai side	29.10	7.29	9.98	4.70	57	2.15	2.93	119	11	1,700,000
L9	The canal behind the laundry factory	29.40	8.53	0.69	3.20	69	1.68	6.99	110	13.5	16,000
L10	Y-junction next to Centara Phu Pano Hotel	28.40	8.07	0.46	4.10	33	2.93	5.47	27	10.5	16,000
L11	Front of Sainai Hotel	27.90	7.90	0.46	4.90	84	2.13	4.26	21	11	9,200
L12	The canal opposite Seaseeker Hotel	29.30	7.67	0.51	4.50	96	2.74	4.96	62	9.8	170,000
L13	Drainage (behind of Bluesotel Hotel)	29.00	7.41	0.52	4.60	102	2.56	4.67	33	8.8	45,000
L14	Under Centara Aonang Hotel	28.10	7.69	0.74	3.50	138	3.20	5.71	64	5.8	790,000
L15	Drainage (Next to Centera Aonang Hotel)	28.70	7.48	0.84	3.10	105	3.29	2.05	76	12.5	16,000
L16	Next to the toliet (Aonang 15)	30.20	7.17	0.60	2.90	147	8.66	1.84	182	10	680,000
L17	Drainage Discharge	27.70	7.76	0.77	3.60	42	4.18	6.98	46	8.5	200,000

Position	Detail	temp (°C)	pH	EC (mS/Cm)	DO (mg/L)	BOD (mg/L)	Ammonia-nitrogen (mgN/L)	Ortho phosphate (mgP/L)	COD (mg/L)	Oil and grease (mg/L)	FCB (MPN/100 mL)
L18	Drainage on Phra Nang Curve	27.70	7.44	1.09	2.60	174	6.89	3.31	264	12.5	4,900,000
L19	Wastewater treatment tank (Police station)	27.90	7.55	0.83	2.90	93	7.29	1.95	64	9	16,000
L20	Front of Peach laguna Hotel	27.30	7.87	0.54	4.30	102	4.36	5.39	46	6	78,000
L21	Front of Aonange Villa	27.60	7.69	0.56	3.40	36	6.09	2.04	155	7.8	5,400
L22	Y-junction in Aonang Villa	27.70	7.85	0.57	2.80	66	5.60	3.38	97	3.5	16,000
L23	Klong Yink Suea pier	27.50	7.84	1.24	2.00	33	3.03	6.58	40	6.3	9,200
L24	Nopparat Thara pier	27.30	7.08	17.67	3.30	60	0.37	4.67	310	5.9	16,000
L25	Klong Son	27.50	7.51	6.14	3.60	33	0.49	5.15	58	2.8	2,400
L26	Drainage on Reeve	27.60	7.40	3.80	1.60	48	6.75	3.95	182	5.1	450,000
L27	Wastewater treatment pond (Krabi Resort)	26.70	7.50	1.55	2.30	51	5.29	1.90	52	4.5	20,000

Source: Prepared by the research team

3.4.2 Organic Pollution (BOD and COD)

BOD and COD were used to assess the magnitude and characteristics of organic pollution across the study area. The results indicated substantial spatial variation, with a general increase in organic loading from upstream locations toward downstream and coastal discharge zones. BOD concentrations ranged from 6 mg/L at L1 to 174 mg/L at L18 (Table 18). Several locations, particularly L13–L16 and L18, recorded BOD values exceeding 100 mg/L (Figure 28 and Figure 29), indicating high levels of biodegradable organic matter. In contrast, upstream locations such as L3 (Figure 27) showed lower BOD concentrations, suggesting less impacted conditions. This upstream–downstream pattern is consistent with the gradual accumulation of organic inputs along the drainage network.

COD concentrations showed a wider range, from 9 mg/L at L3 to 565 mg/L at L6 (Figure 30). Elevated COD values were also observed at L24 (310 mg/L), L18 (264 mg/L), L16 (182 mg/L), and L26 (182 mg/L). In several locations, COD values were substantially higher than BOD, indicating the presence of both biodegradable and non-biodegradable organic substances. For example, the high COD relative to BOD at L6 suggests that a portion of the organic load may consist of less biodegradable compounds.

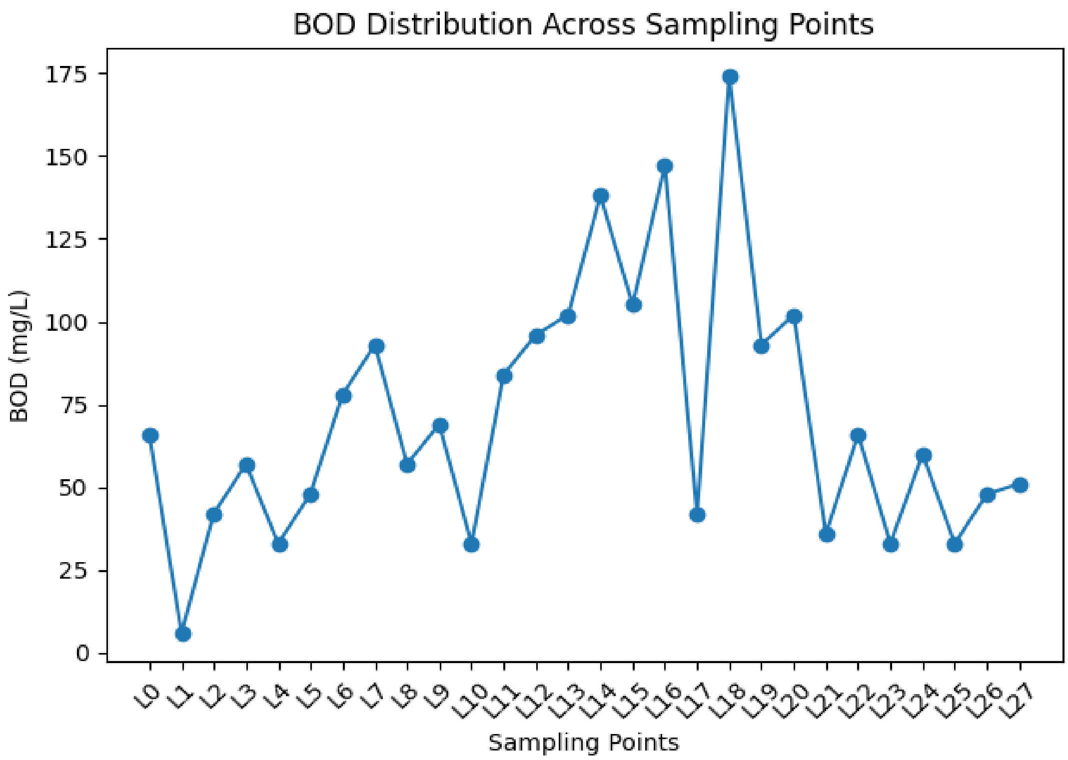
From a spatial perspective, elevated BOD and COD concentrations were generally observed in areas with higher activity density and more complex drainage connections. These patterns are consistent with cumulative inputs from small-scale wastewater-generating activities commonly found in coastal tourism settings. Such activities may include restaurants, accommodation services, and cleaning or washing operations, which typically produce wastewater containing organic matter, oils, and residual chemicals. This analysis did not attribute impacts to specific sources but reflected overall conditions within the drainage system during the sampling period.

Locations such as L13–L16 exhibited consistently elevated BOD values, suggesting sustained organic loading in sections where multiple drainage pathways converge. At L18, the combination of high BOD and COD indicates the presence of both readily biodegradable and more persistent organic substances, consistent with mixed wastewater characteristics. Similarly, at L6, elevated COD together with moderate BOD suggests that part of the organic load may include chemically influenced or less degradable components. Overall, the distribution of BOD and COD indicates that organic pollution within the study area likely reflected the combined influence of multiple diffuse inputs along the drainage network. The results highlight the importance of managing wastewater collectively at the system level, particularly in areas where drainage pathways concentrate flows prior to discharge into coastal waters.

Figure 28 Sampling locations L0 and L13–L22, which discharge into Ao Nang Bay, Krabi Province

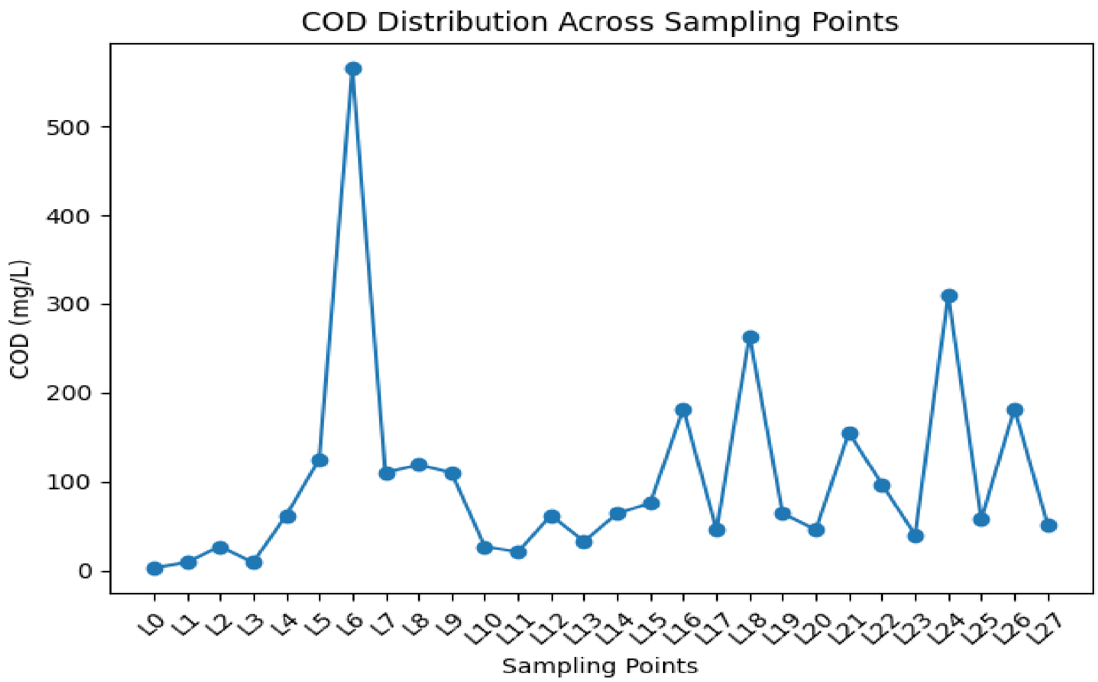
Source: Prepared by Research team

Figure 29 BOD profile of sampling points at L0–L27, Ao Nang Bay, Krabi Province.



