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RESEARCH EVALUATING THE EFFECTIVENESS OF THE WASTEWATER TREATMENT SYSTEM AT THE DOC LET AREA, KHANH HOA PROVINCE

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Abstract: The rapid development of coastal resort areas has significantly increased the amount of domestic wastewater generated, creating an urgent need for pollution control and marine environmental protection. The Doc Let – Phuong Mai tourist area project in Khanh Hoa province, has invested in a centralized wastewater treatment system with a total capacity of 2,750 m³/day to collect and treat all wastewater generated during its operation. This study evaluates the expected treatment efficiency of the system based on an analysis of the characteristics of the wastewater source, the selected treatment technology, and its ability to meet the requirements of QCVN 14:2025/BTNMT. Calculations show that the influent pollutant load is approximately 687.5 kg BOD₅/day, 1,237.5 kg COD/day, and 825 kg TSS/day. With a combined treatment technology including oil and grease separation, equalization, anaerobic and aerobic biological treatment, biological sedimentation, pressure filtration, and disinfection, the expected treatment efficiency is approximately 94% for BOD₅, 91% for COD, and 97% for TSS. The expected effluent concentrations are 15 mg/L BOD₅, 40 mg/L COD, and 9 mg/L TSS, meeting the requirements of current environmental standards. The research results show that the selected technology is suitable for the operating conditions of a large-scale coastal tourist area, contributing to minimizing environmental pollution and promoting sustainable tourism development. In addition to meeting environmental discharge standards, the proposed system offers opportunities for treated wastewater reuse and supports the implementation of circular economy principles in the tourism sector.

Keywords: domestic wastewater, wastewater treatment, circular economy, Khanh Hoa Province.

1. PROBLEM STATEMENT

Over the past 15 years, the global tourism industry has maintained a strong growth trend, except for the downturn caused by the COVID-19 pandemic (2020–2021). According to UN Tourism data, the number of international tourists worldwide increased from approximately 952 million in 2010 to 1.46 billion in 2019, equivalent to an average growth rate of about 4.9% per year. After the pandemic, the tourism industry recovered quickly with approximately 1.3 billion tourists in 2023 and reaching 1.4 billion in 2024, equivalent to 99–100% of pre-pandemic levels.

Table 1. Global international tourist arrivals.

Year	International visitors (billion)
2010	0.95
2015	1.19
2019	1.46
2020	0.40
2021	0.43
2022	0.96
2023	1.30
2024	1.40

During the period 2010–2024, Vietnam's tourism industry experienced strong growth in both scale and visitor numbers. The total number of tourists (including international and domestic visitors) increased from approximately 33 million in 2010 to approximately 127.6 million in 2024, a nearly 3.9-fold increase. Of this, international tourists increased from 5 million to 17.6 million, while domestic tourists increased from approximately 28 million to 110 million. Total tourism revenue in 2024 is projected to reach approximately 840 trillion VND. The rapid increase in tourism activities, especially in coastal tourist areas, has led to a significant increase in the amount of wastewater generated. This necessitates urgent investment in and efficient operation of wastewater treatment systems to protect the environment, maintain the quality of tourism resources, and promote sustainable development.

Table 2. Tourists arrivals in Vietnam during 2010–2024.

Unit: Million tourists

Year	International visitors	Domestic tourists	Total number of tourists
2010	5.0	28.0	33.0
2015	7.9	57.0	64.9
2019	18.0	85.0	103.0
2020	3.8	56.0	59.8
2021	0.16	40.0	40.2
2022	3.66	101.3	105.0
2023	12.6	108.0	120.6
2024	17.6	110.0	127.6

Vietnam boasts over 3,260 km of coastline along with a rich system of islands, bays, and beaches, creating favorable conditions for the development of marine tourism. In recent years, marine tourism has become one of the key drivers of growth for Vietnam's tourism industry, contributing a large proportion to the total national tourism revenue. According to the Vietnam Tourism Development Strategy to 2030, marine and island tourism is identified as one of the main product lines, focusing on development in coastal localities with potential

such as Quang Ninh, Hai Phong, Da Nang, Khanh Hoa, Binh Thuan, Ba Ria - Vung Tau, and Kien Giang.

