OCCASIONAL PAPER

The role of mangroves in supporting ports and the shipping industry to reduce emissions and water pollution

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CIFOR

Occasional Paper 231

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Occasional Paper 231

ISBN: 978-9966-108-67-8
DOI: 10.17528/cifor/008493

Pham HT, Ngo VT, Pham TT, Bui TT, and Nguyen TLG. 2022. *The role of mangroves in supporting ports and the shipping industry to reduce emissions and water pollution*. Occasional Paper 231. Bogor, Indonesia: CIFOR.

Translation of: Phạm HT, Ngô VT, Phạm TT, Bùi TT và Nguyễn TLG. 2022. *Đóng góp của rừng ngập mặn trong việc hỗ trợ giảm phát thải và ô nhiễm từ hoạt động cảng biển*. Báo cáo chuyên đề 230. Bogor, Indonesia: CIFOR.

SWAMP Project
Photo by Mokhamad Edliadi/CIFOR

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We would like to thank all donors who supported this research through their contributions to the CGIAR Fund. For a list of Fund donors please see: http://www.cgiar.org/about-us/our-funders/

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Acknowledgements

This research is funded by the United States Agency for International Development (USAID) through the Sustainable Wetlands Adaptation and Mitigation Program (SWAMP).

Executive summary

The maritime industry plays an important role in socioeconomic development, as well as in cultural and commercial exchanges at both domestic and international levels. However, increasingly greenhouse gas (GHG) emissions and environmental pollution related to maritime operations are becoming a global issue. At COP26, establishment of initiatives like zero-emission maritime routes and zero emission shipping have been supported by many countries, including the United Kingdom, the United States, Canada and Australia, through declarations like the Clydebank Declaration for Green Shipping Corridors and Declaration on Zero Emission Shipping.

One of the most important and sustainable solutions in reducing the environmental impact of maritime operations is the conservation and development of natural ecosystems, to ensure that their inherent ecosystem services – like regulating and supporting services – remain stable and can thus contribute to the absorption of environmental pollution. Mangrove ecosystems, distributed mainly in coastal estuaries and close to seaports, are known for their many important ecosystem services, including GHG absorption and improvement of environmental quality. However, such services are not widely known in the maritime industry, and have not been incorporated into current policy. This is an obstacle when it comes to identifying appropriate stakeholders and potential financial mechanisms to contribute towards the environmental services provided by mangroves.

This document provides strong scientific evidence on the role of mangroves in absorbing GHGs and improving water quality through analysis of monitoring data relating to the water environment in Saigon River (Ho Chi Minh City), greenhouse gas emissions from Ho Chi Minh City seaports, and GHG sequestration in Can Gio mangrove forest (Ho Chi Minh City). This document presents, for the first time, comparative results of water quality indices for 2010–2020, at monitoring points in different areas including metropolitan, seaport, mangrove forest and open coast. A correlation between carbon emissions from seaports, and the amount of carbon absorbed by mangroves in Ho Chi Minh City, was also analysed for the first time. Our findings confirmed that mangroves can support the maritime industry to reduce GHG emissions and protect the environment. This document can assist policymakers to identify those who can financially contribute towards the environmental services that mangroves provide, enabling the effective implementation of policy around payment for forest environmental services. This document also offers guidance on further specific studies, in other areas of the country, in order to build a complete database of the ecosystem services provided by mangroves in Vietnam.

1 Introduction

The expansion of seaports and maritime activities play an important role in socioeconomic development. Seaports are considered a gateway to the world, promoting cultural and commercial exchanges between countries (Catianis et al. 2016) through activities like the transportation of passengers and the shipment of containers as well as solid and liquid bulk cargo (Walker et al. 2019). However, such operations also lead to environmental pollution through waste released and accumulated in both air and water, including sediment and noise (Gómez et al. 2015; Darbra et al. 2005; Barberi et al. 2021; European et al. 2021). It has also been reported that marine transportation-related emissions could increase global GHGs from 2–3% to 17% by 2050, if no mitigation actions are taken (Lükewille 2018). Reducing GHG emissions from this sector is essential to meet global and national climate change mitigation targets, and is considered one of the global outcomes of COP26. Under the Clydebank Declaration for Green Shipping Corridors (The UK 2021), 22 countries, including the United Kingdom, United States, Canada and Australia, have committed to support the establishment of zero-emission maritime routes between two (or more) ports – referred to as green shipping corridors – aiming to set at least six of these corridors by 2025, and gradually increase them by 2030 (Safety4sea 2021).

In this Clydebank Declaration, countries committed to "identify and explore actions to address barriers to the formation of green corridors. This could cover, for example, regulatory frameworks, incentives, information sharing or infrastructure and work to ensure that wider consideration is taken for environmental impacts and sustainability when pursuing green shipping corridors". The Declaration on Zero Emission Shipping by 2050 (Ministry of Industry Business and Financial Affairs 2021), signed by 14 countries, also highlights increasing efforts by global companies who are actively searching for environmental solutions to reduce the sector's emissions.

Vietnam is a country with a large sea area and a long coastline, with many straits and deep bays. In close proximity to bustling trading routes throughout the East Sea, Vietnam spans an island system of 3,000 coastal islands that 'shield' most of the inshore marine areas and coastal areas. Vietnam has 36 seaports, including hundreds of terminals distributed along its coast. It has set a target by 2030 and a vision until 2050 to develop a modern seaport network that meets green port criteria, fully and effectively meeting the country's socioeconomic development needs, while also acting as driving force for the development of the maritime economy (Vietnam Maritime Administration 2021a). However, along with the development and operation of seaports, waste generated from business activities, seaport and shipping operations, equipment to support shipping operations, dredging activities, the maintenance of navigational channels, anchoring areas for transhipment and areas to shelter from storms, also cause serious pollution challenges both in the air (emissions of GHGs like SO_2, CO_2, CO), and water (suspended and fatty pollutants), resulting also in erosion, accretion and deterioration of coastal ecosystems (Mai and Anh 2021). As such, the primary suggestion proposed for seaports at the present time, is to prevent and minimize environmental pollution by building 'green' seaports which can harmonize environmental protection with socioeconomic development objectives.

There are two key aspects involved in achieving this goal:

- Preventing and controlling seaport pollution, through technical solutions and improving the system for specialized agencies on seaport environmental management and regulation;
- Conserving and developing natural ecosystems in seaport areas, so their inherent ecosystem services remain stable and can absorb seaport-derived environmental pollution.

One of the typical ecosystems in question is mangroves, which have the ability to absorb GHGs and store pollutants in their plants (Dunbabin and Bowmer 1992; Wood and Shelley 1999; Yu et al. 2001; Thanh-Nho et al. 2019; Hong Tinh et al. 2020; Pham et al. 2021). Thanh-Nho et al. (2020) also highlight that mangrove ecosystems are significant in terms of depositing, absorbing, storing and self-metabolizing pollutants released from residential areas, industrial parks and ports, contributing to cleaning source water before it flows into the sea. Other studies like Dung et al. (2016), Taillardat et al. (2018), Pham et al. (2019) support this, flagging mangroves' potential to reduce emissions in southern Vietnam.

While previous studies have highlighted that seaport development and operations are one of the primary causes of environmental pollution, and that natural ecosystems like mangroves have the ability to absorb pollutants and purify the aquatic environment through photosynthesis and the metabolism of mangrove trees, little evidence and analysis are available to confirm mangrove's potential role in supporting seaport and marine activities to address both air and water pollution. Due to a lack of evidence on this potentially important role, the Vietnam Forest Protection and Development Fund is unable to build a business case for its 'Payment for Mangrove Forest Environmental Service' scheme which is listed as a national priority for 2021–2030, and in the country's vision until 2050.

Using Can Gio mangrove forest and Ho Chi Minh City as a case study, this paper aims to address this knowledge gap by answering two research questions:

1. *How many emissions are caused by the ports in Ho Chi Minh City, and what is the potential carbon sequestration that mangroves in Ho Chi Minh can offer to the port and shipping sector in offsetting their emissions?*
2. *Can mangroves help to address water pollution in the port areas?*

The study aims to provide important data on the environmental services provided by mangroves, namely carbon sequestration and the cleaning of seaport-related environmental pollution in water, so as to support future policy design regarding payments for mangrove environmental services in Vietnam.