Source: Prepared by Research team

Figure 30 COD profile of sampling points at L0–L27, Ao Nang Bay, Krabi Province.



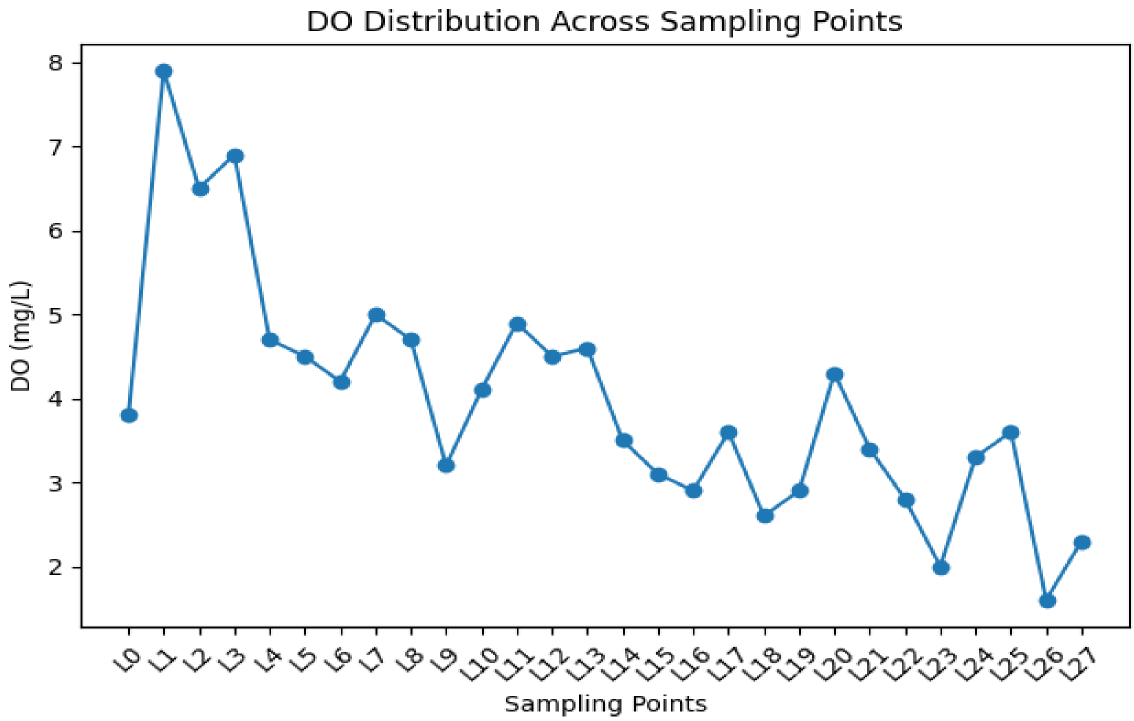
Source: Prepared by Research team

3.4.3 Dissolved Oxygen (DO)

DO concentrations varied considerably across the monitoring locations and generally showed a decreasing trend along the drainage pathway toward downstream and coastal areas. Measured DO concentrations ranged from 1.6 mg/L at L26 to 7.9 mg/L at L1 (Table 18 and Figure 31). Several locations, including L16 and L18 (Figure 28), and L23 and L26 (Figure 32), the DO values were below 3 mg/L, indicating conditions where oxygen availability may be limited. Higher DO concentrations observed at upstream locations, such as L1–L3 (Figure 27), suggest relatively lower organic loading and better aeration conditions. In contrast, reduced DO levels in downstream sections are consistent with increased oxygen consumption, likely associated with the breakdown of organic matter. This relationship is supported by the co-occurrence of low DO and elevated BOD and COD at locations such as L16 and L18, where organic loading appears to be relatively high.

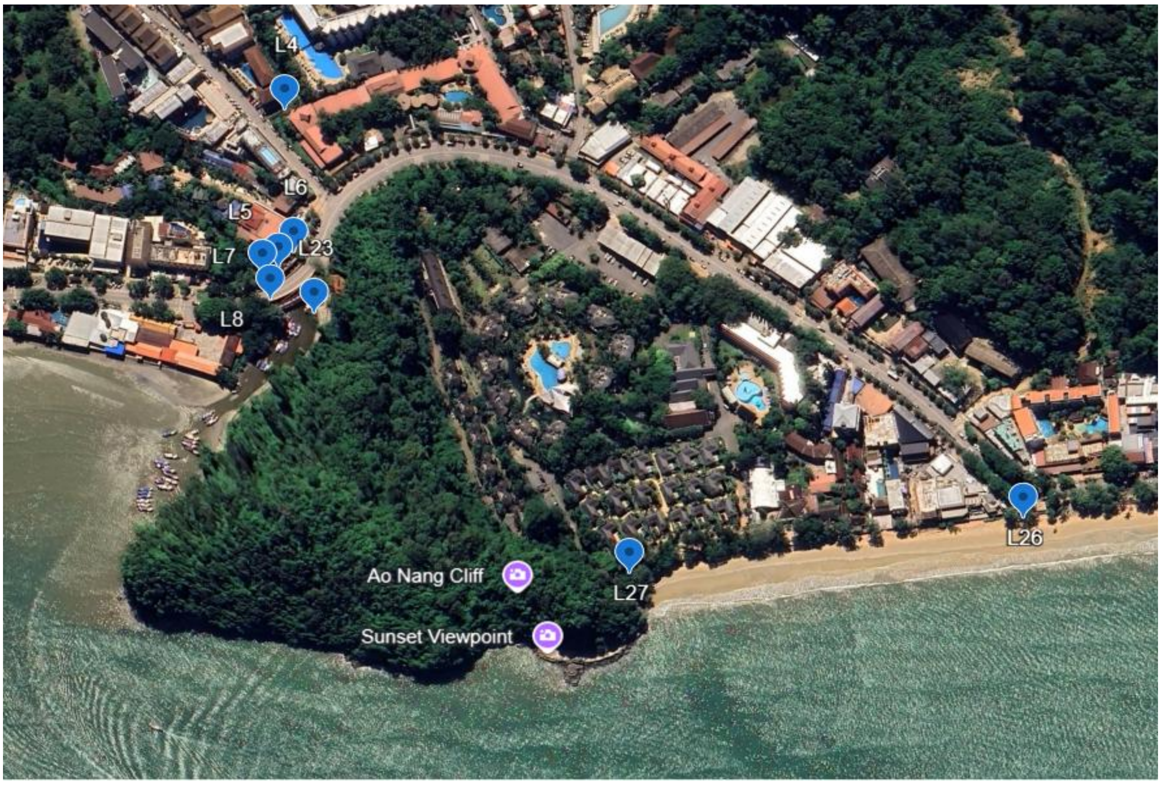
The spatial pattern also reflects the influence of local hydrological conditions. In sections of the drainage system with slower flow or limited mixing, oxygen replenishment may be reduced, allowing oxygen demand to exceed supply. This effect may be further influenced by tidal conditions in downstream areas, where water exchange with coastal waters can vary over time. Although low DO is often associated with organic pollution, it should be noted that DO levels are sensitive to multiple environmental factors, including temperature, flow velocity, and mixing conditions. Overall, the distribution of DO suggests that oxygen depletion becomes more pronounced in areas where organic loading accumulates and hydrological conditions limit re-aeration. These conditions may reduce the capacity of the system to support aquatic life and to naturally assimilate pollutants prior to discharge into coastal waters.

Figure 31 DO profile of sampling points at L0–L27, Ao Nang Bay, Krabi Province.



Source: Prepared by Research team

Figure 32 Sampling locations L4–L8, L23 and L26–L27, which discharge into Ao Nang Bay, Krabi Province.



Source: Prepared by Research team

3.4.4 Nutrient Concentrations (NH4+-N and PO43--P)

Ammonia nitrogen (NH_4^+-N) and phosphate (PO_4^{3-}-P) concentrations showed clear spatial variability across the study area, with several locations exhibiting elevated levels relative to typical background conditions in surface waters. NH_4^+-N ranged from 0.12 to 8.66 mgN/L, with higher concentrations observed at L16, L19, and L26. These values are commonly associated with recent inputs of nitrogen-rich wastewater, where ammonia has not yet undergone significant oxidation. Phosphate concentrations were also consistently elevated, generally ranging from 1.35 to 6.99 mgP/L. Higher values were recorded at L9, L17, and L23. In contrast to NH_4^+-N, PO_4^{3-}-P tends to be more persistent in aquatic systems and can accumulate in areas where there is ongoing input or limited dilution. Elevated phosphate concentrations are often linked to the use of detergents and cleaning agents, which are commonly present in wastewater from washing and cleaning activities.

At several locations, elevated NH_4^+-N and PO_4^{3-}-P were observed concurrently, particularly at L16 and L17. This co-occurrence is consistent with mixed wastewater characteristics, where both nitrogen and phosphorus are present. In coastal tourism settings, such nutrient profiles are often associated with a combination of domestic wastewater and greywater inputs, including wastewater generated from accommodation services, small-scale food preparation, and laundry or washing operations. However, it should be noted that the present analysis did not attribute these patterns to specific sources, but rather reflects general conditions within the drainage system. The relationship between nutrient concentrations and local environmental conditions is also evident. At locations such as L16 and L26, elevated NH_4^+-N coincided with low DO levels, suggesting that nitrification processes may be limited under oxygen-deficient conditions. This can lead to the accumulation of ammonia in the water column.

Nutrient concentrations tended to increase in areas where drainage pathways converge or where water movement is relatively slow. Under such conditions, dilution is reduced and inputs from surrounding areas may accumulate over time. Canal sections with limited flow and flushing capacity are therefore more likely to retain elevated nutrient levels. Overall, the distribution of NH_4^+-N and PO_4^{3-}-P suggests that nutrient enrichment within the study area is influenced by cumulative inputs along the drainage network. The observed patterns are consistent with contributions from a range of small-scale activities typical of coastal tourism areas, including cleaning and washing processes, while reflecting system-level conditions rather than isolated sources.