Along with the strong growth of the tourism industry, the total number of tourists in Vietnam increased from approximately 33 million in 2010 to approximately 127.6 million in 2024, a nearly 3.9-fold increase. Of this total, domestic tourists accounted for about 110 million and international tourists about 17.6 million in 2024. This rapid increase in tourist numbers has spurred investment in the construction of high-end resorts, tourist urban areas, and coastal service complexes nationwide.

Khanh Hoa is one of Vietnam's leading coastal tourism centers, boasting numerous famous scenic spots such as Nha Trang Bay, Van Phong Bay, Cam Ranh Peninsula, Doc Let Beach, and a system of coastal islands with high value in terms of landscape and biodiversity. In recent years, Khanh Hoa province has continuously attracted large-scale tourism investment projects to effectively exploit its marine economic potential and meet the growing demand of domestic and international tourists.

One of the key investment projects in the northern part of Khanh Hoa province is the Doc Let – Phuong Mai tourist area. The project is planned on an area of approximately 159.83 hectares in Dong Ninh Hoa ward, possessing advantages in geographical location, natural beach scenery, and connectivity to the Van Phong economic zone. Once operational, the project will form a large-scale coastal resort, commercial, and service complex, contributing to the socio-economic development of the locality and enhancing the tourism competitiveness of Khanh Hoa province.



Fig. 1. Location of Doc Let tourist area .

(Source: Google map)

However, alongside the socio-economic benefits, tourism activities also significantly increase the amount of domestic wastewater generated from accommodation facilities, restaurants, entertainment areas, and ancillary services. Domestic wastewater from tourist areas often contains high levels of organic matter, suspended solids, animal and vegetable oils and fats, nitrogen and phosphorus compounds, and pathogenic microorganisms. If not collected and treated to meet standards before being discharged into the environment, it will degrade water quality, affect coastal ecosystems, tourist landscapes, and public health.

To meet the requirements of environmental protection and sustainable tourism development, the Doc Let – Phuong Mai tourist area project has invested in a centralized wastewater treatment system with a total capacity of 2,750 m³/day. Evaluating the treatment efficiency of the system is crucial in selecting appropriate technology, optimizing treatment effectiveness, ensuring that treated wastewater meets the requirements of QCVN 14:2025/BTNMT, and contributing to the protection of the coastal marine environment in the Doc Let area, aiming towards the goal of green and sustainable tourism development in Khanh Hoa province.

The study was conducted to evaluate the treatment capacity of the centralized wastewater treatment system at the project, the quality of the effluent, and to compare it with the requirements of current environmental standards.

2. RESEARCH METHODOLOGY

2.1. Data collection and compilation

This study was conducted based on the collection, synthesis, and analysis of documents and data related to the Doc Let – Phuong Mai tourist area project in Khanh Hoa province. The main sources of information include: the basic design documents of the centralized wastewater treatment system; the project's environmental impact assessment report; current technical regulations and standards on drainage and wastewater treatment; and specialized domestic and international literature related to wastewater treatment technology in coastal tourist and resort areas.

The information collected included the project scale, the design capacity of the wastewater treatment system, the characteristics of the wastewater source, the composition and concentration of characteristic pollutants, the treatment process, the design parameters of the individual treatment units, and the required effluent quality. Simultaneously, scientific studies, technical guidelines from APHA, Metcalf & Eddy, Tchobanoglous, and domestic publications on domestic wastewater treatment were also consulted to provide a basis for evaluating the system's treatment efficiency.

After collection, the data are checked, compared, and compiled into data tables to be used for calculating pollution load, evaluating treatment efficiency, and assessing the quality of treated wastewater.

2.2. Methods for calculating pollution load

The pollutant load generated in wastewater is determined to assess the scale of pollution and the treatment capacity of the system. The calculation is performed using the material balance method commonly applied in environmental engineering.

Pollution load is determined by the following formula:

$$L = Q \times C / 1000$$

Where:

- L: Pollutant load (kg/day);
- Q: Wastewater flow rate (m³/day);
- C: Concentration of pollutants in wastewater (mg/l).

The pollution parameters calculated include BOD₅, COD, TSS, total Nitrogen, total Phosphorus, and animal and vegetable oils and fats. The calculated input load serves as the basis for determining the level of pollution generated and evaluating the amount of pollutants removed through the treatment system.

In addition, the treated pollutant load is calculated similarly to determine the amount of pollutants remaining in the wastewater before discharge into the receiving environment.