2 Study site and methods

2.1 Study site

The study was conducted in the seaport area of Ho Chi Minh City and Can Gio mangrove forest (Figure 1). Ho Chi Minh City seaport includes 42 terminals distributed along Saigon River (specifically the section flowing through the districts of Nha Be and Can Gio, about 15–30 km south of Ho Chi Minh city centre). We focus on this area as it is one of the major seaports

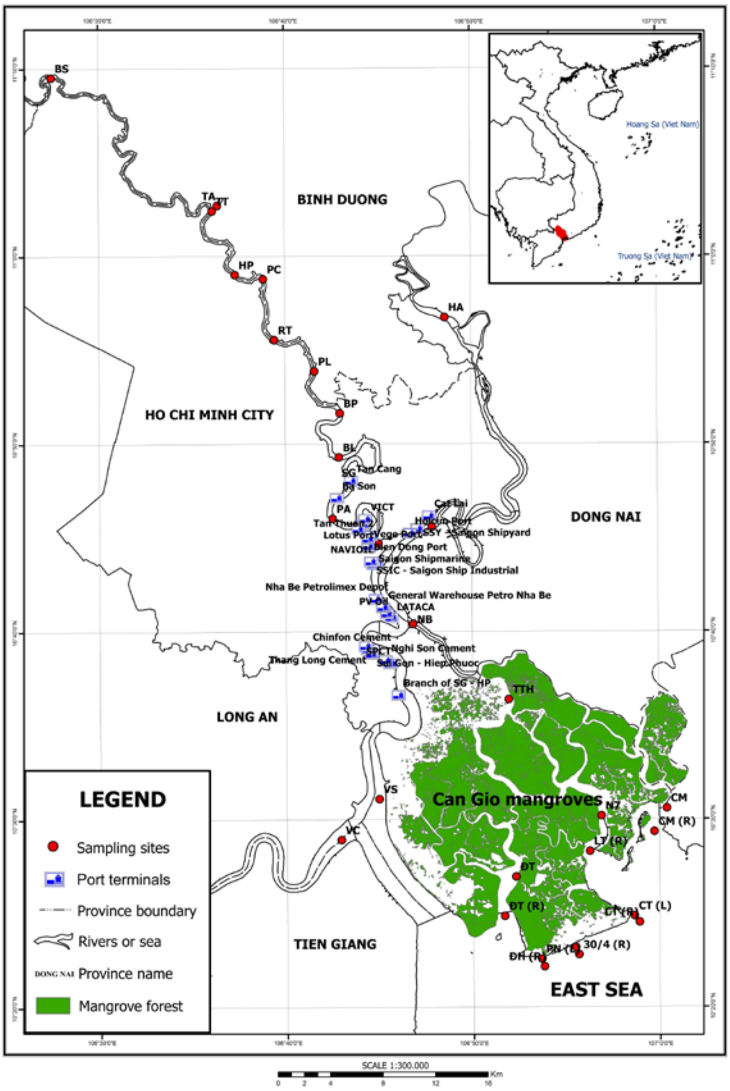

Figure 1. Map of the study site

Source: Author analysis

in Vietnam, with the cargo volume accounting for over 20% of the total shipped through all of Vietnam's seaports (Vietnam Maritime Administration 2021c).

Ho Chi Minh is also home to the Can Gio Bio Reserve, 40 km southeast of the city centre, which in 2000 was recognized by UNESCO as the first World Biosphere Reserve in Vietnam. The reserve spans a total area of 75,740 ha (with a core zone of 4,721 ha, a buffer zone of 41,139 ha and a transition zone of 29,880 ha); this includes 35,000 ha of mangroves with three dominant mangrove species *Avicenia alba, Rhizophora apiculata* and *Phoenix paludosa* (Nam and Sinh 2014). Can Gio mangrove forest plays an essential role in environmental protection for Ho Chi Minh City and its neighbouring provinces, through absorbing and storing carbon dioxide, releasing oxygen and reducing GHG, as well as providing valuable aquatic products, conserving biodiversity and supporting ecotourism (Hoan et al. 2021).

2.2 Data collection, analysis and processing methods

2.2.1 Data collection

Initially secondary data from published reports and statistical data was synthesized, before a spatial analysis method (using ArcGIS) was applied to conduct a comparative assessment of environmental quality in mangroves and areas with and without seaport development.

Monitoring data was collected from the Department of Natural Resources and Environment of Ho Chi Minh City, on the water quality of Saigon River (Ho Chi Minh City) between 2011 and 2020. Data came from 36 monitoring stations (Figure 1), including 8 stations located in the section running through the city centre, 9 stations in the seaport area, 6 stations located in mangrove areas and 9 stations in coastal areas. Monitoring parameters included pH, Total Suspened Solids (TSS), Salinity, Ammonium, Phosphate, Chemical Oxygen Demand (COD), Dissovled Oxygen (DO), Biological Oxygen Demand (BOD_5), Oil, Coliform, *E. coli*, Turbidity, Mn, Fe, Pb, Cd, Hg and Cu concentrations.

Data on GHG emissions from seaport activities were taken from a report calculating GHG emissions from seaport terminals in Ho Chi Minh City, under a project to support the planning and implementation of actions on GHG emission mitigation (Japan International Cooperation Agency 2019). Data on GHG absorption was compiled from a scientific report relating to the project entitled 'Research on the impacts of climate change on the carbon storage capacity of natural mangrove ecosystems in Can Gio and proposed adaptive solutions', led by the Vietnam-Russia Tropical Centre (Thinh 2020).

2.2.2 Data analysis and processing

Method used to calculate water quality assessment parameters

This study used Vietnam water quality index (VN_WQI) (Vietnam Environment Administration 2019) to assess the water quality of the study site. The advantage of this index is that it quantifies water quality through parameters like pH, total organic carbon (TOC), dissolved oxygen (DO), total NH_4^+, total Nitogen (TN), total Phosphorous (TP), as well as concentration of dissolved metal ions, pesticide components and microbiological factors. This index has been used by governments and scientists around the world and in Vietnam (Thanh-Nho et al. 2020).

In this study, the VN_WQI was calculated under the guidance of Vietnam Environment Administration (2019). VN_WQI was calculated separately for each monitoring station, using monitoring data associated with five groups of parameters:

- Group 1. pH parameter
- Group 2. Monitoring parameters of pesticides like Aldrin, BHC, Dieldrin, DDTs (p,p'-DDT, p,p'-DDD, p,p'-DDE), Heptachlor and Heptachlorepoxide
- Group 3. Monitoring parameters of heavy metals like As, Cd, Pb, Cr^{6+}, Cu, Zn, Hg
- Group 4. Monitoring parameters of organic matters and nutrients like DO, BOD_5, COD, TOC, N-NH_4^+, N-NO_3^-, N-NO_2^-, P-PO_4^{3-}
- Group 5. Monitoring parameters of micro-organisms like Coliform, *E. coli*

Table 1. Classification of VN_WQI and water quality

VN_WQI range	Water quality	Suitable usage
91–100	Very good	Domestic water supply
76–90	Good	Domestic water supply after adequate treatment
51–75	Medium	Irrigation
26–50	Poor	Water transport
10–25	Heavily polluted	Heavily polluted, needs treatment for future use
< 10	Very heavily polluted	Poisoned, needs treatment