3.4.5 Microbial Contamination (Fecal Coliform Bacteria, FCB)

FCB concentrations varied markedly across the study area and represent one of the most pronounced water quality concerns observed in this study. Measured values ranged from 78 MPN/100 mL at L0 to approximately 4.9×10^6 MPN/100 mL at L18, indicating a wide gradient in microbial conditions along the drainage network. Elevated FCB levels were recorded at multiple locations, particularly at L4, L5, L8, L14, L16, and L18, where concentrations exceeded 10^5 MPN/100 mL. These values are substantially higher than typical thresholds for surface water used for recreation, suggesting a strong microbial influence in several parts of the system. In contrast, lower FCB concentrations at upstream or less connected locations, such as L0 and L1, indicate comparatively reduced microbial loading.

The spatial distribution of FCB generally follows a downstream pattern, with higher concentrations observed in areas where drainage pathways converge or where water is discharged toward coastal zones. In several locations, high FCB concentrations coincided with elevated NH_4^+-N and BOD values, particularly at L16 and L18. This combination is consistent with wastewater that contains both organic matter and microbial content. Such conditions are commonly observed in drainage systems influenced by domestic wastewater and greywater inputs. In coastal tourism areas, these may include wastewater associated with accommodation, food service, and sanitation-related activities. Environmental conditions may also influence microbial levels. In areas with low flow or limited flushing, bacteria may persist for longer periods, while tidal effects in downstream sections may affect dilution and transport. Despite these factors, the magnitude of FCB observed at several locations suggests that microbial contamination remains significant at the time of sampling.

From a water quality perspective, elevated FCB concentrations are of particular concern in areas connected to coastal waters used for recreational purposes. The presence of high microbial loads in drainage systems that discharge into nearshore environments may influence water quality at the receiving areas, especially under conditions of limited dispersion. Overall, the observed distribution of FCB indicates that microbial contamination is widespread and tends to intensify along the drainage network. The pattern is consistent with cumulative inputs over space and highlights the importance of managing wastewater at multiple points within the system.

3.4.6 Oil and Grease

Oil and grease concentrations showed moderate to elevated levels across several monitoring locations, with values ranging from approximately 2.8 to 13.5 mg/L. Higher concentrations were observed at L9 (13.5 mg/L), L6 (13 mg/L), and L15 and L18 (12.5 mg/L), indicating localized accumulation of hydrophobic substances within the drainage system. The spatial distribution suggests that oil and grease tend to be more prominent in areas associated with drainage outlets and zones closer to coastal discharge. These substances are typically less soluble in water and may accumulate on the water surface or within sediments. Field observations at some locations noted visible surface films, which are consistent with the analytical results.

From a water quality, elevated oil and grease concentrations are often associated with wastewater containing fats, oils, and petroleum-related compounds. In coastal tourism areas, such inputs may be linked to a range of activities that generate wastewater containing food residues, cooking oils, and cleaning agents. In addition, locations near coastal discharge points may also be influenced by marine-related activities, where small amounts of fuel or lubricants can enter the water during routine operations. However, the present analysis reflected general system conditions and did not attribute these observations to specific sources.

The occurrence of higher oil and grease concentrations at locations such as L6 and L9, which also showed elevated COD, suggests a potential association between organic and hydrocarbon-related loading. Similarly, at L18, the presence of oil and grease alongside high BOD, nutrients, and microbial contamination indicates a mixed wastewater profile, where multiple types of inputs may be present. From a physical perspective, the presence of oil and grease can influence surface conditions by forming thin films that reduce oxygen transfer between the atmosphere and the water column. This may contribute, in part, to localized reductions in DO, particularly in areas where water movement is limited. In conclusion, the distribution of oil and grease indicates that these substances are present at several points along the drainage network, with higher concentrations observed in areas where inputs may accumulate prior to discharge into coastal waters. The observed pattern is consistent with contributions from a range of small-scale activities typical of developed coastal environments, combined with site-specific hydrological conditions.

3.4.7 Spatial Patterns and Hotspot Identification

When considered together, the results show a consistent spatial pattern in water quality across the study area. Conditions were generally better at upstream locations and became progressively more degraded along the drainage network toward downstream and coastal discharge zones. This trend is reflected in the increase of BOD, COD, nutrients, FCB, and oil and grease, alongside decreasing DO at several downstream locations. Rather than a uniform distribution, water quality deterioration was concentrated at specific points where multiple drainage pathways converge or where flow conditions may limit dilution. These locations can be considered as relative hotspots within the system based on the simultaneous occurrence of elevated parameters.

Among all monitoring points, L18 stands out as the most impacted location. It showed consistently high values across nearly all parameters, including BOD, COD, NH_4^+-N, FCB, and oil and grease, together with low DO. This combination indicates a strongly affected condition and suggests that this point receives cumulative inputs from upstream areas before discharge into the coastal environment. A second cluster of concern is observed around L13–L16, where BOD concentrations exceeded 100 mg/L and were accompanied by elevated nutrients and microbial contamination. These locations appear to represent a section of the drainage network where organic and nutrient loading remains consistently high, likely reflecting combined inputs from surrounding areas. L6 represents a different type of condition, characterized by extremely high COD relative to BOD, along with elevated oil and grease. This pattern suggests the presence of less biodegradable or chemically influenced organic matter, indicating a wastewater profile that differs from primarily biodegradable sources. Additional locations such as L4, L5, and L8 showed very high FCB concentrations, indicating strong microbial influence, while L23 and L26 were characterized by low DO combined with elevated nutrient levels, suggesting localized oxygen stress in downstream sections. At L24, high EC together with elevated COD reflects the influence of saline intrusion alongside persistent pollutant loading.

Overall, these patterns indicate that water quality conditions within the study area are influenced by cumulative inputs along the drainage network rather than isolated discharges. The combination of organic, nutrient, microbial, and oil-related indicators suggests that multiple small-scale inputs contribute to the observed conditions, particularly in areas where drainage pathways converge before reaching the coast. From a management perspective, the identification of these hotspots provides a practical basis for prioritizing intervention. Locations such as L18, L13–L16, and L6 represent key points where improved wastewater management may have the greatest benefit in reducing pollutant loads before discharge into Ao Nang Bay. Addressing conditions at these points is likely to contribute to broader improvements in water quality across the system.

4. Summary of Providing Technical Support to the Installation of Small-scale Wastewater Treatment Technologies in Small-scale Tourism Enterprises

4.1 Introduction

Dr. Suchanya Wongrod began the presentation explaining the sources of water pollution, giving examples of activities from local consumption, industrial wastewater and agricultural wastewater that flows into rivers and eventually the ocean. In addition, she continued to discuss the quality of Thailand's surface water (in terms of pollution) and introduced the Water Quality Index (WQI) to help determine how "clean" or "polluted" Thailand's water sources are. The key parameters used to help calculate WQI include Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Fecal Coliform Bacteria (FCB), Nutrients: total Nitrogen and total Phosphorus ($NH_3 - N$), and Total Coliform Bacteria (TCB). WQI has 5 water quality standards or ratings: WQI of 0 – 30 is very poor, 31 – 60 is poor, 61 – 70 is fair, 71 – 90 is good, and 91 – 100 is very good. WQI is mostly used for surface water such as water streams, rivers, and lakes. The Marine Water Quality Index (MWQI) is used to measure the water quality of oceans. MWQI has a slightly different standard to categorize water quality: MWQI of 0 – 25 is very poor, 26 – 50 is poor, 50 – 80 is fair, 81 – 90 is good, and 91 – 100 is very good.

After introducing the water quality indexes, Dr. Suchanya Wongrod showed data on the overall water quality (surface water and marine sources) of Thailand. The data displayed that Thailand's coastal waters are in the good and fair category for water quality and beach areas were in the very good category. However, some areas in the inner Gulf of Thailand were constantly in the poor category. Then data on the water quality in Krabi was displayed, showing that MQWI was in the good category (for 20 sample areas) and 4 sample areas were in the poor category. This shows potential for improvement. Then pictures taken from sample areas along Klong Chak and Klong Ying Suea were presented to demonstrate the current condition of those river canals.

Continuing from this, Dr. Suchanya Wongrod began to explain what impurities are in wastewater for instance, pH, color and turbidity (of water), suspended solids, organic matter, inorganic matter, nutrients (Nitrogen and Phosphorus that make algae bloom), odor (such as hydrogen sulfide or "rotten egg gas"), oil and fat, microorganisms (microbes), toxic organic waste (such as heavy metals), and toxic inorganic waste (such as pesticides). Then she explained the characteristics of wastewater categorizing them into three categories: physical, chemical, and biological. The physical characteristics of waste include temperature, color, turbidity, and odor. The chemical characteristics include organic matter (such as surfactants from soap and detergent and pesticides used in agriculture), inorganic matter, BOD value, and gas. The biological characteristics include microorganisms of 3 types: eukaryotes, eubacteria, and archaebacteria. These microorganisms must be analyzed if they come from human waste (that usually comes from hospitals and households), which may carry pathogens such as E. coli. Dr. Suchanya Wongrod further explains that wastewater from households with relatively high BOD levels (more than 400) is mostly due to laundry detergent use that is not treated before disposal. For industrial wastewater, BOD levels are significantly higher than domestic households (BOD levels can reach up to 19,000). This is due to the chemical run offs from facilities such as leather tanning factories, tapioca starch factories, animal slaughterhouses, and pulp mills.

The impact of untreated wastewater could destroy Krabi's beautiful scenery and cause harm to residents and aquatic life (from the contaminated water). Furthermore, it would impact Krabi's tourism as it is known for its breathtaking scenic views and marine life. This also threatens Krabi's sustainability. Thus, there should be collective efforts to protect and conserve Krabi's natural resources. The first step of sustainable water resource management would be to reduce waste or trash being disposed of in water or through preliminary treatment of wastewater (for businesses). It was also suggested to reuse water if possible (closed cycle).