2.3. Methods for evaluating processing performance

The system's treatment efficiency is evaluated based on the operating principles of each unit in the technological process, including the grease trap, equalization tank, anoxic tank, aerobic tank, biological settling tank, pressure filtration system, and disinfection stage.

The treatment efficiency for each pollutant parameter is determined by the following formula:

$$H = (C_{in} - C_{out}) / C_{in} \times 100$$

where:

- H: Processing efficiency (%);
- C_{in} : Concentration of influent (mg/L);
- Output concentration: Concentration of pollutant in the effluent (mg/L).

Based on characteristic treatment performance values, the concentrations of pollutants after treatment are used to assess the ability to meet the requirements of current environmental standards.

2.4. Comparison and Evaluation Method

The quality of treated wastewater is compared with the limit values stipulated in QCVN 14:2025/BTNMT – National technical standard on domestic wastewater and wastewater from urban and concentrated residential areas, in order to assess the ability of the wastewater treatment system to meet environmental protection requirements.

In addition, the quality of the project's wastewater effluent is compared with studies and actual operational data from several coastal tourist areas and resorts in Vietnam with similar scale and treatment technologies. This comparison aims to assess the suitability of the chosen technology, the stable operation of the system, and the expected treatment efficiency under real-world conditions.

The results of the analysis and comparison serve as a basis for a comprehensive assessment of the treatment efficiency of the centralized wastewater treatment system at the Doc Let - Phuong Mai Tourist Area, and simultaneously propose solutions to improve operational efficiency and ensure sustainable tourism development associated with coastal environmental protection.

3. RESULTS AND DISCUSSION

3.1. Characteristics of wastewater sources

With an estimated 9,000 visitors per day from accommodation, restaurants, commercial service areas, entertainment areas, and public facilities in the tourist area, and 1,000 staff members, the average daily wastewater discharge is 2,720 m³. The wastewater composition is typical of domestic wastewater, with relatively high levels of organic matter and microorganisms.

Table 3. Characteristics of influent wastewater.

Parameter	Unit	Value
pH	-	6.5 – 8.0
BOD ₅	mg/L	250
COD	mg/L	450
TSS	mg/L	300
Total N	mg/L	40
Total P	mg/L	8
Grease	mg/L	35
Coliform	MPN/100mL	10 ⁷

Since the emission volume is 2,720 m³ / day, the treatment system is designed with a capacity of 2,750 m³/day, with the input pollution load determined as shown in the following table:

Table 4. Influx pollutant load.

Parameter	Load (kg/day)
BOD ₅	687.5
COD	1,237.5
TSS	825
Total N	110
Total P	22
Grease	96

3.2. Evaluation of processing technology

The domestic wastewater treatment system has a design capacity of 2,750 m³/day, applying Integrated Fixed-Film Activated Sludge (IFAS) technology to enhance the efficiency of removing organic pollutants and nutrients from wastewater. The technological process includes the following stages: wastewater collection, solid waste separation, oil and grease separation, flow and concentration equalization, biological treatment, sedimentation, pressure filtration, disinfection, and sludge treatment. Domestic wastewater from the sanitary and kitchen areas, after the removal of solid waste and oil and grease, is led into a balancing tank to stabilize the pollutant load before entering a biological treatment unit consisting of 2 anoxic compartments and 4 aerobic compartments. In the anaerobic compartments, denitrification takes place, while the aerobic compartments carry out the oxidation of organic matter and nitrification of ammonia. After biological treatment, the water is led through a secondary sedimentation tank, pressure filtration using AFM material to remove remaining suspended solids, and then disinfection with NaOCl before discharge into the receiving water source. Excess sludge is collected, dewatered, and transferred for treatment according to regulations; the effluent water quality meets QCVN 14:2025/BTNMT, column A.