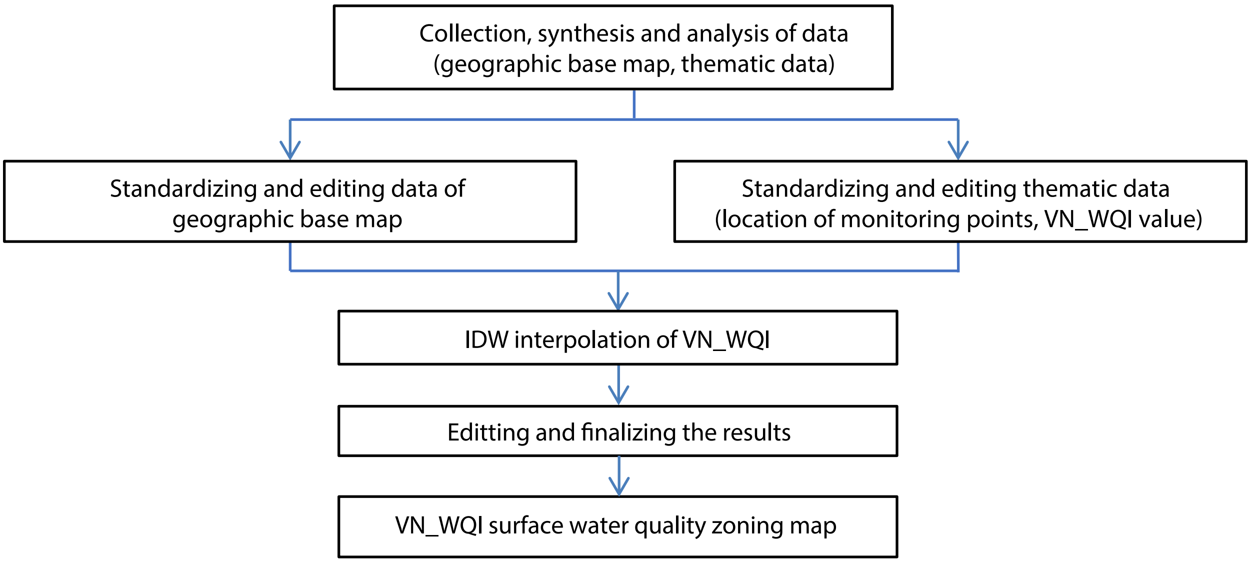

Figure 2. Process of building a VN_WQI – based water quality zoning map

To calculate VN_WQI, data needed to include a minimum of three of the parameter groups above. Group 4 was essential for inclusion in the calculation, and had to cover a minimum of three parameters for calculation. VN_WQI values were classified into six categories, as described in Table 1.

Statistical analysis method

Analysis of variance (ANOVA, T-test (Student Test)) was used to compare and access the average VN_WQI index at different monitoring locations (i.e., in the city centre, port, mangrove and coastal areas) along Saigon River. Calculation and comparison of VN_WQI in different locations helped to assess the quality of surface water at inflow locations where there were pollution sources, mangrove forests and no mangrove forests, and in locations where water flows into the sea. This meant the quality of surface water could be assessed before entering the mangrove forest and after flowing through the mangrove forest, helping us to answer the question: Can mangroves help to improve water quality and air quality in port areas?

Interpolation method and mapping

This study built a water quality zoning map showing an overview of water quality according to the average VN_WQI in the study period for each river section, based on interpolation from calculated VN_WQI data for each monitoring station. The process of making a water quality zoning map according to VN_WQI indices is summarized in Figure 2.

Data used to create a water quality zoning map using VN_WQI indices consisted of two groups of data layers: (i) data for the geographic base map, and (ii) thematic data.

Geographic base map data

The geographic base map data used in the study were extracted and edited from the national geographic base map, including information layers on the administrative boundaries of provinces, water bodies and the sea boundary (Vietnam Publishing House of Natural Resources 2020). All national geographic data was standardized to the VN-2000 coordinate system, in accordance with Ministry of Natural Resources and Environment regulations, and converted using ArcGIS.

Thematic data

Locations of monitoring stations were added to the database in the form of points, and standardized according to the VN-2000 coordinate system. The attributes of VN_WQI and the location of terminals and mangroves were also included.

In this study, the inverse distance weighted (IDW) interpolation method of ArcGIS (ESRI 2021) were used to generate attribute values of VN-WQI for entire water surface area of Saigon river based on the known observations at monitoring stations.

3 The legal framework for marine and seaport development

In recent years, much attention has been paid to seaport investment and development and many policies have been issued in relation to this. Numerous entities invest in and manage the seaport system; however, the state administrative management agencies play the most critical role. Agencies undertaking management as representatives of the State include: the Vietnamese government at all levels, the National Assembly, the Ministry of Transport, the Maritime Administration, the local maritime port authorities and administrations; and

Table 2. Vietnam's major seaport management activities and respective responsible agencies

No.	Management activities	Agencies
1	Promulgate legal documents on the management of seaports and seaport operations	National Assembly, Government, Ministry of Transport, other ministries
2	Promulgate seaport development policy	Government, Ministry of Transport
3	Seaport development planning	Government, Ministry of Transport, Provincial People's Committee, Vietnam Maritime Administration
4	Monitor the implementation of seaport planning	Vietnam Maritime Administration
5	Manage the investment, construction and development of seaports	Ministry of Transport, Provincial People's Committee, Vietnam Maritime Administration
5	Promulgate a framework of marine fees and charges applicable in the seaport area under the management of the Port Management Board	Ministry of Finance
6	Announce and apply maritime fees in seaport areas on the basis of the framework of maritime fees and charges approved by the Ministry of Finance	Seaport Management Board
7	Carry out procedures and manoeuvre ships entering, leaving and operating at seaport	Maritime Port Authority
8	Carry out customs procedures for goods and vehicles at seaports	Customs Administration
9	Carry out border guard procedures for people at seaports	Border Guard
10	Implement medical quarantine, animal quarantine and plant quarantine for people, goods and vehicles at seaports	Department of Health, Subdepartment of Local Animal/Plant Quarantine
11	Inspect and supervise exploitation activities of operators at seaports	Seaport Management Board

other relevant agencies like the Ministry of National Defence's Border Guard Command, the Ministry of Finance's General Department of Customs, the Ministry of Agriculture and Rural Development's Department of Animal Protection and Department of Plant Protection, the Ministry of Public Security's Police Department of Fire Prevention and Fighting and Rescue, and the Ministry of Natural Resources and Environment's Vietnam Environment Administration (Hoan et al. 2019; Cuong 2016). The main seaport management activities, together with the respective agencies responsible for these activities, are presented in Table 2.

The system of legal documents on maritime and seaports has also been promulgated by the National Assembly, the Government and ministries and branches with one law, one ordinance, more than 20 government decrees, 18 Prime Minister decisions, and over 100 decisions and circulars issued by ministries and branches to serve the state management of maritime affairs (Cuong 2016). Some of the main legal documents specifying seaport policy in Vietnam are shown below:

- Resolution No. 36-NQ/TW dated 22 October 2018 of the XIIth Central Committee of the Party, on the sustainable development strategy of Vietnam's marine economy to 2030 and vision to 2045, with the goal of making Vietnam a strong maritime country, achieving the sustainable development criteria of the marine economy.
- Decision No. 355/QD-TTg dated 25 February 2013 of the Prime Minister, approving the adjustment to Vietnam's transportation strategy to 2020, with a vision to 2030, setting a goal for the seaport system to meet the throughput demand for import-export and domestic goods. International gateway seaports in key economic regions are associated with centres for goods distribution and connected traffic systems, to ensure the formation of a modern and efficient logistics infrastructure network.
- Decision No. 1037/QD-TTg dated 24 June 2014 of the Prime Minister and Decree No. 58/2017/ND-CP of the Government: investment in the construction of seaports, ports, wharfs, anchorages, transhipment areas and navigational channels has to conform with the approved master plan on development of the seaport system and other relevant planning. If there is a difference, the investor must send a report on this which has to be accepted by the competent authority in charge of approving planning.
- Decisions No. 2053, 2054, 2055/QD-TTg dated 23 November 2015 of the Prime Minister, approving the adjusted master plan for transportation development in the northern, central and southern key economic regions to 2020 with a vision to 2030. These decisions set clear goals, which are to continue to develop seaports to meet throughput demand; ensure seamless connection between seaports through the national transport network and logistics hubs; and construct inland ports and other infrastructure to support the development of logistics services.
- Decision No. 1579/QD-TTg dated 22 September 2021 of the Prime Minister, approving the master plan on development of Vietnam's seaport system during 2021–2030, with a vision to 2050, with the goal of synchronous and modern seaport system development, with high quality services, meeting the needs of socioeconomic development, ensuring national security and defence, maritime safety and environmental protection, improving economic competitiveness, contributing to our country becoming a country with modern industry and high middle income by 2030.
- Decision No. 2027/QD-BGTVT dated 27 October 2020 of the Minister of Transport, approving the green port development project in Vietnam. The decision stipulated that the Vietnam Maritime Administration plays key role, coordinating with the Vietnam Seaport Association and seaport operators in the sustainable development of Vietnam's seaport system, in which priority must be given to the prevention of pollution incidents and environmental risks; strengthening capacity to respond to climate change; economical and efficient use of energy; and minimizing waste generation; deploying a green port model suitable to Vietnam's conditions.