Dr. Suchanya Wongrod also mentioned the laws, rules and regulations of the Sub-district Administration Organization (SAO) for wastewater management. Regulations (such as measuring BOD) are tools for managing water quality. The standard for communities to manage their wastewater was explained, with emphasis on grease traps. Once grease (from fat or oil) is disposed of in wastewater, it is very difficult to decompose, making the wastewater more polluted or contaminated. Thus, demonstrating the importance of grease traps or not disposing grease with wastewater. Dr. Suchanya Wongrod introduced a simple method to calculate how big the grease traps or grease inceptor (for kitchens) should be designed to be appropriate for household use or for small-scale businesses. Several designs such as underground grease traps and floor-mounted grease traps can be used to properly separate grease.

Thailand's sewage collection system is either connected via main pipes (for traditional communities) or branch pipes (for new communities). Then the water goes to either a central wastewater treatment system or a decentralized wastewater system (cluster or onsite). Some businesses or households may not be connected to their SAO's treatment system, which resulted in untreated wastewater being disposed into canals and the ocean. Dr. Suchanya Wongrod advised which treatment system would be appropriate for each business type. She suggested that an onsite wastewater treatment system with a grease trap, septic tank and coarse sand filter or a system with an anaerobic filter would be good options for homestays or households with a low to medium BOD level. For those with high BOD levels, it was suggested to install a system with a grease trap, septic tank, and aerobic filter. Another option (for homestays located together) constructed wetland (natural wastewater treatment) was recommended. The differences of each option were summarized in a table for clear viewing. Finally, the presentation was finished and continued with a discussion with participants.

4.2 Meeting Attendees

Tourist-related Business: Hotels and Resorts

Name	Business Name	Position
Piriya Songsaeng	Deevana Krabi Resort	Assistant of the Mechanical Manager
Arun Malaikul	Deevana Krabi Resort	n/a
Saipin Khanantai	Snow House	Business Owner
Chanita Sunahu	Snow House	n/a
Somchai Bumrungphong	Infinity Ao Nang Co. Ltd. (Hotels, Resorts and Guesthouses)	Assistant Chief Engineer
Chanomthun Thongkerd	GLOW Ao Nang Krabi	Engineer Supervisor
Thunthaphol Khinglek	GLOW Ao Nang Krabi	Technician
Kritdech Juthamath	Tinidee Hideaway Tonsai Beach Krabi	Operation Manager
Phitak Suwanno	Tinidee Hideaway Tonsai Beach Krabi	Engineer Manager
Chanram Wahndee	Tinidee Hideaway Tonsai Beach Krabi	Restaurant Manager
Saiman Khentid	Vacation Village Phra Nang Inn	Resort Manager
Suthichai Pleumchit	Vacation Village Phra Nang Inn	Chief Engineer
Patra Chanchoti	The Palance Ao Nang Resort	Human Resources
Wasana Waharn	Princeville Ao Nang	n/a

Tourist-related Business: Restaurants

Name	Business Name	Position
Arunwee Maneerath	888 DRINKS AONANG	Employee
Puntapach Tonhui	888 DRINKS AONANG	n/a
Sukanya Thongeaed	THAI ME UP PANG Co., Ltd.	Manager

Tourist-related Business: Laundry Businesses and Laundromats

Name	Business Name	Position
Ophad Kulthawi	Samkor Success Limited Partnership (Laundrymat)	Manager
Kanikar Bhudheed	Karn (Laundrymat)	n/a
Wuthichai Chaiporn	Karn (Laundrymat)	n/a

Local Administrative Organization

Name	Business Name	Position
Watt Ruengsamut	Nongthalay Sub-district Administrative Organization	Secretary to the Mayor of Sub-district Nongthalay
Aphisit Suknui	Ao Nang Sub-district Administrative Organization	Environmental Specialist
Maerisa Sribuathong	Ao Nang Sub-district Administrative Organization	Assistant Environmental Specialist

King Mongkut's University of Technology Thonburi

Name	Organization
Dr. Suchanya Wongrod	Faculty Member of the Environmental Technology Program, School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi (KMUTT)
Ms. Siriwan Wongsod	School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi (KMUTT)
Ms. Papornchanok Chalermsarp	School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi (KMUTT)

Thailand Development Research Institute

Name	Position
Mr. Adis Israngkura	Project Manager
Mrs.Thippawan Keawmesri	Senior Researcher
Ms. Prinyarat Leangcharoen	Senior Researcher
Ms. Panida Phranphanat	Researcher
Mr. Peerawat Suriyaburaphakul	Researcher
Ms. Pichamon Keakij	Researcher
Ms. Ramida Hansaward	Project Coordinator

Independent Researchers

Name	Position
Ms. Jaruwan Enright	Lead Researcher
Ms. Chalinee Supanbua	Researcher
Ms. Wanida Bhunyanun	Researcher

4.3 Meeting Agenda

Agenda for Disseminating Technical Assistance to Istall Small-scale Wastewater Treatment Systems for Small-scale Tourism Enterprises (Focus Group)

Under the Integration of Natural Capital Account in Public and Private Sector Policy and Decision-making for Sustainable Landscapes Project

Tuesday October 28th, 2025

9:30 am – 01:00 pm

At Deevana Plaza Krabi Ao Nang Hotel (Hornbill Ballroom 2)

9:30 am – 10:00 am	Registration
10:00 am – 10:15 am	Welcome remarks, a brief introduction of the project and explanation of the meeting's objective given by Assoc. Prof. Dr. Adis Israngkura from Thailand Development Research Institute
10:15 am – 10:30 am	Refreshment Break
10:30 am – 11:30 am	Present technical information on installing small-scale wastewater treatment systems for small-scale tourism enterprises in Krabi province by Dr. Suchanya Wongrod from King Mongkut's University of Technology Thonburi
11:30 am – 12:00 pm	Question and Answer Discussion with participants and closing remarks
12:00 pm – 1:00 pm	Lunch

4.4 Discussion with Participants

Speaker 1 **Dr. Suchanya Wongrod**	**If anyone has any questions or comments, please feel free to ask**
Speaker 2 **Mr. Watt Ruengsamut**	You mentioned organic matter in the water, but some hotels, like boutique hotels, use chemicals to clean. How does the organic matter in those tanks [treatment system] work with the chemicals intended to clean [such as bathrooms]? Is it environmentally friendly?
Speaker 1	Thank you for the question. I would recommend using diluted chemical cleaners to not disturb the treatment system, which normally would be biological treatment (not physical treatment) to minimize electricity costs. The best way would be to use chemical cleaners only if necessary (not excessively).
Speaker 2	Since you have mentioned the high costs of installing these systems, how can SAO come in to help support locals financially or co-finance to encourage locals to install these systems? Also, how can we use the current laws or regulations to propose more budgets to support installation of wastewater treatment systems since many locals may not have the financial resources to cover the costs themselves
Speaker 1	I am not sure if I can answer this question, but the costs of installing these systems are expensive. However, these systems are to provide examples of which systems may be applicable to each person's situation. In terms of financial support, perhaps this presentation or topic could be discussed further at a different time, incorporating more voices to find a solution (or mechanism) that satisfies all parties.
Speaker 3 **Ms. Jaruwan Enright**	[Introduced herself as a researcher working with TDRI] I had the chance to do a site-visit with Ao Nang locals to discuss collaborative efforts on what we can do to save [conserve] Ao Nang and Krabi. In which, next month we will conduct another meeting to discuss this topic [how to reduce waste and conserve natural resources] in detail. So, I would like to ask that we save this topic to discuss then, currently planned for November 17th. I would like to invite everyone to come join the discussion to productively find a solution. [The microphone was passed to Mr. Aphisit]
Speaker 4	I would like to ask Dr. Suchanya a question. As a representative from SAO Ao Nang. Currently, we are facing challenges with laundromat businesses, particularly

Mr. Aphisit Suknui	laundromat services and individual coin laundry machines that have multiplied in Ao Nang since COVID-19. In our experience conducting on-site inspections, although laundromat businesses have septic tanks for preliminary treatment of wastewater, we noticed wastewater (with laundry detergent and fabric softener) looked no different after going through the septic tank that costs around 20,000 to 30,000 baht (which most likely doesn't no comply with current regulations or standards for wastewater disposal if sent to a lab to test). So, I was wondering if you had any suggestions on technology or mechanisms to better treat wastewater from laundromat businesses. I understand this may be difficult, but when SAO inspects these businesses, we would like to provide suggestions on how to effectively treat wastewater (to pass the mandated regulations on water quality). On a different note, hotels (which have their own systems) would encounter some maintenance issues such as insufficient employees or mechanics with expertise in wastewater treatment. They have monitors and methods to measure if their wastewater complies with the regulation, but when it doesn't pass the regulation (standard of acceptable water quality), they would add EM (effective microorganisms) to treat their wastewater. In which some say that adding EM is good for treating water because it lowers BOD levels, while others say that adding EM is bad because it disturbs the organic matter in the septic tank which is supposed to treat the wastewater. So, I would like to ask you [Dr. Suchanya] for your opinion whether EM is good or bad for water treatment. Thank you.
Speaker 1	Laundry detergent products often have surfactants and phosphates which are inorganic matter and cannot be biodegraded. The septic tanks that these businesses install would only treat organic matter in wastewater, hence why the wastewater in and out has no difference in color or turbidity, but the septic tank does help with odor. These inorganic matters would need to rely on mechanisms such as membrane technology such as NF (nanofiltration) or microfilter to break down these inorganic materials. When using this membrane technology, the water would be cleaner than canal water. For factories in Central Thailand, they have a closed-loop cycle (treating their wastewater to reuse) which aligns with Thailand's National Strategy. EM is usually used to alleviate (water quality of) wastewater, but it cannot treat wastewater (thus, the BOD levels do not align with the standard). Hotel treatment systems were designed to last 20 to 30 years which may be outdated or overcapacity in which the system usually has an aeration system to keep oxygen levels within the standard.