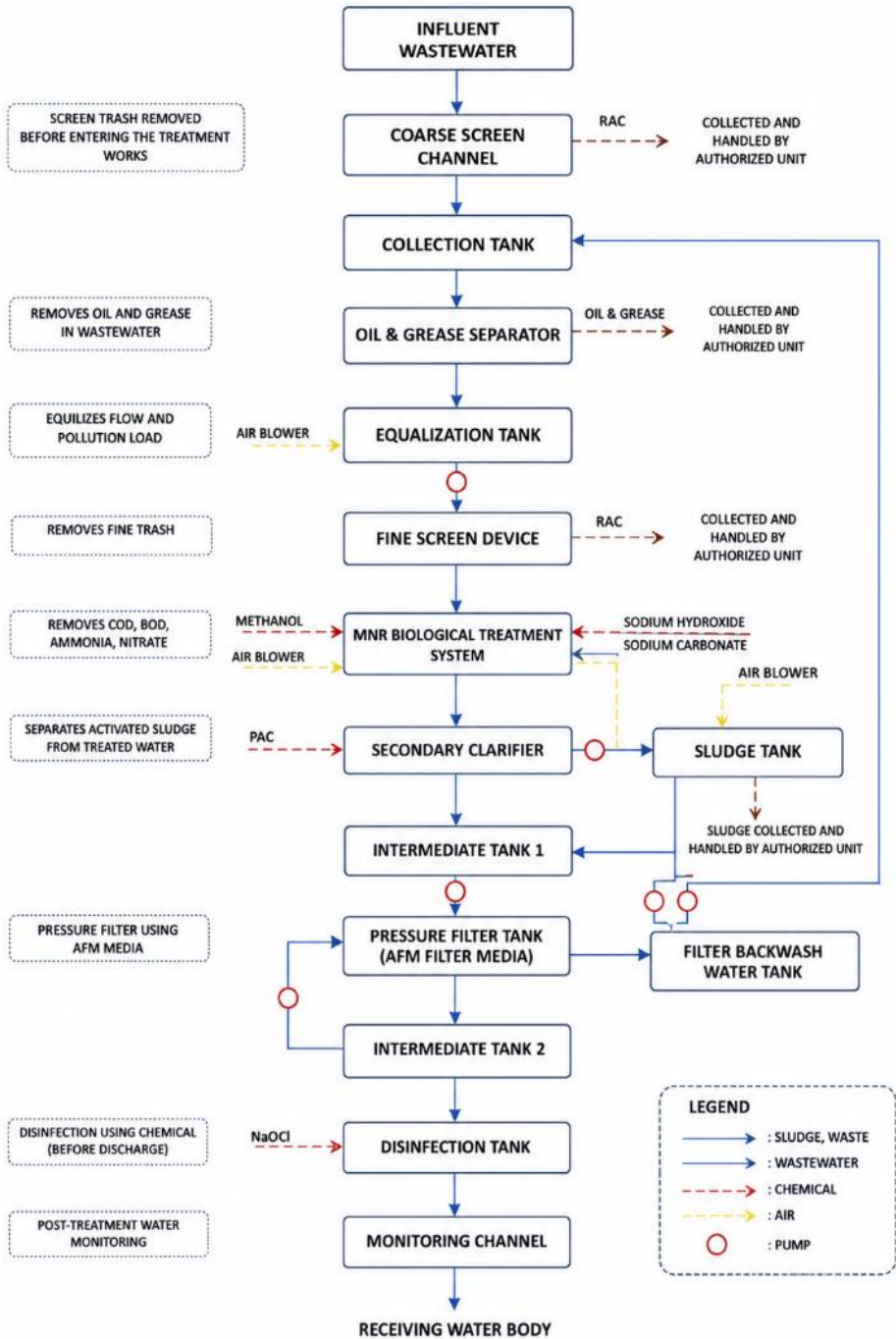


Fig. 2. Wastewater treatment system.

3.3. Treatment efficiency

The system's processing performance is presented in Table 5.

Table 5. Wastewater quality before and after treatment.

Parameter	Before processing	After processing	QCVN 14:2025/BTNMT
BOD ₅	250	15	30
COD	450	40	75
TSS	300	9	50
Total N	40	12	20
Total P	8	3	4
Grease	35	3	10

Treatment efficiency reached approximately 94% for BOD₅, 91% for COD, 97% for TSS, 70% for total nitrogen, and 62.5% for total phosphorus.

Comparison with QCVN 14:2025/BTNMT shows that all parameters are below the permissible limits, proving that the system is capable of meeting environmental protection requirements when put into operation.

Compared to some existing coastal tourist areas:

Table 6. Comparison of treatment efficiency of several areas in Vietnam.