4 The current status of seaport development in Vietnam and Ho Chi Minh City

4.1 Seaport development in Vietnam

According to Article 73 of the 2015 Vietnam Maritime Law (Vietnam National Assembly 2015), a seaport is an area that includes port land and port waters, where there is infrastructure built and equipment installed for vessels that arrive at and depart the port to load and unload cargo, pick up and drop off passengers and perform other services. A seaport has one or more terminals. A terminal has one or more piers. Vietnam's seaports are part of the transport infrastructure, meeting the requirements of loading, unloading, preserving and transhipping cargo and passengers by sea, to meet socioeconomic development needs at the same time as promoting development and world economic integration, and contributing to national security and defence and national sovereignty over coastal areas and territorial seas. Article 76 of the 2015 Vietnam Maritime Law (Vietnam National Assembly 2015)also specifies the basic functions of seaports, including: providing services to support vessels arriving and leaving the port; providing the necessary means, equipment and human resources for vessels to anchor, load and unload cargo, and pick up and drop off passengers; providing services for the transporting, loading, unloading, storing and preserving of cargo in the port; being the focal point connecting the traffic system outside the seaport; being a place for vessels to shelter, be repaired, maintained or perform necessary services in an emergency; and providing other services for vessels, people and cargo.

According to the development master plan for Vietnam's seaport system, approved by the Prime Minister in Decision 1579/QD-TTg dated 22 September 2021 (Prime Minister 2021a), Vietnam's seaport system is currently divided into five geographical groups:

- **Group 1 – Northern seaports:** Hai Phong, Quang Ninh, Thai Binh, Nam Dinh and Ninh Binh;
- **Group 2 – North Central seaports:** Thanh Hoa, Nghe An, Ha Tinh, Quang Binh, Quang Tri and Thua Thien Hue;
- **Group 3 – South Central seaports**: Da Nang, Quang Nam, Quang Ngai, Binh Dinh, Phu Yen, Khanh Hoa, Ninh Thuan and Binh Thuan;
- **Group 4 – Southeast seaports**: Ho Chi Minh City, Dong Nai, Ba Ria – Vung Tau, Binh Duong and Long An;
- **Group 5 – Mekong Delta seaports**: Can Tho, Dong Thap, Tien Giang, Vinh Long, Ben Tre, An Giang, Hau Giang, Soc Trang, Tra Vinh, Ca Mau, Bac Lieu and Kien Giang.

The seaports are also divided into four types, according to size and scope:

1. **Special seaports** (Large-scale seaports serving national and international socioeconomic development): Hai Phong and Ba Ria – Vung Tau;
2. **Level 1 seaports** (Large-scale seaports serving national socioeconomic development): Quang Ninh, Thanh Hoa, Nghe An, Ha Tinh, Thua Thien Hue, Da Nang, Quang Nam, Quang Ngai, Binh Dinh, Khanh Hoa, Ho Chi Minh City, Dong Nai, Can Tho, Long An and Tra Vinh;
3. **Level 2 seaports** (Medium-sized seaports serving regional socioeconomic development): Quang Binh, Quang Tri, Ninh Thuan, Binh Thuan, Hau Giang, Dong Thap;
4. **Level 3 seaports** (Smaller-sized seaports serving local socioeconomic development): Thai Binh, Nam Dinh, Ninh Binh, Phu Yen, Binh Duong, Vinh Long, Tien Giang, Ben Tre, Soc Trang, An Giang, Kien Giang, Bac Lieu, Ca Mau.

The seaports are distributed along the Vietnamese coastline from Quang Ninh Province to Kien Giang Province (Figure 3).

In recent years, Vietnam's seaport system has seen robust development. It has met approved planning development goals to become a driving force for economic and industrial development in urban coastal areas, by ensuring that imported and exported cargo and freight can pass between the country's regions by sea. Statistics show that 427.8 million tons of cargo passed through seaports in 2015; this accounts for 81.8% of the volume of cargo passing through all Vietnamese ports, including seaports, inland waterway ports and airports (Figure 4). By 2020, the volume of cargo passing through the seaport system reached 692.3 million tons, equivalent to 78.7% of total cargo volume passing through all Vietnamese ports. During 2016–2020, the volume of cargo passing through seaports increased by 61.8%, an average increase of about 10% per year (Le Anh 2021). Some gateway seaports for international transhipment have been established in the North, like Lach Huyen port (Hai Phong) which receives container vessels of up to 132,000 DWT (deadweight tonnage) and in the South like Cai Mep seaport (Bia Ria – Vung Tau) which receives container vessels of up to 214,000 DWT. A total of 25 international shipping routes and 7 domestic sea shipping routes have been established to locations both within the country and across the globe. According to Decision 1579/QD-TTg, approving the master plan for development of Vietnam's seaport system for the period 2021–2030 with a vision to 2050 (Prime Minister 2021a), the Vietnamese seaport system will undergo comprehensive development to ensure high-quality, modern services that meet socioeconomic development, security and defence, maritime safety and environmental protection needs, enhancing economic competitiveness, and enabling the passing-through of 1.140 to 1.423 million tons of cargo and 10.1 to 10.3 million passengers.

4.2 Seaport development in Ho Chi Minh City

According to Decision No. 761/QD-BGTVN dated 24 April 2020 of the Minister of Transport, announcing the list of Vietnamese seaport terminals (Ministry of Transport 2020), Ho Chi Minh City seaport has 42 terminals, operated by various companies, including national and local state-operated military agencies and foreign maritime organizations (Table 1). Ho Chi Minh

Figure 3. Map of the Vietnamese seaport system
Source: Chung and Loan (2021)

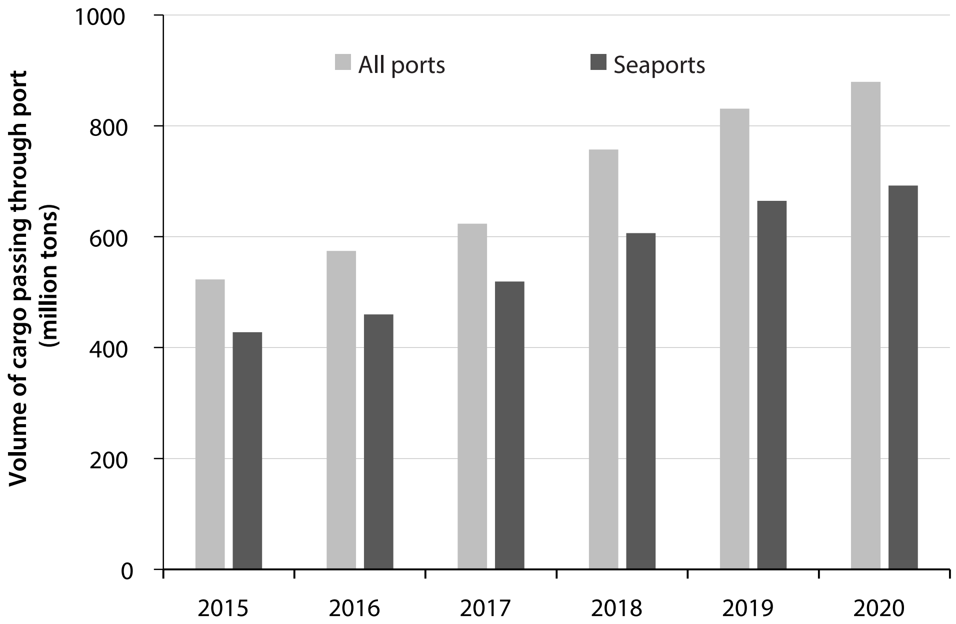

Figure 4. Volume of cargo (million tons) passing through Vietnamese seaports during 2015–2020

Source: Vietnam General Statistics Office (2021)

City seaport is one of Vietnam's biggest seaports, playing an important role in the country's seaport system, with a large volume of cargo passing through, accounting for more than 20% of the total cargo that passes through all of the country's seaports. The seaport's terminals Sai Gon, Ben Nghe, Tan Thuan and Sai Gon-Hiep Phuoc currently occupy the largest land area, serving both international and domestic trading activities. The terminals of Ho Chi Minh City seaport vary in size and capacity, and are run by different sectoral businesses (Table 3).