Speaker 4	I would also like to ask if you recommend hotels use an aeration system (such as an anaerobic system) or install an aeration pipe to keep BOD levels low or low enough to pass the standard? Would it be an adequate solution to minimize costs?
Speaker 1	This depends on what system they have. If the system is an anaerobic system (sealed without air) then I would not recommend adding aeration because it may worsen the water quality. To minimize costs, I would recommend maintenance of the tank instead, which can help lower BOD as well. [...] If there are no other questions, would any participants like to share or comment on their experience or issues they would like to ask?
Speaker 5 **Representative of laundromat businesses**	Hi, I would like to ask more on how the septic tanks are supposed to work [if it doesn't help for laundry run off]
Speaker 1	From previous studies on this technology, septic tanks cannot breakdown inorganic matter (especially from chemical run offs in laundry detergent products), so I would like to suggest using additional filtration such as MF/UF (Microfiltration/Ultrafiltration) to aid with filtering inorganic matter before the wastewater is treated in the septic tank. Membrane technology could also work.
Speaker 6 **Ms. Prinyarat Leangcharoen**	Could I ask participants from other businesses, hotels, or restaurants to share your experiences on this topic? [Passed the microphone to a participant]
Speaker 7 **Representative of restaurant businesses**	Currently, we're using a two-tank system (suggested by the SAO) to treat our water [also physically disposing grease often].
Speaker 1	Do you encounter any issues with the system such as clogged pipes?
Speaker 7	Yes, sometimes. At first we had one tank and experienced some blockages so when SAO came to inspect the water, they suggested having two tanks to relieve the blockage. When cloggage happens, we try to clean it [the pipes and tank]
Speaker 1	Then I would like to suggest not to use wood or plastic to unblock the blockages because it could damage the internal filters in the tank. I recommend regular draining (disposing the separated grease) instead.

Speaker 7	Yes we do that every morning.
Speaker 8 **Ms. Maerisa Sribuathong**	[Ms. Maerisa raised her hand to speak] I would like to share that when the SAO does on-site inspections, one issue we encounter is with septic tanks is that sometimes there are grease residue [in the sink or tank] in which people often resort to using hot water to get rid of the residue. This only makes the grease residue stuck in the pipes, making it more difficult to clean.
Speaker 1	Yes, that's true. Instead of using hot water I would suggest manually draining and cleaning the tank (treating grease like solid waste) On that note, would any representatives from hotels or homestays like to share their experience?
Speaker 9 **Representative of hotels**	For our hotel, we passed our inspections, and we would like to ask (suggest) SAO to do random inspections to ensure that all businesses are ready [for inspection] and ensure compliance with regulations. We also treat our water and reuse it to water our plants. And we have the appropriate tanks that we clean (maintain) every day and would like to ask SAO to ensure that businesses are always ready for inspection (if they know they are complying with regulations) as they have their operating licenses.
Speaker 4	The issue of not doing random inspections is because when SAO randomly shows up, to check the wastewater treatment system, the manager or owner needs to come give access which takes significant time to contact or sometimes they are not within the vicinity then the inspection would have to be rescheduled. And unfortunately, due to limited human resources, we are unable to inspect all businesses (currently we are only inspecting businesses with operating licenses). However, we [SAO] hope to make changes to improve operations in solving these issues [inspections and wastewater management]. In some cases, we do inspections and found that the system does not fully comply with regulations (i.e. they system is outdated or overcapacity) which often is not intended. So, we would like to ask businesses to cooperate with us (and the regulations). When officials have to impose fines on businesses that do not comply with the regulations, people think that officials do it intentionally to take advantage of the system. But I can assure that officials do not want to impose fines because there is a lot of paperwork and risks (with legal mechanisms to ensure transparency).

	So, we would like to request cooperation with everyone. If you are unsure if your system is up to standard, you can contact us [SAO] so we can provide some assistance in terms of information or advice.
Speaker 2	I would like to add that we need to foster people's subconscious to give importance to the environment, especially when we are using resources for business. We need the cooperation of both small businesses and locals, so that we can achieve sustainable tourism.
Speaker 10 **Representative of hotels**	Hi, I would like to ask Dr. Suchanya for advice. Our hotel has septic tanks and a cesspool, we use one tank for every two rooms. The issue we face is sometimes the water won't drain which causes the tank to overflow and we have to pump the water out. Is there any solution to this problem?
Speaker 1	I'm unsure but if the soil is damp this may be difficult to solve. I would suggest changing the location of the cesspool so the soil can help absorb the overflowing water.
Speaker 11 **Representative of hotels**	I would like to suggest an alternative solution. Using bionic in toilets which can help with better drainage and help with wastewater treatment (help breakdown organic matter)
Speaker 12Representative of hotels	For our hotel treatment system is adding air, we have a manhole (small reservoir) and a grease trap (for wastewater from the kitchen). We have issues with the grease trap; it often gets blocked. Is there a solution to either melt or dissolve the grease build up that does not use hot water?
Speaker 1	It is difficult to resolve this since the grease in the pipes is difficult to see and reach those spots to clean. I think I could give better advice if I could see what system it is, but the best way would be to manually dispose of grease.
Speaker 4	I would like to share a similar experience from another hotel face with grease build up. They bought organic matter to eat (breakdown) the grease in the tank but that did not solve the issue completely and it increased the water's BOD (but it could be a possible solution for places with low BOD levels). You could ask them for advice because they have an expert on this. Possible solutions could be having more strict protocols in cleaning grease from septic tanks before it goes into the pipes; fixing the problem and the root cause.

4.5 Key Takeaways

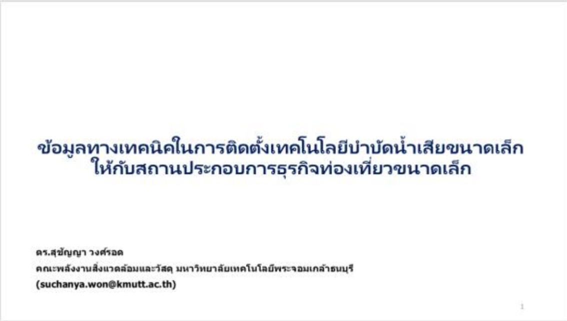
1. Wastewater from small-scale tourism enterprises and other anthropogenic activities contributes to the destruction of Krabi's natural resources and ecosystems. Through collective efforts from residents and (small-scale) businesses, Krabi's beautiful scenery can be conserved for sustainable tourism and development.
2. Parameters such as BOD, DO, Fecal Coliform Bacteria, and the biological breakdown of what is in wastewater are crucial in understanding water quality. For hotels and restaurants, proper disposal of grease can help with better treatment of their wastewater. Laundromat businesses should take notice of phosphate levels from detergent use. Understanding the components of wastewater can guide business owners to choose appropriate treatment systems for wastewater that are up to mandated standards (before disposing).
3. There are different options for wastewater management that can be viable for small-scale businesses such as grease-traps that can separate grease properly. This makes a significant difference in the water quality of wastewater, making it easier to treat wastewater.

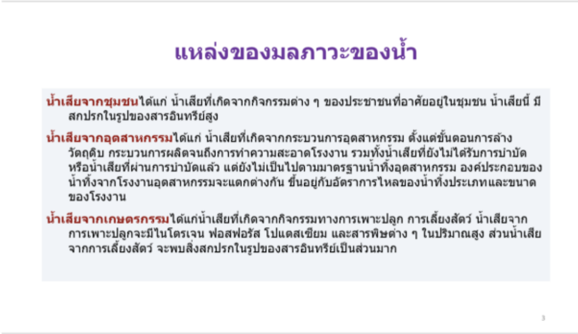
4.6 Remaining Issues (Challenges)

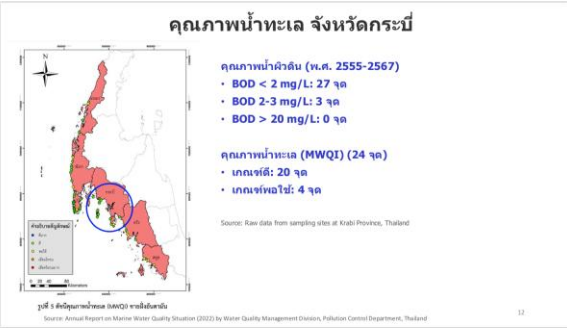
1. Insufficient government officers to conduct on-site inspections to ensure compliance with wastewater treatment from tourist enterprises (businesses).
2. Insufficient personnel with specialized knowledge or expertise in wastewater management (treatment) to maintain wastewater that complies with the mandatory requirements or standards
3. Financial and/or technical assistance for adequate treatment for small-scale business owners' respective enterprises. This is due to significant costs installing new wastewater treatment systems and continued maintenance, which can be burdensome for small businesses. The SAO also faces budgetary constraints to co-finance or provide support to encourage effective treatment of wastewater.
4. How to reach new business owners to receive wastewater management information (for correct treatment) and ingrain the importance of environmental conservation through wastewater management with tourist enterprises.

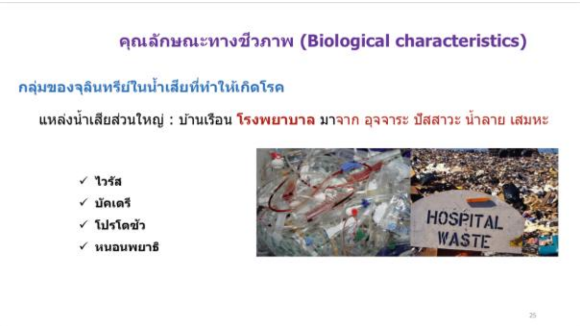
4.7 Meeting documents and photos

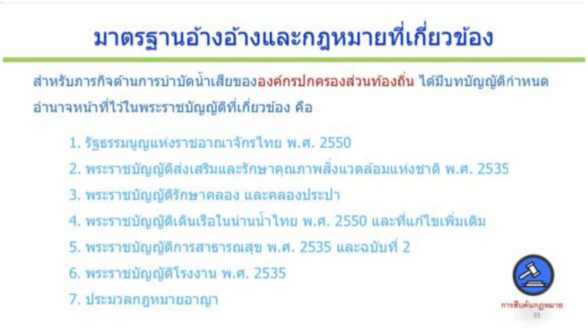
4.7.1 Presentation Slides Sample

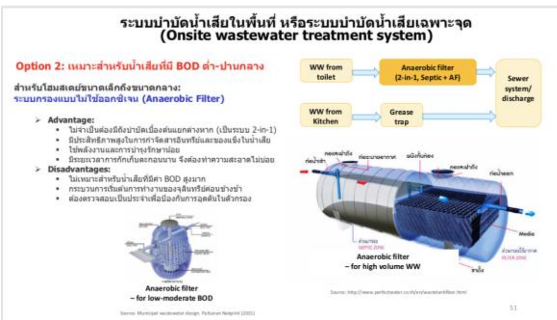












4.7.2 Meeting Agenda in Thai

Funded by　Executing Agencies

กำหนดการประชุมเผยแพร่ข้อมูลทางเทคนิคในการติดตั้งเทคโนโลยีบำบัดน้ำเสียขนาดเล็ก ให้กับสถานประกอบการธุรกิจท่องที่ยวขนาดเล็ก จังหวัดกระบี่

