

# **ABSTRACT OF DOCTORAL DISSERTATION IN ENGINEERING**

## **I. Information**

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4. Thesis Title: *Development of an integrated Water Stress Index (WSI)–Life Cycle Assessment (LCA) model for supporting the sustainable management of the water supply system in Da Nang City.*
5. Training Institution: University of Science and Technology - The University of Da Nang

## **II. Dissertation Summary**

### **1. Research Rationale**

Water is an essential resource that underpins life, production, and socio-economic development. However, increasing global population, rapid urbanization, and the impacts of climate change have significantly intensified water demand, leading to growing risks of water insecurity. This has become one of the most critical challenges of the 21st century. The United Nations has emphasized the importance of water through Sustainable Development Goal 6 (SDG 6), which aims to ensure the availability and sustainable management of water and sanitation for all by 2030. According to the UNESCO World Water Development Report (2023), global water demand is projected to increase by approximately 1% per year, resulting in a total increase of 20–30% by 2050. Meanwhile, climate change is profoundly altering the hydrological cycle, causing spatial and temporal imbalances in water availability and accessibility. Therefore, developing scientific and adaptive models for water resource assessment and management is an urgent requirement for sustainable development.

In Vietnam, coastal cities such as Da Nang are facing increasing challenges related to saltwater intrusion due to reduced dry-season flows and sea level rise. These impacts not only threaten raw water supply but also increase operational risks and costs in water supply systems, while imposing additional environmental pressures. At the same time, rising water demand driven by urbanization and economic recovery further exacerbates the imbalance between supply and demand. Water supply processes—from abstraction, treatment, and distribution to consumption and discharge—require energy, chemicals, and natural resources, and generate environmental impacts at multiple stages.

Life Cycle Assessment (LCA) has been widely recognized as an effective tool for quantifying environmental impacts throughout the entire lifecycle of water systems. In parallel, the Water Stress Index (WSI) has been highlighted in international studies as a useful indicator for assessing the extent to which water abstraction exceeds local ecological thresholds. However, in Vietnam, the application of LCA in the water sector remains limited and largely relies on generic international emission factors, lacking localization to reflect specific conditions such as saltwater intrusion and hydrological variability in central river basins. Moreover, there is currently no integrated quantitative framework capable of simultaneously assessing water resource stress at the source and environmental impacts along the treatment chain to support planning and decision-making.

To achieve a comprehensive understanding of urban water supply systems, it is essential to integrate methodologies that can evaluate both the impacts of raw water abstraction and the environmental burdens associated with treatment processes. The need to develop a safe, sustainable, and climate-resilient water supply system with reduced greenhouse gas emissions is becoming increasingly urgent, particularly under conditions of growing water scarcity. Therefore, the development of an integrated WSI–LCA model for urban water supply systems is of strategic importance.

Based on this context, the doctoral dissertation entitled “*Development of an integrated Water Stress Index (WSI)–Life Cycle Assessment (LCA) model for supporting the sustainable management of the water supply system in Da Nang City*” aims to address existing research gaps and contribute a novel methodological framework for sustainable urban water management. This integrated model provides a comprehensive perspective on environmental impacts while offering a scientific basis for selecting optimal water supply scenarios toward environmentally friendly, safe, and sustainable systems.

## **2. Research Objectives**

The main objective of this study is to develop and validate an integrated model combining the Water Stress Index (WSI) and Life Cycle Assessment (LCA) to comprehensively evaluate both environmental impacts and water scarcity associated with raw water abstraction and drinking water production in urban water supply systems.

The results of the study provide a scientific basis for optimizing water supply scenarios under climate change conditions.

## **3. Research Objects and Scope**

Research objects: The study focuses on the Water Stress Index (WSI), Life Cycle Assessment (LCA), and the processes of raw water abstraction, conveyance, and

drinking water production. The case study is conducted at Cau Do Water Treatment Plant, the largest plant in Central Vietnam, which is significantly affected by saltwater intrusion and dry-season flow variability.

Research scope:

- Spatial scope: The study focuses on raw water abstraction, conveyance, and treatment processes at Cau Do Water Treatment Plant.

- Temporal scope: Hydrological data are collected from monitoring stations in the Vu Gia – Thu Bon river basin for the period 1980–2023. WSI is calculated based on dry-season average conditions. Operational data of the water treatment plant are collected over 365 days in 2023. Water supply scenarios are developed for 2030 and vision to 2045 under the RCP 8.5 climate change scenario.

- Content scope: Limiting the system boundary to raw water abstraction, conveyance, and treatment allows for a focused analysis of material and energy flows that are critical in life cycle assessment, while directly capturing the relationship between water resource stress and environmental emissions. The results provide a solid scientific basis for optimizing upstream processes, with future studies potentially expanding to the entire urban water cycle.

Data for scenario development are based on the Da Nang Water Supply Master Plan to 2030 with a vision to 2050 and its updated version approved in 2025.

#### **4. Research Contents**

The research is structured into the following main components:

- Development of an integrated WSI–LCA model for assessing water scarcity and environmental impacts in urban water supply systems.