Vietnam's open-door investment policy has promoted development and improved the quality of port operations and services across all Vietnamese seaports, including Ho Chi Minh City. Some of the world's major shipping lines have now invested in and are operating at terminals in Ho Chi Minh City, including DP World Group (UAE) which has invested in and operates SPCT – Ho Chi Minh City port, Hutchison Group (Hong Kong) which has invested to work together with the international container port of Saigon Vietnam SITV, and APMT Group (Denmark) which has invested in Cai Mep port (Vietnam Maritime Administration 2021b).

From 2015 to 2020, the volume of cargo passing through Ho Chi Minh City's seaport increased continuously from 93.14 million tons in 2015 to 170.67 million tons in 2019, before declining slightly in 2020 to 163.26 million tons due to the impact of the Covid-19 pandemic. The volume of cargo passing through Ho Chi Minh City's seaport therefore averaged a growth rate of 16.35% during 2015–2019, accounting for 23–30% of the total volume of cargo passing though all Vietnamese seaports (Table 4).

Table 3. List of Ho Chi Minh City seaport terminals

No	Terminal	Established	Area (ha)	Throughput capacity (ton/year)	Operating agency	Throughput goods and services	Website
1	Sai Gon	1986	24.31	15,000,000	Sai Gon Port Joint Stock Company	Bulk cargo, dry cargo, passengers	http://www.csg.com.vn
2	Tan Thuan Dong	1976	2.37	500,000	Sai Gon Transport Service Joint Stock Company	Bulk cargo, dry cargo	http://tranaco.com.vn
3	Ba Son Sea Ship Building and Repair Factory	Unknown	Unknown	Unknown	Ba Son Corporation	Port services, ship building, repairs	https://basonshipyard.vn
4	Tan Cang	1989	Unknown	Unknown	Sai Gon Newport Corporation	Port services, containers	https://saigonnewport.com.vn
5	Vietnam International Container Terminal (VICT)	1998	0.62	800,000	Logistical Development Joint Venture Company No. 1	Bulk cargo, dry cargo, containers	https://www.vict-vn.com
6	Sai Gon ELF Gas	Unknown	2	60,000	Vietnam TOTAL GAZ Ltd Company	Liquid cargo: petroleum, liquefied petroleum gas, vegetable oil	Unknown
7	Nha Be Petrolimex Depot	Unknown	Unknown	3,900,000	Petrolimex Company Region II	Liquid cargo: petroleum, liquefied petroleum gas, vegetable oil	https://kv2.petrolimex.com.vn
8	Nha Be Vegetable Oil (Navioil)	Unknown	8	650,000	Corporation of Vegetable Oil Industry of Vietnam	Bulk cargo, dry cargo; Liquid cargo: petroleum, liquefied petroleum gas, vegetable oil	https://vocarimex.com.vn
9	Sai Gon Shipbuilding and Marine Industry Company (Sai Gon Shipmarine)	1977	6	Unknown	Sai Gon Shipbuilding and Marine Industry Company	Port services, ship building and repairs; bulk cargo, dry cargo	https://ssmi.com.vn
10	An Phu Shipbuilding/ Shipyard	1979	5	Unknown	An Phu Shipbuilding One-member Ltd Company	Port services, ship building and repairs	http://www.dongtauanphu.com.vn
11	Ben Nghe	1987	32.22	15,000,000	Ben Nghe Port One-member Ltd Company	Bulk cargo, dry cargo	http://www.bengheport.com

Table 3. Continued

No	Terminal	Established	Area (ha)	Throughput capacity (ton/year)	Operating agency	Throughput goods and services	Website
12	Vegetable and Fruit	1991	3.2	500,000	Vegetable & Fruit Port Joint Stock Company	Bulk cargo, dry cargo	https://www.vegeport.com.vn
13	Bong Sen	Unknown	15	1,873,000	Bong Sen Joint Venture Company	Bulk cargo, dry cargo	https://www.lotusport.com
14	New Cat Lai	1998	10.85	4,000,000	Corporation of Sai Gon New Port	Bulk cargo, dry cargo, container	https://saigonnewport.com.vn
15	Sai Gon Petro	1986	20.4	6,000,000	Petrolemex One-Member Ltd Company of Ho Chi Minh City	Liquid cargo: petroleum, liquefied petroleum gas, vegetable oil	http://saigonpetro.com.vn
16	Nha Be PVOIL	Unknown	13.6	1,700,000	PVOIL Petroleum Port	Liquid cargo: petroleum, liquefied petroleum gas, vegetable oil	https://www.pvoil.com.vn
17	Sao Mai Cement	Unknown	13	705,048,000	Siam City Cement Ltd Company (Vietnam)	Bulk cargo, ore	Unknown
18	X51	Unknown	15.4	Unknown	Hai Minh Ship Building and Repair One-Member Ltd Company	Port services, ship building and repair	Unknown
19	Lam Tai Chanh (Lataca)	Unknown	2.45	217,330	Lam Tai Chinh SPHD Trading Company	Liquid cargo: petroleum, liquefied petroleum gas, vegetable oil	https://ltcpetroleum.com
20	Cat Lai	Unknown	13	Unknown	Tan Cang Sea Service Joint Stock Company	Container	https://saigonnewport.com.vn
21	Petroleum Depot VK.102	Unknown	5	1,550,000	Logistics Department of Military Region 7	Liquid cargo: petroleum, liquefied petroleum gas, vegetable oil	Unknown
22	Sai Gon Ship Industry	Unknown	N/A	300,000	Sai Gon Ship Industry One-Member Ltd Company (SSIC)	Ship building and repairs, other means of transport, marine construction equipment and shipbuilding industry products	http://www.ssic.com.vn

Continued on next page

Table 3. Continued

No	Terminal	Established	Area (ha)	Throughput capacity (ton/year)	Operating agency	Throughput goods and services	Website
23	Hiep Phuoc Power	Unknown	0.52	Unknown	Công ty TNHH điện lực Hiệp Phước	Liquid cargo: petroleum, liquefied petroleum gas, vegetable oil	Unknown
24	Hai Phong Chinfon Cement (in Hiep Phuoc)	1992	0.6	500,000	Hiep Phuoc Clinker Crushing Plant	Specialized port with bulk cargo, ore	https://www.cfc.vn/
25	Hiep Phuoc Holcim Cement	Unknown	3.69	Unknown	Vietnam Holcim Cement Ltd Company	Unloading raw materials, cement	Unknown
26	Nghi Son Cement	Unknown	7.9	Unknown	Nghi Son Cement Company	Bulk cargo, ore	Unknown
27	Fico Cement	Unknown	0.6	500,000	Tay Ninh Fico Cement Joint Stock Company	Bulk cargo, ore	https://fico-ytl.com
28	Minh Tan Petroleum Transport Commercial	Unknown	1.34	Unknown	Minh Tan Petroleum Trading & Transport Ltd Company	Bulk cargo, ore	Unknown
29	Hang Giang II Technical and Professional College	Unknown	N/A	Unknown	Waterway Transport College II	Port services, ship building and repair	Unknown
30	Bien Dong	Unknown	18.07	300,000	Seafood Industry Joint Stock Company	Port services, ship building and repair	Unknown
31	Calofic Specialized	1996	12.2	142,542,000	Branch of Cai Lan Oils & Fats Industry Company in Hiep Phuoc, Ho Chi Minh City	Liquid cargo: petroleum, liquefied petroleum gas, vegetable oil	https://www.calofic.com.vn
32	Thang Long Cement	Unknown	0.6	990,000	Thang Long Cement Joint Stock Company	Bulk cargo, ore	https://www.thanglongcement.com.vn/
33	Ha Tien Cement Terminal No.1	Unknown	23.23	1,000,000	Ha Tien Cement Joint Stock Company No. 1	Bulk cargo, ore	https://www.hatien1.com.vn