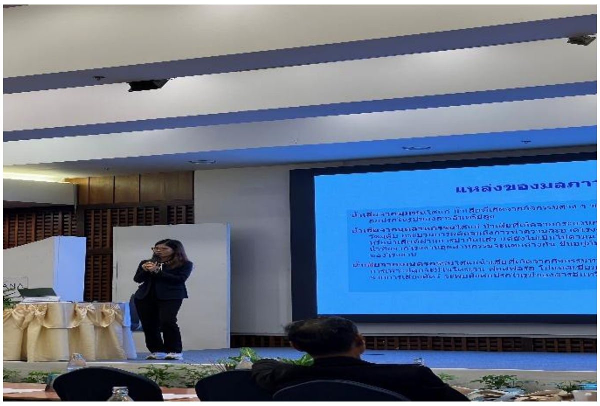
ภายใต้โครงการจัดทำบัญชีทุนทางธรรมชาติเพื่อการตัดสินใจเชิงนโยบายสู่การพัฒนาที่ยั่งยืน
(Integration of Natural Capital accounting in public and private sector policy and decision-making for sustainable landscapes)

วันที่ 28 ตุลาคม 2568 เวลา 9.30 – 13.00 น.

ณ ห้องประชุม Hornbill Ballroom 2 โรงแรม ดีวาน่า พลาซ่า กระบี่ อ่าวนาง

09.30 – 10.00 น.	ลงทะเบียนเข้าร่วมการประชุม
10.00 – 10.15 น.	กล่าวต้อนรับและความเป็นมาของโครงการและวัตถุประสงค์ของการจัดประชุม โดย รศ.ดร. อดิศร์ อิศรางกูร ณ อยุธยา สถาบันวิจัยเพื่อการพัฒนาประเทศไทย
10.15 – 10.30 น.	รับประทานอาหารว่าง
10.30 – 11.30 น.	นำเสนอข้อมูลทางเทคนิคในการติดตั้งเทคโนโลยีบำบัดน้ำเสียขนาดเล็กให้กับสถานประกอบการธุรกิจท่องที่ยวขนาดเล็ก จังหวัดกระบี่ โดย ดร. สุชัญญา วงศ์รอด มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าพระนครเหนือ
11.30 – 12.00 น.	ถาม-ตอบ สรุปผล และปิดการประชุม
12.00 – 13.00 น.	รับประทานอาหารกลางวัน

4.7.3 Images from the Focus Group



4.7.4 Attendee Signature Sheet

รายชื่อผู้เข้าร่วมการประชุมกลุ่มย่อยผู้เชี่ยวชาญ (Fogus Group)

เรื่อง "กรอบแนวคิดในการจัดทำบัญชีทุนทางธรรมชาติระดับประเทศ (Natural Capital Accounting: NCA) : ภาคการท่องเที่ยว และภาคทรัพยากรน้ำ และแผนที่นำทาง (Roadmap)"

ภายใต้

โครงการจัดทำบัญชีทุนทางธรรมชาติเพื่อการตัดสินใจเชิงนโยบายสู่การพัฒนาที่ยั่งยืน (Integration of Natural Capital Accounting in Public and Private Sector Policy and Decision-making for Sustainable Landscapes)

วันอังคารที่ 28 ตุลาคม 2568 เวลา 09.30 - 13.00 น.

ณ ห้องประชุม Hornbill Ballroom 2 โรงแรม ดีวาน่า พลาซ่า กระบี่ อ่าวนาง

รายชื่อผู้เข้าร่วมการประชุม: สถานประกอบการธุรกิจท่องเที่ยว

	รายชื่อ		ตำแหน่ง	สถานประกอบการ	ลายเซ็น และอนุญาต PDPA
1.	คุณพิริยะ	ส่งแสง	ผู้ช่วยผู้จัดการฝ่ายช่าง	โรงแรมดีวาน่า กระบี่รีสอร์ท	
2.	คุณสายพิน	ขนานใต้	เจ้าของกิจการ	โรงแรม สโนว์เฮ้าท์	
3.	คุณชนิตา	สูน่าหู่		โรงแรม สโนว์เฮ้าท์	
4.	คุณโอภาส	กูลทวี	ผู้จัดการ	ห้างหุ้นส่วนจำกัดสามกอ ซัคเซส (ซัก อบ รีด)	
5.	คุณสมชาย	บำรุงพงศ์	Asst. Chief Engineer	บริษัท อินฟินิตี้ อ่าวนาง จำกัด (โรงแรม/รีสอร์ท/เกสต์เฮ้าส์)	
6.	คุณชนมธัญ	ทองเกิด	Engineer Superviser	โรงแรมโกลว์ อ่าวนาง กระบี่	
7.	คุณทัตพล	กิ่งเล็ก	Technician	โรงแรมโกลว์ อ่าวนาง กระบี่	
8.	คุณกษิดิ์เดช	จุฑามาตย์	Operation manager	โรงแรม Tinidee Hideaway Tonsai Beach Krabi	
9.	คุณพิทักษ์	สุวรรณโน	Engineer Manager	โรงแรม Tinidee Hideaway Tonsai Beach Krabi	

1

รายชื่อผู้เข้าร่วมการประชุมกลุ่มย่อยผู้เชี่ยวชาญ (Fogus Group)

เรื่อง "กรอบแนวคิดในการจัดทำบัญชีทุนทางธรรมชาติระดับประเทศ (Natural Capital Accounting: NCA) : ภาคการท่องเที่ยว และภาคทรัพยากรน้ำ และแผนที่นำทาง (Roadmap)"

ภายใต้

โครงการจัดทำบัญชีทุนทางธรรมชาติเพื่อการตัดสินใจเชิงนโยบายสู่การพัฒนาที่ยั่งยืน (Integration of Natural Capital Accounting in Public and Private Sector Policy and Decision-making for Sustainable Landscapes)

วันอังคารที่ 28 ตุลาคม 2568 เวลา 09.30 - 13.00 น.

ณ ห้องประชุม Hornbill Ballroom 2 โรงแรม ดีวาน่า พลาซ่า กระบี่ อ่าวนาง

	รายชื่อ		ตำแหน่ง	สถานประกอบการ	ลายเซ็น และอนุญาต PDPA
10.	คุณสายม่าน	เข็มทิศ	Resort manager	โรงแรม พระนางอินน์	
11.	นายสุทธิชัย	ปลื้มจิตต์	chief.Engineer	โรงแรม พระนางอินน์	
12.	คุณภัทรา	จันทรโชติ	ฝ่ายบุคคล	เดอะพาเลส อ่าวนาง รีสอร์ท	
13.	คุณกรรณิการ์	บุตรอีด		กานต์ ซัก อบ รีด	กรรณิ.
14.	คุณวุฒิชัย	ไชยพร		กานต์ ซัก อบ รีด	
15.	คุณอุรวี	มณีรัตน์	พนักงาน	ร้านอาหาร 888 DRINKS AONANG	อุรวี.
16.	คุณสกุณา	ทองเอียด	ผู้จัดการ	ร้านอาหาร ไทย มี อัพ แป้ง จำกัด	
17.	นางสาว ชนกนัย ต้นหุ้ย			ร้าน 888 Aonang	ชนกนัย
18.	นายวาสนา ทนะรัฐ			โรงแรมอ่าวนางปรินซ์วิลล่า	
19.	นาย อรุณ ศาลัยกูล			โรงแรมดีวาน่ากระบี่	

2

รายชื่อผู้เข้าร่วมการประชุมกลุ่มย่อยผู้เชี่ยวชาญ (Fogus Group)

เรื่อง “กรอบแนวคิดในการจัดทำบัญชีทุนทางธรรมชาติระดับประเทศ (Natural Capital Accounting: NCA) : ภาคการท่องเที่ยว และภาคทรัพยากรน้ำ และแผนที่นำทาง (Roadmap)”

ภายใต้

โครงการจัดทำบัญชีทุนทางธรรมชาติเพื่อการตัดสินใจเชิงนโยบายสู่การพัฒนาที่ยั่งยืน (Integration of Natural Capital Accounting in Public and Private Sector Policy and Decision-making for Sustainable Landscapes)

วันอังคารที่ 28 ตุลาคม 2568 เวลา 09.30 - 13.00 น.

ณ ห้องประชุม Hornbill Ballroom 2 โรงแรม ดีวาน่า พลาซ่า กระบี่ อ่าวนาง

	รายชื่อ	ตำแหน่ง	สถานประกอบการ	ลายเซ็น และอนุญาต PDPA
20.	จันทร์แรม หวานดี	Restaurant Manager	โรงแรม ทินิดี้ ต้นไทร ไฮอะเวย์	[signature]
21.				
22.				
23.				
24.				
25.				
26.				
27.				
28.				

รายชื่อผู้เข้าร่วมการประชุมกลุ่มย่อยผู้เชี่ยวชาญ (Fogus Group)

เรื่อง "กรอบแนวคิดในการจัดทำบัญชีทุนทางธรรมชาติระดับประเทศ (Natural Capital Accounting: NCA) : ภาคการท่องเที่ยว และภาคทรัพยากรน้ำ และแผนที่นำทาง (Roadmap)"

ภายใต้

โครงการจัดทำบัญชีทุนทางธรรมชาติเพื่อการตัดสินใจเชิงนโยบายสู่การพัฒนาที่ยั่งยืน (Integration of Natural Capital Accounting in Public and Private Sector Policy and Decision-making for Sustainable Landscapes)

วันอังคารที่ 28 ตุลาคม 2568 เวลา 09.30 - 13.00 น.