- Application of the model to evaluate the current status of water supply in Da Nang.

- Development of water supply scenarios for Da Nang up to 2045 under climate change and saltwater intrusion conditions.

- Application of the integrated model to compare scenarios and identify optimal solutions that balance water security and environmental performance.

#### **5. Research Methods**

The study employs a combination of methods, including literature review and secondary data collection, field surveys, experimental design, laboratory analysis, data processing and modeling, evaluation methods, forecasting, and expert consultation. The integrated WSI–LCA modeling approach serves as the core methodology, linking hydrological modeling with life cycle assessment tools.

#### **6. Dissertation Structure**

- Introduction

- Chapter 1: Literature Review
- Chapter 2: Research Objects and Methodology
- Chapter 3: Development and Validation of the Integrated WSI–LCA Model
- Chapter 4: Evaluation of Water Supply Scenarios in Da Nang Using the Integrated Model
- Conclusion and Recommendation

## **7. Research results and publications**

### **- Research results:**

The dissertation successfully established an integrated model combining the Water Stress Index (WSI) with the Life Cycle Assessment (LCA) framework, in which the WSI serves to characterize spatiotemporal water stress levels. The novel contribution of this model lies in its ability to bridge hydrological data with Life Cycle Inventory (LCI) data, enabling the simultaneous quantification of local water resource pressure and global environmental impacts. Validation results demonstrate high model reliability, scientific rigor, and reproducibility, facilitating its application to urban water supply systems with similar watershed characteristics.

### **Key Findings and Environmental Impacts**

- Through this integrated model, the study quantified two critical dimensions of the Da Nang water supply system: the degree of water source stress and the environmental impacts arising from raw water extraction and treatment processes.

- Environmental "Hotspots": Results indicate that environmental impacts are primarily concentrated in the operational phase, driven by electricity consumption at raw water pumping stations (notably the An Trach dam) and the use of treatment chemicals.

- Carbon Footprint: Emissions from electricity consumption contribute over 90% of the total carbon footprint of the water treatment plants (WTP).

- Efficiency Gains: By implementing energy and chemical efficiency measures in new production lines, emission indices can be reduced by 11–13% compared to legacy systems.

- The research also identifies significant seasonal fluctuations in water stress at the intake point (Cau Do WTP), highlighting the trade-off between ensuring water security and increasing environmental burdens.

In May—the peak of the dry season, characterized by severe saltwater intrusion and intensified extraction at the An Trach dam—greenhouse gas (GHG) emissions are nearly 70% higher than in December (the rainy season).

During the dry season (March to August), the WSI at the Cau Do plant reaches a high level of 1,035. Consequently, every 1 m<sup>3</sup> of clean water produced during this period generates an environmental impact equivalent to the consumption of 1,17 m<sup>3</sup> of water under scarcity conditions, defined as the Water Scarcity Footprint (WSF).

## **Scenario Simulation and Strategic Recommendations**

The dissertation simulated and conducted a comparative analysis of five water supply scenarios for Da Nang City toward the 2045 horizon. The findings demonstrate that:

- **Optimal Strategy:** The scenario involving a structural shift of water sources upstream (at the An Trach dam) is the most sustainable and optimal solution. It effectively minimizes the WSI while maintaining control over carbon emissions and energy consumption.

- **Resource Relief:** Compared to the baseline scenario, infrastructure expansion at the An Trach dam resolves the water scarcity issue during the dry season at the Cau Do intake point, reducing the resource burden by 78%.

- **The Emissions Balance:** Notably, this effort to alleviate source pressure does not exacerbate carbon emissions; the emission index for Scenario 4 (S4) reached 0.207 kg CO<sub>2</sub> eq, which is lower than the baseline (S1).

- **The Desalination Trade-off:** Conversely, while Reverse Osmosis (RO) technology addresses water security (reducing WSI by over 40%), it imposes a massive environmental burden due to high energy intensity, resulting in carbon emissions 2,7 times higher than the baseline.

These results provide a robust scientific foundation to support municipal authorities in selecting water supply strategies that are resilient to climate change and saltwater intrusion.

### **Publications related to the dissertation:**

- 03 papers published in proceedings of international conferences indexed in Scopus.
- 03 papers published in reputable national journals.

## **8. Scientific Contributions of the Dissertation**

This dissertation proposes a novel methodological approach for the life cycle assessment of urban water supply systems by integrating the Water Stress Index (WSI) into the Life Cycle Assessment (LCA) framework. This integration enables the simultaneous evaluation of environmental impacts and water resource stress under specific geographical and socio-economic conditions at the local scale.

- For the first time, the dissertation develops and validates an integrated WSI–LCA model specifically designed for urban water supply systems under conditions of water resource variability and saltwater intrusion. This approach demonstrates a high level of generalizability and can be extended to other urban areas in Vietnam.

- The integrated WSI–LCA model is applied to evaluate and compare water supply scenarios for the period 2030–2045, thereby identifying optimal solutions in terms of environmental performance and water security under climate change conditions.

*Da Nang, date...../...../2026*

**Supervisors**

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