Tourist area	BOD ₅ output	Output COD	TSS output
Doc Let – Phuong Mai	15	40	9
North Cam Ranh	18 – 22	45 – 60	12 – 18
Ho Tram	5 – 10	20 – 30	<5
Da Nang	20 – 30	50 – 70	15 – 25

The results show that the treatment efficiency of the proposed system is equivalent to or significantly better than the wastewater treatment systems currently in use at coastal resorts.

Compared to some tourist destinations around the world that have already implemented this:

Table 7. Advantages of some wastewater treatment technologies worldwide.

Technology	Area of application	Advantage
MBR (Membrane Bioreactor)	Singapore, Japan, UAE	High water quality, space-saving.
SBR	USA, Mexico, Thailand	Flexible to handle fluctuating traffic flow.
Traditional activated sludge	Europe, North Africa	Low investment cost
Constructed Wetland	Ecotourism area	Energy saving, environmentally friendly.
MBBR	Northern Europe, Australia	High organic load capacity, simple operation.

(Sources: Metcalf & Eddy (2014); UNEP (2021); APHA (2023))

In there:

- At Marina Bay Sands (Singapore): Wastewater treatment technology is applied, combining water reuse for irrigation, toilet flushing, and cooling systems. Condensate water from the air conditioning system is recovered and reused, saving approximately 77,000 liters of water per day.

- At Mazagan Beach & Golf Resort, activated sludge technology is used; the treated water is reused for landscaping and the golf course, reducing the exploitation of natural water resources.

3.4. Proposal

The treated wastewater from the Doc Let tourist area is within the limits of QCVN 14:2025/BTNMT. However, the treated wastewater is currently only discharged into the area's general drainage system and has not been considered for other uses. Therefore, the author proposes that the treated wastewater could be used for watering plants, washing roads, or supplying water to the landscape lake. This aligns well with current ESG (Environmental, Social and Governance) trends.

3.5. Discussion

The research results show that the centralized wastewater treatment system of the Doc Let – Phuong Mai Tourist Area is capable of effectively treating typical pollutants in domestic wastewater. With influent concentrations of approximately 250 mg/L BOD₅, 450 mg/L COD, and 300 mg/L TSS, the system is expected to achieve treatment efficiencies of 94%, 91%, and 97%, respectively. These values fall within the typical efficiency range of anaerobic-aerobic biological technology combined with biological sedimentation, as published in specialized literature on urban and tourism wastewater treatment.

Compared to wastewater treatment systems in some coastal tourist areas in Vietnam, the effluent water quality of Doc Let – Phuong Mai is considered good. The expected effluent BOD₅ concentration is only about 15 mg/L, lower than many coastal resorts in North Cam Ranh and Da Nang. This indicates that the chosen technology is suitable for the characteristics of the effluent source and the scale of the project. However, the results are still lower than some MBR membrane technology systems in high-end resorts, where effluent BOD₅ can be maintained below 10 mg/L.

Overall, the research results show that the centralized wastewater treatment system of the Doc Let – Phuong Mai Tourist Area is capable of meeting the environmental protection requirements according to QCVN 14:2025/BTNMT. The chosen technology is suitable for the conditions of a large-scale coastal tourist area, and also provides a foundation for the development of water reuse solutions and environmental management in the direction of a circular economy in the future.

CONCLUSION

The study demonstrates that IFAS-based biological treatment is a suitable solution for large-scale coastal tourism developments in Vietnam. The proposed system not only complies with QCVN 14:2025/BTNMT but also provides opportunities for water reuse and circular economy implementation in the tourism sector.

This study evaluated the expected treatment efficiency of the centralized wastewater treatment system at the Doc Let – Phuong Mai Tourist Area Project, with a total capacity of 2,750 m³/day. The selected treatment technology is capable of effectively removing organic pollutants, suspended solids, and nutrients from domestic wastewater.

Calculations show that the concentrations of treated wastewater reached approximately 15 mg/L BOD₅, 40 mg/L COD, and 9 mg/L TSS, meeting the requirements of QCVN 14:2025/BTNMT. The total pollutant load removed reached approximately 646 kg BOD₅/day, 1,128 kg COD/day, and 800 kg TSS/day.

The wastewater treatment system is deemed suitable for the characteristics of wastewater from large-scale coastal tourist areas, contributing to minimizing the risk of water pollution, protecting coastal ecosystems, and aiming for sustainable tourism development in Khanh Hoa province.

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