ณ ห้องประชุม Hornbill Ballroom 2 โรงแรม ดีวาน่า พลาซ่า กระบี่ อ่าวนาง

องค์กรปกครองส่วนท้องถิ่น

	รายชื่อ		ตำแหน่ง	สถานประกอบการ	ลายเซ็น และอนุญาต PDPA
29.	นายประหยัด	หนูสงฆ์	รองนายก	องค์การบริหารส่วนตำบลเกาะกลาง	
30.	นายวัฒน	เริงสมุทร	เลขานุการนายก	องค์การบริหารส่วนตำบลหนองทะเล	
31.	นางปาวิดา	วะจิดี	พนักงานจ้างทั่วไป	องค์การบริหารส่วนตำบลหนองทะเล	
32.	นายอภิสิทธิ์	สุขนุ้ย	นักวิชาการสิ่งแวดล้อมปฏิบัติการ	องค์การบริหารส่วนตำบลอ่าวนาง	
33.	นางสาวเมริษา	ศรีบัวทอง	ผู้ช่วยนักวิชาการสิ่งแวดล้อม	องค์การบริหารส่วนตำบลอ่าวนาง	
34.					
35.					
36.					

4

รายชื่อผู้เข้าร่วมการประชุมกลุ่มย่อยผู้เชี่ยวชาญ (Fogus Group)

เรื่อง “กรอบแนวคิดในการจัดทำบัญชีทุนทางธรรมชาติระดับประเทศ (Natural Capital Accounting: NCA) : ภาคการท่องเที่ยว และภาคทรัพยากรน้ำ และแผนที่นำทาง (Roadmap)”

ภายใต้

โครงการจัดทำบัญชีทุนทางธรรมชาติเพื่อการตัดสินใจเชิงนโยบายสู่การพัฒนาที่ยั่งยืน (Integration of Natural Capital Accounting in Public and Private Sector Policy and Decision-making for Sustainable Landscapes)

วันอังคารที่ 28 ตุลาคม 2568 เวลา 09.30 - 13.00 น.

ณ ห้องประชุม Hornbill Ballroom 2 โรงแรม ดีวาน่า พลาซ่า กระบี่ อ่าวนาง

	รายชื่อ	ตำแหน่ง	สถานประกอบการ	ลายเซ็น และอนุญาต PDPA
37.	ดารุวรรณ [illegible]			
38.	[illegible]			
39.	[illegible]			
40.				
41.				
42.				
43.				
44.				

5

รายชื่อผู้เข้าร่วมการประชุมกลุ่มย่อยผู้เชี่ยวชาญ (Fogus Group)

เรื่อง "กรอบแนวคิดในการจัดทำบัญชีทุนทางธรรมชาติระดับประเทศ (Natural Capital Accounting: NCA) : ภาคการท่องเที่ยว และภาคทรัพยากรน้ำ และแผนที่นำทาง (Roadmap)"

ภายใต้

โครงการจัดทำบัญชีทุนทางธรรมชาติเพื่อการตัดสินใจเชิงนโยบายสู่การพัฒนาที่ยั่งยืน (Integration of Natural Capital Accounting in Public and Private Sector Policy and Decision-making for Sustainable Landscapes)

วันอังคารที่ 28 ตุลาคม 2568 เวลา 09.30 - 13.00 น.

ณ ห้องประชุม Hornbill Ballroom 2 โรงแรม ดีวาน่า พลาซ่า กระบี่ อ่าวนาง

มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

	ชื่อ-นามสกุล		หน่วยงาน	ลายเซ็น
1.	ดร.สุชัญญา	วงศ์รอด	อาจารย์ประจำหลักสูตรเทคโนโลยีสิ่งแวดล้อม คณะพลังงานสิ่งแวดล้อมและวัสดุ มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี (มจธ.)	สุชัญญา วงศ์รอด
2.	นางสาวสิริวรรณ	วงษ์สด	คณะพลังงานสิ่งแวดล้อมและวัสดุ มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี (มจธ.)	สิริวรรณ วงษ์สด.
3.	นางสาวปพรชนก	เฉลิมทรัพย์	คณะพลังงานสิ่งแวดล้อมและวัสดุ มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี (มจธ.)	ปพรชนก เฉลิมทรัพย์

สถาบันวิจัยเพื่อการพัฒนาประเทศไทย

	ชื่อ-นามสกุล		ตำแหน่ง/หน่วยงาน	ลายเซ็น
1.	นายอดิศร์	อิศรางกูร ณ อยุธยา	หัวหน้าโครงการ สถาบันวิจัยเพื่อการพัฒนาประเทศไทย	อดิศร์
2.	นางทิพวัลย์	แก้วมีศรี	นักวิจัยอาวุโส สถาบันวิจัยเพื่อการพัฒนาประเทศไทย	[illegible]
3.	นางสาวปริญญารัตน์	เลี้ยงเจริญ	นักวิจัยอาวุโส สถาบันวิจัยเพื่อการพัฒนาประเทศไทย	[illegible]
4.	นางสาวกาญจนา	ย่าเสน	นักวิจัย สถาบันวิจัยเพื่อการพัฒนาประเทศไทย	
5.	นางสาวปณิดา	พรานพนัส	นักวิจัย สถาบันวิจัยเพื่อการพัฒนาประเทศไทย	[illegible]

6

รายชื่อผู้เข้าร่วมการประชุมกลุ่มย่อยผู้เชี่ยวชาญ (Fogus Group)

เรื่อง "กรอบแนวคิดในการจัดทำบัญชีทุนทางธรรมชาติระดับประเทศ (Natural Capital Accounting: NCA) : ภาคการท่องเที่ยว และภาคทรัพยากรน้ำ และแผนที่นำทาง (Roadmap)"

ภายใต้

โครงการจัดทำบัญชีทุนทางธรรมชาติเพื่อการตัดสินใจเชิงนโยบายสู่การพัฒนาที่ยั่งยืน (Integration of Natural Capital Accounting in Public and Private Sector Policy and Decision-making for Sustainable Landscapes)

วันอังคารที่ 28 ตุลาคม 2568 เวลา 09.30 - 13.00 น.

ณ ห้องประชุม Hornbill Ballroom 2 โรงแรม ดีวาน่า พลาซ่า กระบี่ อ่าวนาง

	ชื่อ-นามสกุล		ตำแหน่ง/หน่วยงาน	ลายเซ็น
6.	นายพีรวัช	สุริยบูรพกูล	นักวิจัย สถาบันวิจัยเพื่อการพัฒนาประเทศไทย	
7.	นางสาวพิชามญชุ์	เกื้อกิจ	นักวิจัย สถาบันวิจัยเพื่อการพัฒนาประเทศไทย	พิชามญชุ์
8.	นางสาวรมิดา	หาญสวัสดิ์	ผู้ประสานงานโครงการ	Romida H.

7

5. References

Adu-Ofori, K., Amfo-Otu, R., & Hodgson, I. (2016). Organic matter and nutrient removal by waste stabilization ponds. Journal of the Ghana Science Association, 17(1), 9–17. Retrieved fromhttps://www.researchgate.net/publication/319549599_Organic_matter_and_nutrient_removal_by_waste_stabilization_ponds_Adu-Ofori_et_al

Adu-Ofori, K., Amfo-Otu, R., & Hodgson, I. (2016). Organic matter and nutrient removal by waste stabilization ponds. Journal of the Ghana Science Association, 17(1), 9–17. Retrieved from https://www.researchgate.net/publication/319549599_Organic_matter_and_nutrient_removal_by_waste_stabilization_ponds_Adu-Ofori_et_al

Alramthi, S. M., Ali, G. H., Elthagafi, A. M., Eldosari, S. H., Zhu, B.-K., & Safaa, H. M. (2022). Oxidation ditches for recycling and reusing wastewater are critical for long-term sustainability-a case study. MDPI. December 14. Retrieved from https://www.mdpi.com/2071-1050/14/24/16737

Annie. (2023). Krabi governor succeeds Klong Jak's wastewater treatment system avoid seawater pollution. Your guide to Thailand. (2023, February 8). Retrieved from https://thailand.locality.guide/2023/02/08/krabi-governor-succeeds-klong-jaks-wastewater-treatment-system-avoid-seawater-pollution/

APHA.; AWWA.; WEF. (2023). Standard Methods for the Examination of Water and Wastewater, 24th ed.; American Public Health Association: Washington, DC, USA; American Water Works Association: Denver, CO, USA; Water Environmental Federation: Alexandria, VA, USA.

Aquatic Resources Research Institute, Chulalongkorn University, (n.a.). Retrieved from https://www.mkh.in.th/index.php?option=com_content&view=article&id=69&Itemid=71&lang=th#:~:text=ต้นทุนการผลิตน้ำทะเล,ขึ้น%5B4%5D%20แต่อย่างไรก็ตามอนาคต หรือ Marine Knowledgement Hub ฐานข้อมูลความรู้ทางทะเล

Aquatic Resources Research Institute, Chulalongkorn University, (n.a.) Retrieved from https://www.mkh.in.th/index.php?option=com_content&view=article&id=69&Itemid=71&lang=th#:~:text=ต้นทุนการผลิตน้ำทะเล,ขึ้น%5B4%5D%20แต่อย่างไรก็ตามอนาคต

Araya Yotmongkol. (n.d.). The New National Water Law for Improving Water Management Problems in Thailand, Focused on Water Allocation and Water Resources Conservation. Retrieved from http://project-wre.eng.chula.ac.th/aseanacademicnetwork/files/THA2022/TC/TC-301S.pdf

Boguniewicz-Zablocka, Capodaglio, A. G.. (2017). Sustainable wastewater treatment solutions for rural communities': Public (centralized) or individual (on-site) – case study. Economic and Environmental Studies, 17(44), 1103–1119. Retrieved from https://doi.org/10.25167/ees.2017.44.29

Boguniewicz-Zablocka, J., Klosok-Bazan, I., Capodaglio, A. G., & Ploskonka, J. (2018). Planning the optimal solution for wastewater management in rural areas - case study. MATEC Web of Conferences, 174, 01035. Retrieved from https://doi.org/10.1051/matecconf/201817401035

BOI. (2015). The Factory Act. Retrieved from https://www.boi.go.th/index.php?page=the_factory_act&language=en#:~:text=The%20Factory%20Act%20of%201992,Updated:%20November%202015

Deng, Y., & Wheatley, A. (2016). Wastewater treatment in Chinese rural areas. Asian Journal of Water, Environment and Pollution, 13(4), 1–11. Retrieved from https://www.researchgate.net/profile/Yihuan-Deng/publication/308918907_Wastewater_Treatment_in_Chinese_Rural_Areas/links/59df490ba6fdccfcfda34b3d/Wastewater-Treatment-in-Chinese-Rural-Areas.pdf

Department of Marine and Coastal Resources. (2020). Marine and coastal water quality report of Thailand 2020. Ministry of Natural Resources and Environment, Bangkok, Thailand.