Table 3. Continued

No	Terminal	Established	Area (ha)	Throughput capacity (ton/year)	Operating agency	Throughput goods and services	Website
34	Sai Gon Premier Container Terminal (SPCT)	2009	2.05	1500	Sai Gon Premier Container Terminal Company	Containers	https://www.spct.vn/
35	Sai Gon – Hiep Phuoc	2009	36.06	8,700,000	Sai Gon – Hiep Phuoc Port Joint Stock Company	Bulk cargo, dry cargo	http://saigonporthiepphuoc.com
36	Sai Gon Shipyard Decoration	2009	9.71	N/A	Sai Gon Shipyard Ltd Company (SSY)	Port services, ship building and repairs	Unknown
37	Expanded Petroleum Depot 102 (formerly: Thanh Le Petroleum Terminal)	Unknown	7.9	390,000	Logistic Department of 7th Military Region	Liquid cargo: petroleum, liquefied petroleum gas, vegetable oil	Unknown
38	Hiep Phuoc New Port	2014	15.4	500,000	Hiep Phuoc New Port JS Company	Containers	http://tancanghiepphuoc.com.vn
39	International Container Terminal SP-ITC	2001	N/A	900,000	International Transport and Commerce JS Company	Bulk cargo, dry cargo	https://sp-itc.com.vn
40	Vietnam Saint-Gobain Ltd Company (Vinh Tuong Terminal)	Unknown	3	150,000	Vietnam Saint-Gobain Ltd Company	Bulk cargo, dry cargo	https://www.saint-gobain.com.vn/
41	Ha Long Cement Plant Terminal (Southern Crushing Station)	Unknown	0.82	1,200,000	Ha Long Cement Company	Bulk cargo, ore	Unknown
42	Tan Thuan Terminal No. 2	Unknown	25.7	1,500,000	Branch of Sai Gon Port One-Member Ltd Company	Bulk cargo, dry cargo	http://saigonport.vn/

Source: Vietnam Maritime Administration (2021b)

Table 4. Cargo volume through Ho Chi Minh City seaport compared to all Vietnam seaports

Year	Total cargo volume through all Vietnam seaports (million tonnes)	Cargo volume through Ho Chi Minh City seaport	
		Million tonnes	Percentage (%)
2015	371.49	93.14	25.07
2016	416.37	100.52	24.14
2017	512.17	150.98	29.48
2018	596.56	160.60	26.92
2019	664.61	170.67	25.68
2020	692.29	163.26	23.58

Source: Vietnam Maritime Administration (2021c)

5 The impact of seaports on water quality and the role of mangroves

Port activities – including construction, access channel dredging and port operations – can generate waste that poses adverse impacts on the quality of the air and water environment (Trozzi and Vaccaro 2000). During the processes of port construction and access channel dredging, the water environment in the port area may be affected by domestic wastewater and wastewater from surface washing and machinery cleaning. Such wastewater can increase turbidity, suspended solid waste, concentrations of heavy metals, grease and microorganisms in the port area, in both river and sea water. When the port is operational, wastewater generated from the activities of workers, crews and passengers, overflowing rainwater, bilge water, ballast water and oil-containing water, for example, are sources of pollutants that result in degradation of the

Table 5. Surface water quality parameters in Saigon River, Ho Chi Minh City during 2011–2020

No	Parameter	No. of monitoring stations	Min	Max	Mean	SD	Limit values*	
							A1	B2
1	pH	36	4.5	9.0	6.9	0.8	6–8.5	5.5–9
2	TSS (mg/L)	27	47.85	270.25	115.56	71.96	20	100
3	Amoni (mg/L)	36	0.05	4.02	0.67	1.00	0.3	0.9
4	Phosphat (mg/L)	27	0.03	0.20	0.06	0.03	0.1	0.5
5	COD (mg/L)	36	2.02	9.42	5.35	2.07	10	50
6	DO (mg/L)	36	3.03	6.30	4.50	0.72	≥6	≥2
7	BOD5 (mg/L)	27	2.26	5.59	3.38	0.88	4	25
8	Oil (mg/L)	36	0.02	0.07	0.03	0.02	0.3	1
9	Mn (mg/L)	27	0.02	0.19	0.09	0.04	0.1	1
10	Fe (mg/L)	24	0.91	2.86	1.57	0.53	0.5	2
11	Pb (mg/L)	17	0.0020	0.0137	0.0089	0.0039	0.02	0.05
12	Cd (mg/L)	16	0.0003	0.0014	0.0010	0.0003	0.005	0.01
13	Hg (mg/L)	15	0.0000	0.0002	0.0001	0.0001	0.001	0.002
14	Cu (mg/L)	17	0.0052	0.0300	0.0085	0.0061	0.1	1

Note: * Limit values of surface water quality used for domestic water supply (Colume A1) and for waterway transportation and other purposes (column B2) (Ministry of Natural Resources and Environment 2015)

Source: Ho Chi Minh City environmental monitoring reports for 2011–2020 water environment in the port area (Stakeniene et al. 2011; Gómez et al. 2015; Catianis et al. 2016; Jahan and Strezov 2019). This not only causes negative impacts on river and coastal ecosystems, but also reduces the value of existing ecosystem services like tourism, aquaculture and fishing productivity (Trozzi and Vaccaro 2000). Barberi et al. (2021) in their literature review also confirmed the impact that shipping and port operations had on the air environment, with GHG emissions being generated by vessels entering and leaving the port, onshore energy-using vehicles like loading and unloading cranes, and cargo trucks, as well as lighting systems at the port.

Surface water monitoring data from the seaport area of Ho Chi Minh City shows that, although concentrations of most surface water quality parameters remain within the allowable limits, according to the Vietnamese Standard QCVN 08-MT:2015/BTNMT (Ministry of Natural Resources and Environment 2015), concentrations of some parameters, like TSS, DO and Fe, exceed the allowable limits (Table 5).

There is a general trend across all surface water quality parameters that concentrations are higher in the seaport area, decreasing gradually in monitoring stations further from the port terminals. Specifically, the surface water quality index (VN_WQI) decreases gradually in areas far from the port terminals (Figure 5). Figure 5 also shows that water quality, after running through mangroves, has significantly improved.

As indicated in Table 1, the higher the VN_WQI, the better the surface water quality. As Saigon