Department of Tourism. (2025). “Number of tourist in year 2558-2566”. (Digital file)

ENVI 101 Geotechnical specialist. (n.a.). Constructed Wetland. Retrieved from https://envi101.co.th/featured_item/ระบบบำบัดน้ำเสียแบบบึง/

FAO. (n.d.). FAOLEX Database, Act on the Maintenance of the Cleanliness and Orderliness of the Country, B.E. 2535 (1992). Retrieved from https://www.fao.org/faolex/results/details/fr/c/LEXFAOC209432/#:~:text=This%20Act%20consists%20of%2062,or%20waterway%20(Section%2033)

G.A.M. Legal Alliance. (n.d.). Thai Public Health Act in Thailand. Retrieved from https://gam-legalalliance.com/thai-statutory-laws/thai-public-health-act/

Gikas, G. D., Papaevangelou, V. A., Tsihrintzis, V. A., Antonopoulou, M., & Konstantinou, I. K. (2021). Removal of Emerging Pollutants in Horizontal Subsurface Flow and Vertical Flow Pilot-Scale Constructed Wetlands. Processes, 9(12), 2200. https://doi.org/10.3390/pr9122200

GIZ Thailand. (2019). domestic-wastewater-management (2019, January 2). Retrieved from https://www.thai-german-cooperation.info/en_US/thailand-and-germany-join-up-to-support-domestic-wastewater-management-moving-thailand-towards-becoming-a-low-carbon-society/

Kanchanapiya, P., & Tantisattayakul, T. (2022). Wastewater reclamation trends in Thailand. *Water Science and Technology*, *86*(11), 2878–2911. Retrieved from https://doi.org/10.2166/wst.2022.375

Krabi Provincial Office of Natural Resources and Environment (n.d.). Lack of news about enforcement of wastewater law. Retrieved from https://www.mnre.go.th/en/index.

Krabi Provincial Statistical Office (2025) Population of Krabi in year 1993-2024. (Digital file)

Krabi Provincial Statistical Office. (2023). Krabi Provincial Statistical Report 2023. Retrieved from https://krabi.nso.go.th/images/ebook/KRABI%20PROVINCIAL%20STATISTICAL%20REPORT%202023.pdf

Len HEND. (n.a.). Septic Tanks in Thailand. Retrieved from https://lenhend.com/building-in-thailand/septic-tanks/

Nippon Dynawave Packaging Company. (2016). Process Effluent Treatment System Operating Plan Nippon Dynawave Packaging Company Longview, Washington October 2016. Retrieved from file:///Users/sirasartsukcharoensin/Downloads/Wastewater%20Treatment%20Operating%20Plan%20October%202016%20A.pdf.

Office of the Council of state. (n.d.). Navigation in the Thai Waters act, be 2456 (1913). (n.d.-a). Retrieved from https://faolex.fao.org/docs/pdf/tha218661.pdf

Perfect Solution Water. (2020). Anaerobic BIG FIBER TANK. Retrieved from http://www.perfectwater.co.th/en/wastetankfiber.html

Pollution Control Department (n.d.). Overall information comes from the department, however data and information were also listed in more specific sources. Retrieved from https://www.pcd.go.th/.

Pollution Control Department (n.d.). "Community wastewater" from website http://www.greenandcleansolution.com/%E0%B8%84%E0%B8%A7%E0%B8%B2%E0%B8%A1%E0%B8%A3%E0%B8%B9%E0%B9%89%E0%B8%97%E0%B8%B2%E0%B8%87%E0%B8%A7%E0%B8%B4%E0%B8%8A%E0%B8%B2%E0%B8%81%E0%B8%B2%E0%B8%A3%E0%B8%94%E0%B9%89%E0%B8%B2%E0%B8%99%E0%B8%AA%E0%B8%B4%E0%B9%88%E0%B8%87%E0%B9%81%E0%B8%A7%E0%B8%94%E0%B8%A5%E0%B9%89%E0%B8%AD%E0%B8%A1/%E0%B8%99%E0%B9%89%E0%B8%B3%E0%B9%80%E0%B8%AA%E0%B8%B5%E0%B8%A2%E0%B8%8A%E0%B8%B8%E0%B8%A1%E0%B8%8A%E0%B8%99-Domestic-Wastewater.html Information more specifically comes from Considerations Regarding the Quantity and Characteristics of Municipal Wastewater in Thailand, Proceedings of the 36th Institute for the Promotion of Teaching Science and Technology - IPST Conference, Environmental Society of Thailand, 2536.

Pollution Control Department (n.d.). "Domestic Wastewater" Retrieved from http://www.greenandcleansolution.com/%E0%B8%84%E0%B8%A7%E0%B8%B2%E0%B8%A1%E0%B8%A3%E0%B8%B9%E0%B9%89%E0%B8%97%E0%B8%B2%E0%B8%87%E0%B8%A7%E0%B8%B4%E0%B8%8A%E0%B8%B2%E0%B8%81%E0%B8%B2%E0%B8%A3%E0%B8%94%E0%B9%89%E0%B8%B2%E0%B8%99%E0%B8%AA%E0%B8%B4%E0%B9%88%E0%B8%87%E0%B9%81%E0%B8%A7%E0%B8%94%E0%B8%A5%E0%B9%89%E0%B8%AD%E0%B8%A1/%E0%B8%99%E0%B9%89%E0%B8%B3%E0%B9%80%E0%B8%AA%E0%B8%B5%E0%B8%A2%E0%B8%8A%E0%B8%B8%E0%B8%A1%E0%B8%8A%E0%B8%99-Domestic-Wastewater.html Information more specifically comes from Project on Prioritizing Community Wastewater Management, Office of Natural Resources and Environmental Policy and Planning, 2538.

Pollution Control Department. (2017a). Surface water quality standards of Thailand (B.E. 2560). Ministry of Natural Resources and Environment, Bangkok, Thailand.

Pollution Control Department. (2017b). Coastal water quality standards of Thailand (B.E. 2560). Ministry of Natural Resources and Environment, Bangkok, Thailand.

Prateep Na Talang, R., Sirivithayapakorn, S., & Polruang, S. (2022). Life cycle impact assessment and life cycle cost assessment for centralized and decentralized wastewater treatment plants in Thailand. Scientific Reports, 12(1). https://doi.org/10.1038/s41598-022-18852-y Figures do not come from range, from case studyAnnie. (2023, February 8). Krabi governor succeeds Klong Jak's wastewater treatment system avoid seawater pollution. Your guide to Thailand! Retrieved from https://thailand.locality.guide /2023/02/08/krabi-governor-succeeds-klong-jaks-wastewater-treatment-system-avoid-seawater-pollution/

Prateep Na Talang, R., Sirivithayapakorn, S., & Polruang, S. (2022). Life cycle impact assessment and life cycle cost assessment for centralized and decentralized wastewater treatment plants in Thailand. Scientific Reports, 12(1). https://doi.org/10.1038/s41598-022-18852-y

Shahryar Jafarinejad. (2017). "Aerated Lagoons" Treatment of Oily Wastewater, Petroleum Waste Treatment and Pollution Control, Pages 185-267 Retrieved from https://www.sciencedirect.com/topics/engineering/anaerobiclagoon#:~:text=In%20aerated%20lagoons%2C%20removal%20efficiencies,the%20end%20of%20the%20system

Singhirunnusorn, W., & Stenstrom, M. K. (2010). A critical analysis of economic factors for diverse wastewater treatment processes: Case studies in Thailand. *Sustainable Environment Research, 20*, Article 20. Retrieved from https://www.researchgate.net/publication/267382358_A_critical_analysis_of_economic_factors_for_diverse_wastewater_treatment_processes_Case_studies_in_Thailand

The Nation. (2021). Two Krabi restaurants fined for releasing untreated wastewater. nationthailand. (2021, April 15). Retrieved from https://www.nationthailand.com/in-focus/30363856

Tourism Authority of Thailand. (2020). Tourism statistics 2019: Annual report. Tourism Authority of Thailand, Bangkok, Thailand.

TTR Weekly. (2025). Thailand tourism outlook: 2025 forecast. Retrieved from https://www.ttrweekly.com /site/2025/08/tat-inspires-tourism-reimagined/

United States Environmental Protection Agency. (2021). National recommended water quality criteria: Aquatic life criteria table. Office of Water, Washington, D.C., USA. Retrieved from https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

Wang, M., Zhu, J., & Mao, X. (2021). Removal of Pathogens in Onsite Wastewater Treatment Systems: A Review of Design Considerations and Influencing Factors. Water, 13(9), 1190.)

Wastewater Management Authority (Krabi office). (2025). The Wastewater Management Organization has allocated 300 million baht to solve the wastewater problem in Ao Nang. MGR Online. (2025, March 13). Retrieved from https://mgronline.com/south/detail/9680000024299#google_vignette

Whiteford, L., Koenig, E., & Zarger, R. (2014). The impacts of tourism development on perceptions and practices of sustainable wastewater management on the Placencia Peninsula, Belize. Journal of Cleaner Production. (January 1) Retrieved from https://www.academia.edu/32392867/The_impacts_of_tourism_development_on_perceptions_and_practices_of_sustainable_wastewater_management_on_the_Placencia_Peninsula_Belize

World Bank Group. (2024). Wastewater? from waste to resource. World Bank. (March 27) Retrieved from https://www.worldbank.org/en/topic/water/publication/wastewater-initiative,

World Health Organization. (2017). Guidelines for drinking-water quality: Fourth edition incorporating the first addendum. World Health Organization, Geneva, Switzerland.

THE INTEGRATION OF NATURAL CAPITAL ACCOUNTING IN PUBLIC AND PRIVATE SECTOR POLICY AND DECISION-MAKING FOR SUSTAINABLE LANDSCAPES

NATURAL CAPITAL

Funded by gef UN environment programme

Executing Agencies TDRI THAILAND DEVELOPMENT RESEARCH INSTITUTE