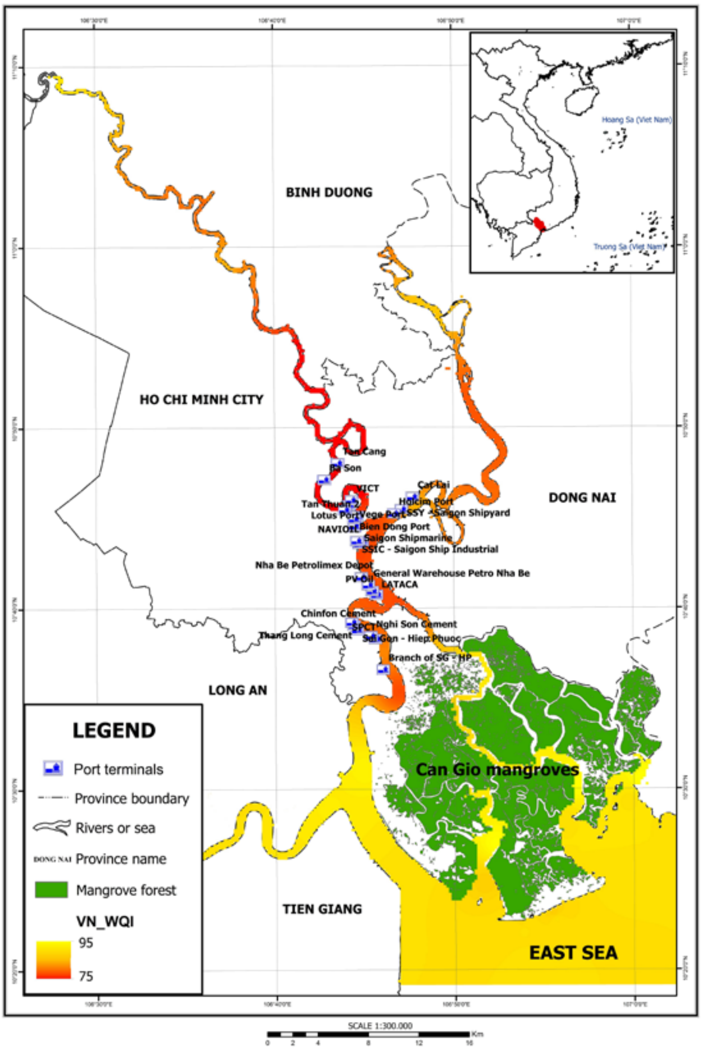

Figure 5. Surface water quality (VN_WQI) in Saigon River, Ho Chi Minh City

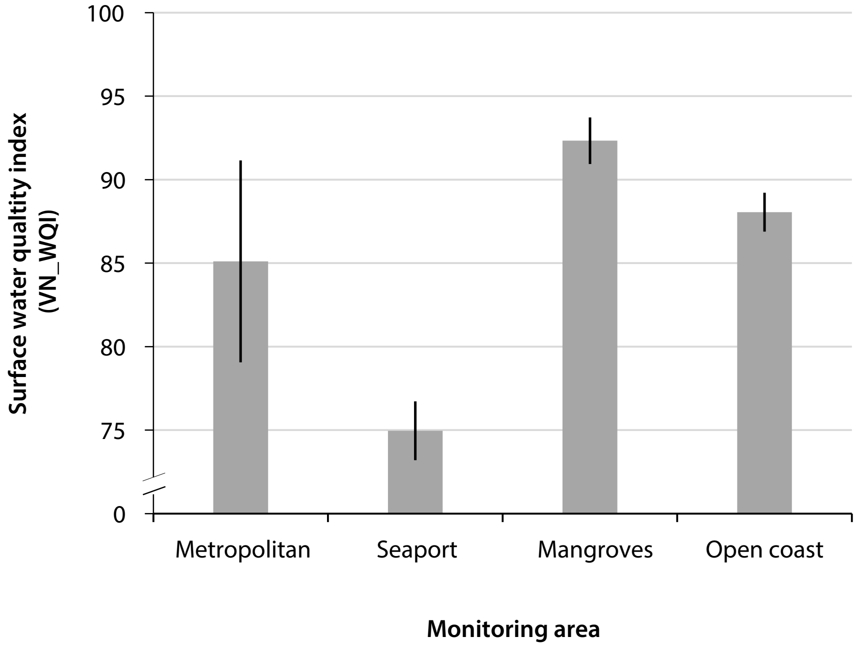

Figure 6. Surface water quality index in different monitoring areas along Saigon River, Ho Chi Minh City

River flows through Ho Chi Minh City, the surface water quality is best in the mangrove area (VN_WQI = 92.3), followed by the coastal area (VN_WQI = 88.1), and the city centre (VN_WQI = 85.1), whereas it is lowest in the seaport area (VN_WQI = 75) (Figure 6). It can be confirmed from these findings that Ho Chi Minh City seaport operations impact the quality of surface water in the Saigon River, but that the level of this impact is not high, and concentrations of most pollutants in surface water remain within allowable limits (Ministry of Natural Resources and Environment 2015); surface water quality remains at or above average level (Vietnam Environment Administration 2019). However, given the plans for further seaport development in the near future, if port environmental protection activities are not well managed, surface water quality in the seaport area of Ho Chi Minh City could become severely degraded.

6 Seaport emissions and the role of mangroves in mitigating emissions

Regarding GHG emissions from port operations around the world, Psaraftis and Kontovas (2021) estimated that GHG emissions (carbon dioxide equivalents – CO_2e) increased from 977 million tons in 2012 to 1,076 million tons in 2018 (up 9.6%) with CO_2 making up almost 98% of total GHGs. Greenhouse gas emissions have also been estimated for major ports across the region and world, for example Chennai has been estimated to generate 280,558 tons/year (Misra et al. 2017), Osaka 97,000 tons/year, Sydney 95,000 tons/year, Gothenburg 150,000 tons/year and Long Beach 240,000 tons/year (Styhre et al. 2017).

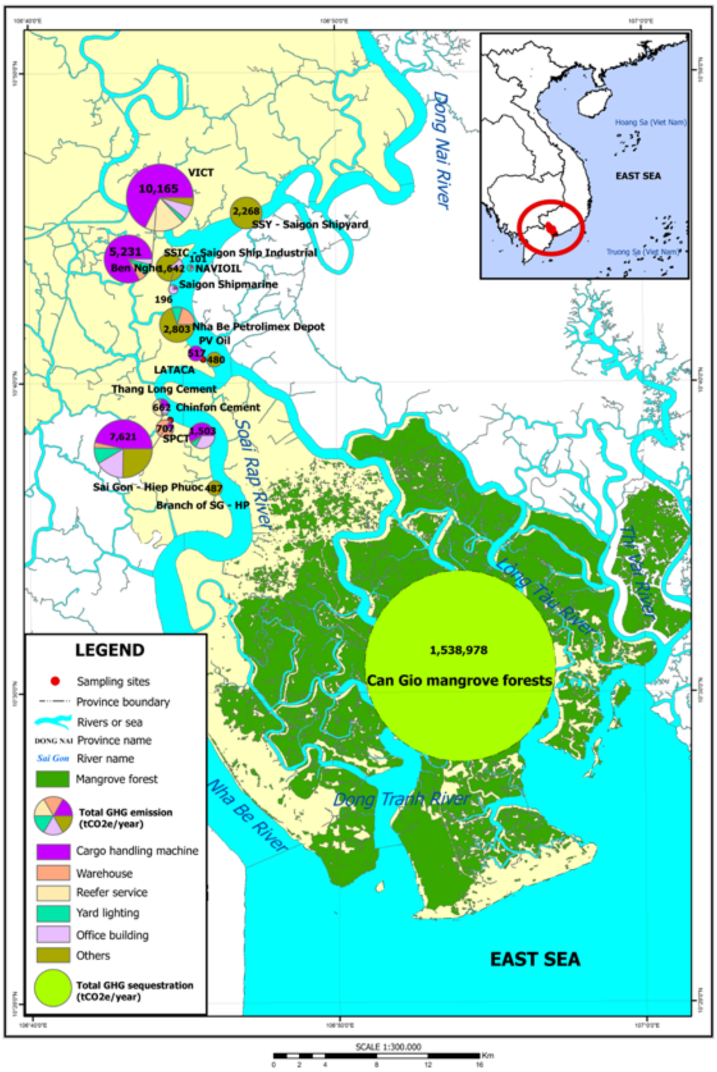

Figure 7. GHG emissions from 15 Ho Chi Minh seaport terminals, in correlation with GHG sequestration by Can Gio mangrove forest

In Vietnam, there are insufficient studies to calculate the amount of GHG emissions from maritime and port activities. In Ho Chi Minh City, Japan International Cooperation Agency (2019) implemented the 'Project to Support the Planning and Implementation of Nationally Appropriate Mitigation Actions' (SPI-NAMA) which involved collecting data and calculating GHG emissions from 15 typical terminals in Ho Chi Minh City seaport. The results show that total GHG emissions (CO_2e) for the port were 34,768 tons/year (Table 6). However, GHG emissions were mainly concentrated in large terminals like VICT (10,165 tons/year), Saigon-Hiep Phuoc (7,621 tons/year), Ben Nghe (5,231 tons/year) and Nha Be (2,803 tons/year).

Can Gio mangrove forest has been referred to as the "green lung" of Ho Chi Minh City and neighbouring provinces, thanks to its ability to absorb CO_2, release O_2 and clean the air (Environment and City 2021). Research findings also show that, with an area of 35,000 ha, Can Gio mangrove forest has the ability to absorb a large amount of CO_2 from the air through the photosynthesis process of mangroves, helping to reduce GHGes and making an important contribution to Vietnam's response to climate change (Thinh 2020). Can Gio mangrove forest can absorb an average of about 1.54 million tons CO_2/year, thus potentially contributing to balancing out the amount of CO_2 emitted from socioeconomic development activities, including shipping and seaport operations.

7 Discussion

Across the world and within Vietnam, many studies have been undertaken into the ecosystem services provided by mangroves (Mukherjee et al. 2014; Himes-Cornell et al. 2018; Mitra 2020; Pham et al. 2021). This includes services like cleaning up the water environment (Dunbabin and Bowmer 1992; Wood and Shelley 1999; Yu et al. 2001; Thanh-Nho et al. 2019; Thanh-Nho et al. 2020) and absorbing GHGs from the air (Clough et al. 2000; Tue et al. 2014; Nam et al. 2016; Hong Tinh et al. 2020; Rovai et al. 2021). Can Gio mangrove forest in Ho Chi Minh City spans a total area of 35,000 ha, and has high biodiversity with 35 true mangrove species (Nam et al. 2014) and many other valuable mangrove fauna species (Hong 2004; Nam et al. 2014). In addition to ecosystem services like provision of aquatic products and firewood, aquaculture support, climate regulation and ecotourism development (Kuenzer and Tuan 2013), Can Gio mangrove forest has been proven to play an important role in cleaning up the environment, thanks to its ability to absorb and accumulate pollutants in sediment and mangrove vegetation. Thanh-Nho et al. (2018) confirmed that the content of some metal ions that had dissolved in water were absorbed in suspended sediment when passing through the mangrove system, thus contributing to an increased ability to remove metals from water after sediment is deposited into a mangrove area. Thanh-Nho et al. (2019) went on to suggest that studied mangrove species (*Avicennia alba* and *Rhizophora apiculata*) in Can Gio mangrove forest can act as reservoirs, whereby pollutants are stored in their root systems. When studying the accumulation of heavy metals in Can Gio mangrove forest, Nguyen et al. (2020) also suggested that mangroves could be considered a natural wastewater treatment system (which uses a vegetation-based treatment process). Similar results around the role of mangroves in absorbing and accumulating heavy metals have also been reported and confirmed by other authors in the region, including Yunus et al. (2009); Mahmudi et al. (2021); Ariyanto et al. (2020) and Mahmudi et al. (2021).

The above results around mangroves' ability to clean surface water environment, through the process of deposition, absorption and accumulation of pollutants, confirm the results of our surface water quality assessment. Looking at Saigon River as it flows through the centre of Ho Chi Minh City to the seaport area, before entering Can Gio mangrove forest and then the sea (Figure 6), the results indicate that water quality around Ho Chi Minh City is good (VN_WQI $\geq$ 75), however the best surface water quality was recorded at monitoring stations in the mangrove forest area (VN_WQI = 92.3), meanwhile surface water quality was at its lowest (VN_WQI = 75) in the seaport area, and just average (VN_WQI = 82–85) in the metropolitan and open coastal areas. This suggests that one of the main pollution sources for surface water is seaport operations.

Although other activities like tourism, agricultural production, industry and fishing can also generate pollutants, a point which merits further investigation, it should be noted that numerous scientific studies confirm that port operations cause disturbances and release pollutants into the environment (Stakeniene et al. 2011; Darbra et al. 2005; Catianis et al. 2016; Misra et al. 2017; Jahan and Strezov 2017; Jahan and Strezov 2019). Such findings not only prove the role of mangroves in cleaning up the environment, but also offer an important take-away that shipping and port operations, as some of the biggest sources of waste, must also be targeted so as to increase revenue of payment for forest environmental services (PFES) for mangrove conservation.

Besides the impact of polluting surface water, seaport operations are also a major source of GHG emissions. Further studies and surveys need to be carried out to fully estimate the total amount of GHGs released into the environment by all 42 terminals of Ho Chi Minh City seaport; however, the estimated data show that the level of GHG emissions from Ho Chi Minh City seaport is quite large. In the context of the country's economic development goals and plan to further develop the seaport system during 2021–2030 and beyond (Vietnam Maritime Administration 2021a), the level of GHG emissions from the Vietnamese seaport system as a whole, as well as Ho Chi Minh City seaport specifically, will continue to increase. It is necessary, therefore, to adopt solutions that will reduce emissions and balance out GHGs (Barberi et al. 2021), to contribute to respond to climate change and implement the National Green Growth Strategy for 2021–2030 with a vision to 2050, with the goal of reducing the intensity of GHG emissions per GDP and greening economic sectors (Prime Minister 2021b).

The above-mentioned results, demonstrating Can Gio mangroves' ability to clean up the nearby surface water environment and absorb GHGs, confirm its critical role in helping the seaport and shipping industry compensate for GHG emissions and protect the environment. Since mangroves remain under threat due to the impacts of climate change and socioeconomic development pressures (Tong et al. 2004; Seto and Fragkias 2007; Son et al. 2016; Van et al. 2015), these findings also highlight the importance of conducting further studies, as well as proposing policies that encourage stakeholders in all sectors, including the shipping industry, to become actively engaged in payments for mangrove environmental services.

8 Conclusion

Vietnam's seaport system has developed rapidly in recent years, becoming a driving force for socioeconomic development in coastal areas through facilitating the import, export and movement of maritime cargo between regions. Ho Chi Minh City seaport is one of the country's main seaports, with cargo volume passing through it accounting for more than 20% of the total cargo volume passing through all Vietnamese ports. Of the many entities involved in managing, investing and developing seaports, central to local-level state administrative agencies – including the Maritime Administration, the Ministry of Transport and local maritime port authorities – are the most important.

Seaport construction and operation activities can generate waste, affecting the quality of both water and air environments in seaport areas. In general, the surface water quality of Saigon River remains at or above average levels. However, the quality of the surface water declines gradually from the city centre to the seaport area, before becoming very good in Can Gio mangrove forest, then flowing into the sea. An estimation of GHG emissions, based on 15 out of 42 terminals in Ho Chi Minh City's seaport, also shows that around 34.8 thousand tons of CO_2e are released into the environment annually. Given the plans for marine economic development and the goal to develop the seaport system between 2021 and 2030, the environmental impact of the shipping industry in general, and seaports in particular, will continue to increase.

Mangroves have a proven ability to absorb GHGs through mangrove vegetation photosynthesis, as well as the ability to clean surface water through depositing, absorbing and accumulating pollutants in sediment and mangroves. This means that in areas where the environment is polluted by waste sources, including seaports, mangroves can act as a natural wastewater treatment system, helping prevent pollutants from discharging into the aquatic environment, and balancing greenhouse gases that have been emitted into the atmosphere from seaport operations. This is critical knowledge upon which to base any proposed solutions and policies that are intended to encourage and promote the shipping industry to participate more actively in payments for forest environmental services, thus contributing to maintaining and expanding the mangrove area, increasing Vietnam's capacity to respond to climate change, and fulfilling the country's commitment to environmental protection.

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ISBN 978-9966-108-67-8
DOI: 10.17528/cifor/008493

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This report provides scientific evidence on the role of mangroves in absorbing greenhouse gases and improving water quality through analysis of monitoring data relating to the water environment in Saigon River (Ho Chi Minh City), greenhouse gas emissions from Ho Chi Minh City seaports, and greenhouse gas sequestration in Can Gio mangrove forest (Ho Chi Minh City). This document presents, for the first time, comparative results of water quality indices for 2010–2020, at monitoring points in different areas including metropolitan, seaport, mangrove forest and open coast. A correlation between carbon emissions from seaports, and the amount of carbon absorbed by mangroves in Ho Chi Minh City, was also analysed for the first time. Our findings confirmed that mangroves can support the maritime industry to reduce greenhouse gas emissions and protect the environment. These findings can assist policymakers to identify those who can financially contribute towards the environmental services that mangroves provide, enabling the effective implementation of policy around payment for forest environmental services. We also highlight the need to have further specific studies, in other areas of the country, in order to build a complete database of the ecosystem services provided by mangroves in Vietnam.

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